The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities

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CERTIFICATE

I certify that this thesis has not already been submitted for any degree and is not being submitted as part of candidature for any other degree.

I also certify that this thesis has been written by me and that any help that I have received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Signature of Candidate

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ABSTRACT

It has long been recognised that environmental matters are important to the survival of the construction industry. Yet, in general, the construction industry continues to degrade the environment, exploiting resources and generating waste, and is reluctant to change its conventional practices to incorporate environmental matters as part of the decision-making process.

Building development involves complex decisions and the increased significance of external effects has further complicated the situation. Cost benefit analysis (CBA) is one of the conventional tools used widely by public and private sectors when appraising projects. It sets out to measure and compare the total costs and benefits of different projects that are competing for scarce resources in monetary terms. However, there are growing concerns that the values of environmental goods and services are often ignored or underestimated in the CBA approach which has led to the overuse and depletion of environmental assets. Consequently, CBA's usefulness and relevance in this respect is increasingly controversial.

Project development is not just concerned with financial return, but is also conscious of the long-term impacts on living standards for both present and future generations. Sustainable development is an important issue in project decision-making and environmental effects need to be incorporated into the evaluation process. A multi-dimensional evaluation approach attracts increasing attention around the world as the way to incorporate environmental issues in the decision-making process. This approach uses the conventional market approach to monetarise economic aspects of a development, whilst using a non-monetary approach to evaluate the environmental matters.

The purpose of this thesis is to critically examine the impact of construction activities on the environment and methods of quantifying environmental matters. This thesis also evaluates the principal sustainable development determinants for modelling, and evaluating long-term environmental performance of buildings during the project appraisal stage. Projects can be assessed using an index system that combines the principal determinants of sustainable development.

The four criteria as identified in this research are financial return, energy consumption, external benefits and environmental impact. The derived sustainability index combines the four identified attributes into a single decision-making tool. The attributes are each expressed in units that are best suited to their quantitative assessment. The development of a sustainability index is a way of combining economic and environmental criteria into the decision-making framework.

The sustainability index has also been developed into computer software called SINDEX to be used as a benchmarking tool to aid design and the sustainability assessment of projects. SINDEX is a sustainability modelling tool used to calculate and benchmark sustainable performance of proposed buildings, new and existing facilities.

Conventional project appraisal techniques measure net social gain to select a project, whilst the sustainability index measures the relative ranking of projects from a sustainable development view. Buildings have a long life, so any improvement in appraisal techniques for choosing the best option amongst the alternatives will significantly reduce their future environmental impact. As such, a methodology that embraces various criteria in relation to project development is crucial in this respect. The development of a sustainability index is a way to combine multiple criteria measured using different units. Using the sustainability index will greatly assist the construction industry to realise sustainable development goals, and thereby make a positive contribution to identifying optimum design solutions.

CHAPTER
ONE

INTRODUCTION

1.1 FOUNDATION FOR THE RESEARCH

Global environment deterioration has captured people's attention and been the focus of constant mass media reports locally, nationally and worldwide (Joubert et al., 1997; Bentivegna et al., 2002). Environmental crises concerning matters such as ozone layer depletion, global warming, ecosystem destruction and resource depletion are of increasing importance in our daily life (Langston & Ding, 2001).

Environmental economics and sustainable development have become central concerns to people from all disciplines and in all countries (Cole, 1999a; Holmes & Hudson, 2000). Much environmental discussion centres on the concept of ecologically sustainable development. Ecologically sustainable development, from a project development point-of-view, is efficiently using resources to meet the requirements and needs of present and future generations, whilst minimising adverse effects on the natural environment (Best & de Valence, 1999).

Project development potentially contributes to the economic and social advancement of society, enhancing both the standard of living and the quality of life. However it is often also associated with impairment of the environment (Azqueta, 1992). Project development may result in the loss of valuable agricultural land, forests and wilderness, cause pollution of air, land and water, generate noise, consume non-renewable natural resources and minerals and use large amounts of energy (Spence & Mulligan, 1995).

To harness project development positively, it can be used to contribute to the sustainable development by thorough assessment of environmental issues at an early stage to help choose the most efficient development option among competing alternatives (van Pelt, 1993b; Lowton, 1997). The choice of the best development proposal depends not only on the plant and materials used and profit generated, but also upon the selection of the most appropriate site and design options to meet environmental criteria and to respect the feelings and views of community (Winpenny, 1991b; Langston & Ding, 2001).

1.2 PROBLEM DEFINITION

A monetary unit is a common unit that has been used to facilitate comparison among project alternatives. The conventional project appraisal methodology employs cost benefit analysis (CBA) as the main tool in the decision-making process, particularly in the public sector (Harvey, 1987; Tisdell, 1993; Perkins, 1994; van Pelt, 1994). CBA is designed to show whether the total benefits of a project exceed the total costs in order to determine a preferred option. Although CBA may appear reasonable and practical, there are growing concerns that this approach often ignores or underestimates the values of environmental goods and services, leading to overuse and depletion of environmental assets (Tisdell, 1993; Hobbs & Meier, 2000; RICS, 2001).

Literature on CBA and environmental protection indicates that using a single objective in the evaluation process is insufficient when taking environmental values into account (Zeleny, 1982; Hanley, 1992; Nijkamp et al., 1990; Spash, 1997). The environment's complexity means its relationship with human activities remains largely unknown (Gregory et al., 1993; van de Burgh, 1996; Harding, 1998).

Current project appraisal techniques measure project costs and benefits based on market transactions and price. However monetary value, when applied to environmental assets is difficult, if not impossible to ascertain. CBA methodology is concerned with measuring project costs and benefits in monetary units, whilst environmental effects frequently cannot be successfully priced through the same conventional approach (Janssen, 1992; Powell, 1996; Abelson, 1996; Harding, 1998; Crookes & de Wit, 2002).

Research on non-monetary techniques has been undertaken to search for alternative methods so that environmental values can be identified and evaluated in a proper manner. One such method is multi-criteria analysis which uses a weighted score approach to evaluate environmental issues. This has gained significant attention in operational research (Voogd, 1983; Nijkamp et al., 1990; van Pelt, 1994; Hobbs & Meier, 2000).

Completely replacing a monetary market approach with non-monetary techniques has limitations, however both methods are regarded as complementary tools by many researchers (Watson 1981; Jones, 1989; Nijkamp et al., 1990; Gregory et al., 1993; van Pelt, 1993b; Powell, 1996; Joubert et al., 1997; Mirasgedis & Diakoulaki, 1997; RICS, 2001). There is no strategic model for project appraisal that embraces significant sustainable development determinants where these determinants are assessed using methods that suit their nature.

Therefore a gap exists between conventional project evaluation techniques and the incorporation of environmental values in the decision-making process. In order to bridge the gap, current appraisal methodologies require thorough examination leading to a new model that incorporates the principal determinants of sustainable development into the decision-making process using a multi-criteria approach as opposed to the current single dimensional approach. Therefore, the aim of this research is to establish an empirical model to evaluate projects other than in monetary terms and incorporate environmental values in the decision-making framework.

1.3 RESEARCH HYPOTHESIS

This research focuses on identifying, quantifying and incorporating environmental issues into the decision-making process. A decision-making model will be developed to embrace the broader sense of environmental protection at the appraisal stage of project development.

This requires a comprehensive examination of the existing decision-making methodology used in the construction industry. The use of CBA and environmental valuation techniques are investigated and an examination of the current literature will also identify significant variables for decision-making on environmentally sensitive projects. The investigation is in three main areas:-

1) a literature review to identify impact variables,
2) using findings from the literature as a basis for an extensive industry survey to rank the identified major sustainable development determinants, and
3) the formulation of a decision-making model based on the survey results.

A sample of twenty public high school projects is studied to establish the criteria and data are collected and analysed to determine relationships between the criteria. Finally, the model will be tested for robustness and validity.

The industry survey to rank major sustainable development determinants comprises an extensive questionnaire for professionals currently practising in the construction industry. Their opinions on the ranking of a series of decision-making variables are examined and collated to develop a framework for decision-making. This framework is proposed to be a composite index system. The technique of multi-criteria analysis is used to bring these variables together into a single model. A sustainability index (SI) will then be developed to calculate the level of sustainability of a project and facilitate the choice of the best option. The principal role of the sustainability index is to incorporate environmental and social issues into the decision-making process at an early stage. It is intended that this model will bring together the strength of CBA and multi-criteria analysis into a single decision-making tool.

The research proposition forms the reference point for the literature review. The working hypothesis (Hw) for this research is expressed as:

> Hw: The use of a sustainability index in the decision-making process for environmentally sensitive projects can significantly enhance the prospects of sustainable development in the construction industry.

The research builds upon the appraisal techniques that are available in the field. Their advantages and disadvantages are investigated to provide the ground work for the development of a model to assess sustainability of built projects and facilities. While the outcome of this research is to develop a methodology for incorporating environmental goods and services in decision-making, the research findings in the literature review and the survey will increase understanding of the level of environmental awareness in the construction industry.

1.4 RESEARCH AIMS AND OBJECTIVES

The aim of this research is to develop a strategic decision-making model by objectively incorporating environmental and social issues into the decision-making process at an early stage of a development. The model can then be applied to choose the best development option and be further enhanced to benchmark the performance of projects and facilities. Specifically, it is envisaged that this research will promote environmental sustainability in the construction industry.

The specific objectives of this research that will realise the research aim are to:

i. identify, investigate and examine development impacts on the environment,
ii. suggest ways to improve the conventional decision methodology used in the construction industry,
iii. evaluate the principal sustainable development determinants for modelling decision-making for built projects and facilities,

iv. develop a new decision-making model that comprises both quantitative and qualitative analysis, and
v. test the effectiveness and usefulness of the new decision model.

1.5 RESEARCH METHODOLOGY

This research involves both quantitative and qualitative data. The methodology engaged in this research will, therefore, consist of a combination of strategies. A literature search involves a thorough review of current practices and previous research in the areas of environmental evaluation and project appraisal. The literature search also explores the background issues in relation to the development of a sustainability index as a decision-making tool. Data collection has been divided into two parts. The first part used questionnaire survey to obtain data from the building professionals for developing the model of sustainability index. The second part involved retrieving building data from the project archive to quantify the criteria as identified from the questionnaire survey.

It was decided to use an industry questionnaire to obtain data on professionals' opinions about sustainability criteria in the construction industry. The purpose of the questionnaire is to identify variables to be included in the decision-making model for sustainability. A mail survey was employed due to the benefits of administration, wider coverage and the speed of data collection. Following the identification of key variables for the decision-making model, case study research was used to collect data for the variables. The decision-making model is primarily developed to appraise built projects and facilities and, therefore, case study methodology is a rational approach to the research (Yin, 2003).

Data was collected for twenty public high school projects using a questionnaire and other measurement techniques. The interaction of these variables was examined using linear and multiple regression analysis to establish probabilistic models. The hypothesis of this research was then tested for correlation. Details of the data analysis are discussed in Chapters 6 and 7. The robustness and soundness of the sustainability index is demonstrated on another project with different design options.

1.6 THESIS STRUCTURE

The thesis structure is presented in Figure 1.1 and the specific chapter descriptions are as follows:

Chapter One

This chapter provides background information for this research. It also explains why this research was undertaken and how this research is significant to the construction industry. A working hypothesis (Hw) was developed to provide a reference point for the literature review.

Chapter Two

This chapter builds a theoretical foundation for the research by reviewing literature and previous research. The research also examines the nature and extent of environmental degradation of the built environment in relation to economic development. This study provides information and argument for the importance of incorporating environmental values in the appraisal of built projects and facilities. The techniques available for the quantification of environmental values are also critically reviewed. A multi-criteria approach for project appraisal is reviewed and contrasted to the conventional market-based approach. The argument established provides a platform for further investigating the literature concerning other environmental valuation techniques such as non-monetary approaches.

Chapter Three

Whilst the previous chapter focuses on the broader discussion of environmental issues, this chapter concentrates on the relationship between environmental issues and the construction industry. This chapter starts by examining construction activity effects on the natural and man-made environment and how using an environmental management system can help to enhance sustainable goals in the construction industry. The impact of energy consumption in the built environment is also investigated from a life-cycle approach. The energy analysis of the built environment includes the study of both embodied and operational energy throughout a development's life span. The energy study also highlights the importance of energy consumption in achieving sustainable practice in construction.

Chapter Four

This chapter critically reviews the environmental building assessment methods currently used at national and international levels when evaluating a building's environmental performance. A multi-dimensional approach to the sustainable appraisal of projects is discussed as opposed to the conventional single-dimensional approach. This chapter also presents the conceptual development of a sustainability index for project appraisal. The sustainability index uses a multi-dimensional approach to appraise projects and its development is built on the theoretical foundation arising from the literature review as reviewed in Chapters Two and Three.

Chapter Five

Following the conceptual development of a sustainability model to aid decision-making, this chapter aims to identify key determinants of sustainable development that may be important to the decision-making process when assessing environmentally sensitive projects. The findings from the literature review provide a foundation for an industry questionnaire. This chapter details the questionnaire sent to the construction industry, followed by a pilot study. The main purpose of this survey is to obtain opinions from practising professionals in the construction industry to rank the criteria identified from the literature. These will be incorporated into a decision-making model. This chapter also presents the analysis of the survey results enabling a mathematical model of a sustainability index to be developed.

Chapter Six

The sustainability index model is tested in this chapter by using a sample of public high school projects. Twenty public high schools were assessed to provide data for the analysis. The detailed research methodology and data collection processes are presented and the working hypothesis established in Chapter One is also refined and extended to provide a foundation for analysis. The criteria are then measured and put together to form a decision-making model.

Chapter Seven

This chapter reports on the underlying principle of data analysis and presents findings from the data analysis of the sample. The properties and characteristics of data are discussed and presented for each criterion in the sustainability index. Data analyses also include comparing projects by age and by the geographical location of the projects. Further analyses are also carried out to examine the relationships for building cost and energy consumption to the size of projects.

Chapter Eight

In this chapter both linear and multiple relationships between variables are analysed and discussed. The hypotheses developed in Chapter Six are also tested and reported. The sustainability index developed in the previous chapter is then applied and tested for robustness and validity on a separate project with different design options.

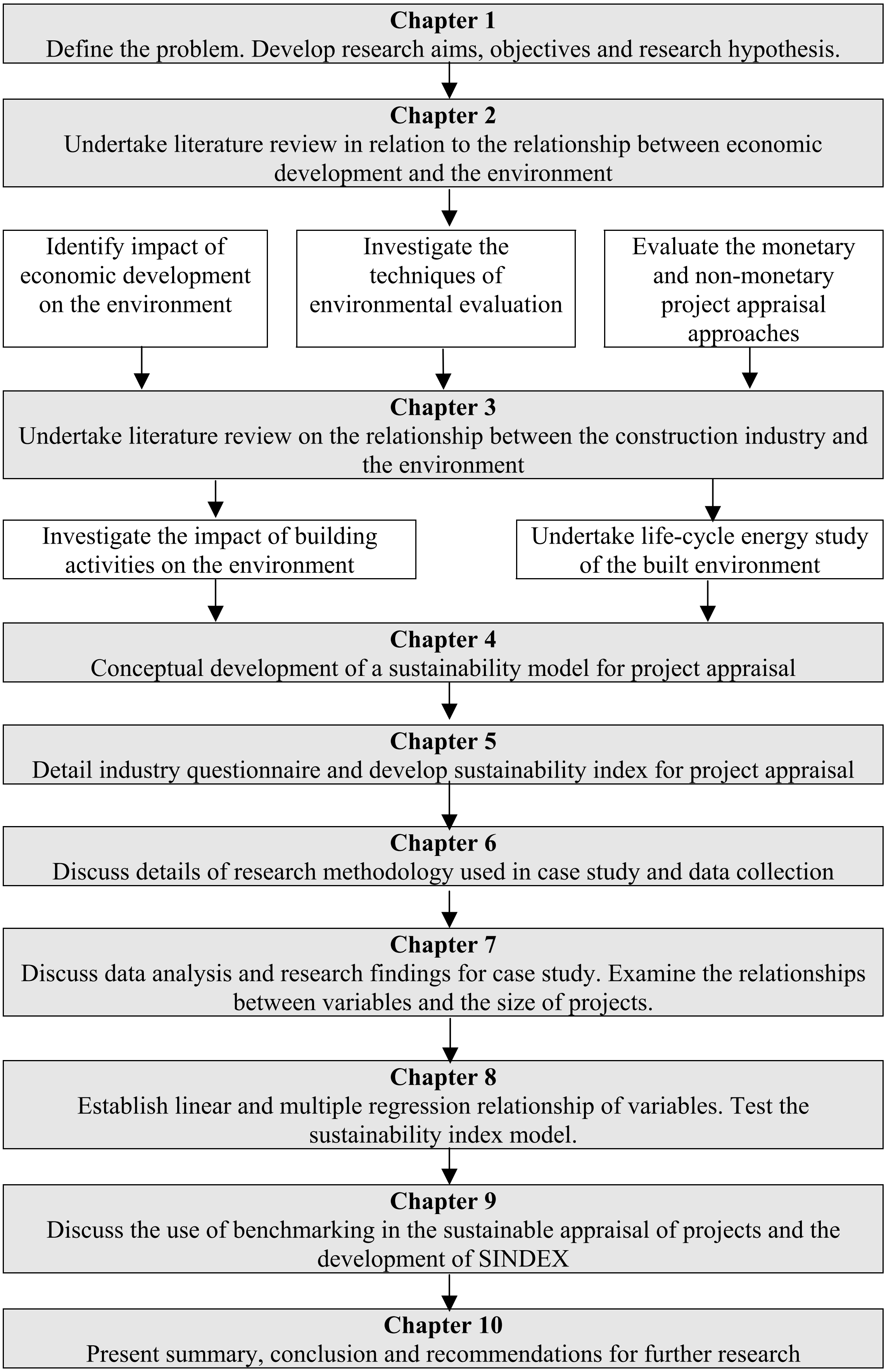
Chapter Nine

This chapter draws on the findings from the literature review and industry survey, providing a comprehensive discussion on developing benchmarking as an evaluation tool to assess project sustainability. Computer software, called SINDEX, was developed as a benchmarking tool based on the concept and model of the sustainability index for assessing built projects and facilities. The detailed methodology of its development is discussed and presented.

Chapter Ten

This chapter summarises the research and states the conclusions. Conditional statements are made with respect to the application of the sustainability index in the construction industry. Limitations of the research and the possibilities of further research are made at the end of the chapter.

Figure 1.1 Thesis structure


Chapter 1
Define the problem. Develop research aims, objectives and research hypothesis.
Chapter 2
Undertake literature review in relation to the relationship between economic development and the environment
Identify impact of economic development on the environment
Investigate the techniques of environmental evaluation
Evaluate the monetary and non-monetary project appraisal approaches
Chapter 3
Undertake literature review on the relationship between the construction industry and the environment
Investigate the impact of building activities on the environment
Undertake life-cycle energy study of the built environment
Chapter 4
Conceptual development of a sustainability model for project appraisal
Chapter 5
Detail industry questionnaire and develop sustainability index for project appraisal
Chapter 6
Discuss details of research methodology used in case study and data collection
Chapter 7
Discuss data analysis and research findings for case study. Examine the relationships between variables and the size of projects.
Chapter 8
Establish linear and multiple regression relationship of variables. Test the sustainability index model.
Chapter 9
Discuss the use of benchmarking in the sustainable appraisal of projects and the development of SINDEX
Chapter 10
Present summary, conclusion and recommendations for further research

CHAPTER
TWO

ECONOMIC DEVELOPMENT AND THE ENVIRONMENT

2.1 INTRODUCTION

This chapter investigates the impact of economic growth on the natural environment and the importance of incorporating environmental values into project appraisal. The conventional market-based approach to decision-making is examined in detail, compared with the multi-criteria approach to evaluating environmental values.

Economic growth and environmental protection are symbiotic; the environment being the prime supplier of raw materials needed for economic growth which, in turn, relies on a steady supply of those raw materials such as iron ore, timber, and quarried stone (Thampapillai, 1991; Common, 1995; Spence & Mulligan, 1995).

Now economic growth, particularly in the construction industry, is under threat from overuse or finite limits of supply (Rees, 1999). External effects such as air and water pollution generated from mining, manufacturing and construction processes can also seriously affect the environment's capacity to continue producing raw materials (Kein et al., 1999).

Economic growth and the natural environment jointly affect mankind's well-being, therefore the efficient allocation of scarce resources for project development is an important issue to both present and future generations, and decisions taken during project appraisal are of paramount importance if the balance of our social fabric is to be maintained.

The activities which precipitated this environmental crisis relate mainly to man exhausting and degrading natural resources, population growth and pollution. Research shows that non-market characteristics are the main causes and these environmental issues possibly affecting society's economic growth (Nijkamp et al., 1990; Hanley & Spash, 1993; Abelson, 1996, Joubert et al., 1997). So it can be seen that the relationship between the environment and economic growth is vital and much depends upon its investigation and improvement.

2.2 THE ENVIRONMENT AND THE ECONOMY

2.2.1 Introduction

Economic growth and environmental protection have a two-way interaction. The environmental crisis is now of global importance. Human economic activity is the principal cause through exploitation and pollution, yet such activity relies heavily on a healthy environment for continuation and productivity (Common, 1995). There is, hence, a vital partnership upon which much depends. This section investigates the role of the environment in economic growth and the environmental problems associated with these activities.

2.2.2 The role of the natural environment

The economy and the environment are mutually dependent on each other's existence for survival. Common (1995) states that the linkages between economic activity and the environment are pervasive and complex. The complexity of the relationship is due to the inherent, and difficult to quantify value of the natural environment to the economy and the natural environment supporting the economy. Hill (1997) suggests that the biosphere would seem to have infinite value, since without the biosphere, nothing can survive.

According to the World Bank (1998), mankind values environmental goods and services. The value can be intrinsic, or in the form us use, option and bequest. When considering environmental assets' values, Shechter and Freeman (1994) argue that moral rights and interest should also be assigned to the non-human nature of the environment. Therefore, the environment has a value, no matter whether humans are around to sense, consume or experience it.

The environment serves the economy in many ways including as a resource base and providing renewable and non-renewable resources as required (Thampapillai, 1991; Common, 1995). Renewable resources are the biotic population of flora and fauna that have potential to regenerate through natural reproduction when there are losses from economic extraction, such as timber. Non-renewable resources are minerals such as fossil fuels that cannot regenerate and so cannot be used sustainably. These stocks also require geological surveys to estimate their size and value and are used to produce goods and services consumed in the economy. As Booth (1998) says, the supply of environmental resources is critical in order to sustain our living standard.

Whilst the environment serves as a resource base, it also consumed by performing as a receptacle for wastes. Economic activities produce waste products, often described as pollutants, that are discharged into the natural environment. The law of conservation of mass states that energy can neither be created nor destroyed by human activity (Common, 1995), it is merely transformed from one state to another. The environment's ability to absorb waste products is assimilative, as it is capable of receiving waste matter, degrading it and converting it to nutrients, which then feed the occupants of an ecosystem. However, that capacity depends on the waste's biodegradability or whether the level of biodegradable material is exceeded (Pearce, 1998).

Despite the environment's direct value through providing the necessary materials for economic activities and absorbing the waste product as a result of these activities, the environment also adds an indirect value to the normal functioning of the economy by providing humans with recreational facilities and other sources of pleasure and stimulation (Thampapillai, 1991). This function does not directly involve any consumptive material flow however its excessive use may lead to changes in its character such as soil erosion and vegetation loss. This function is important to our quality of life. Finally, the environment provides the life support system for mankind to survive, such as breathable air, range of temperatures and water (Abelson, 1996). These functions do not directly contribute to economic activities, but if its existence ceased to function there would, no doubt, be not only a serious affect on the economic growth but also on human life.

When the environment is exploited non-sustainably and rapidly polluted, there is a loss of one or more of environmental services such as health, productivity or amenity and the survival of the human race is seriously under threat. When a rare species or feature of the environment disappears, there is not only a loss to man, but also an irreversible loss of existence value. The economy often regards the adoption of environmental protection as a costly measure that jeopardises profitability (Boughey, 2000). However, there is a strong association between labour productivity and a high standard of environmental quality such as output losses due to illness and absenteeism. Clearly, the natural environment is an important component of the economic system and without it the economic system would not be able to function. Therefore, as Thampapillai (1991) states, the natural environment should be treated as an asset and a resource on the same basis as the other factors of production.

The supply of public goods in the global common is often abundant and once it is available for everyone it will not exclude anyone else from consuming it. Once it is provided it bears no extra cost to additional consumers. Environmental goods are free gifts of nature and there is no private property right of its ownership. However, up to a certain extent, the public properties of environmental assets will cease and they will become private goods. Beyond this point people may need to pay for the consumption of environmental goods. According to OECD (1995), based on an economic viewpoint, something that is abundantly available to all has no economic value. However, when the assets start to become scarce, it starts to have potential economic value. This zero price condition leading to market failure has led to these goods being excessively used, resulting in depletion, deterioration and no incentive for their protection (Datta & Mirman, 1999).

The problem of market failure is caused by the inability of the price mechanism to reflect the value of social costs and benefits of resource use due to the environmental assets are non-measurable and non-valuable (Thampapillai, 1991; OECD, 1995). As such, the market cannot signal the relative scarcity of different resources through their prices in the market. Market failure is also caused by the mismanagement and inefficient use of natural resources and can be traced to malfunctioning, distorted or totally absent markets. However, even though environmental goods have no market price, they significantly affect the well-being of mankind both now and in the future.

As society fails to protect the environment and destruction occurs, these goods become external to the market (Beder, 1996). The natural environment has been shown to be an important factor for economic growth. Therefore, as natural environmental resources are eroded and destroyed, the result will be jeopardised, if not limited, economic growth (Thampapillai, 1991).

There are ongoing discussions about whether a constraint should be placed on economic growth as environmental degradation is so evident (Xepapadeas & Amri, 1998). Some people argue that economic growth is necessary to pay for environmental protection and reverse environmental deterioration (Booth, 1998). Daly (1992) supports a steady-state economy under which the natural resources are consumed at a fixed, sustainable rate and the quality of the environment is maintained at a level that protects the health of human individuals, species and ecosystems. Booth (1998) advocates that economic growth is contrary to any notion of sustainability. He goes on to state that even if all environmental costs were successfully internalised, economic growth could still lead to environmental deterioration. Hence, in according with his opinion, the only way to protect or preserve the environment is to cease all kinds of economic activity.

Daly’s (1992) opinion is more acceptable as it is more realistic about maintaining a balance for economic growth and environmental protection. In fact, it is impossible to stop all economic activities for the sake of protecting the environment. On one hand, if economic activities are reduced in order to protect the environment, environmental degradation will also be caused as a result of increased unemployment and poverty (Thampapillai, 1991; Spence & Mulligan, 1995; Langston & Ding, 2001; Reed, 2002). Therefore, neither extreme will benefit the environment.

Barbier (2003) suggests that the environmental and natural resources should be treated as important assets and described as natural capital. Better understanding of these complex environmental values may lead to more sustainable economic development. The natural environment is an important component of the economic system, which affects many aspects of mankind now and in the future. Renewable resources should not be consumed at a rate greater than their natural rate of regeneration. Even though non-renewable resources cannot be replaced, they should be conserved and used in a more efficient way. Through technological improvements, their conservation can be achieved by preventing their exhaustion by the present generation (Pearce & Turner, 1990).

2.2.3 Environmental problems

Environmental destruction is apparent everywhere, precipitating a crisis that is now of global proportions. Global warming, thinning of the ozone layer, loss of biodiversity, depletion of natural resources, widespread deforestation and the resulting deserts are examples of global environmental degradation. Human economic activity is the principal cause of the environmental crisis through exploitation and pollution, and yet such activity relies heavily on a healthy environment for its continuance and productivity. Rees (1999) says that ‘empirical evidence’ suggests that resource consumption already exceeds the productive capacity of critical biophysical systems on every continent. He further suggests that waste production has already violated the assimilative capacity of many ecosystems at every scale.

Climate change has become synonymous with global warming (Loáiciga, 2003) and it is caused by the build-up of greenhouse gases, which trap energy on the Earth’s surface. Significant climate change over the next century is expected. The continuing of global warming has intensified many atmospheric extremes leading to significant increase in the frequency and severity of heat waves (Glasby, 2002).

The greenhouse gas effect is not a new problem. As early as 1896, a Swedish chemist already proposed that the changing atmospheric carbon dioxide concentration was the major cause of global temperature fluctuations (Kininmonth, 2003). In accordance with Loáiciga (2003), the carbon dioxide concentration in 1765 was about 280 parts per million by volume (ppmv) but it has increased to approximately 364 ppmv in 2000. The concentration of carbon dioxide was due to the burning of fossil fuels leading to global warming.

In 1985, researchers claimed that global warming was caused by human activities (Kininmonth, 2003) and the first Intergovernmental Panel on Climate Change (IPCC) confirmed this claim in 1988. The subsequent report, published in 1990, confirmed that there is a greenhouse effect and the increased atmospheric concentration of carbon dioxide was caused by human activities. A second IPCC followed in 1995 and a third in 2001 both expressed increasing confidence that greenhouse gases will cause dangerous future climate change (Bala, 1998; Kininmonth, 2003; Meadows & Hoffman, 2003).

Apart from the increased atmospheric concentration of carbon dioxide, atmospheric concentrations of other greenhouse gases such as methane, nitrous oxide and chlorofluorocarbons are also increasing as a result of human activities (Loáiciga, 2003). According to the third IPCC in 2001, the Earth's surface temperature has increased between 0.3°C and 0.6°C during the last 150 years (Loáiciga, 2003), and if no environmental pressure or controls are introduced, an increase in global mean temperature of about 2.5°C can be expected by the year 2100 (Houghton, 1997).

The increased temperature has already caused severe problems in the precipitation pattern as global surface warming affects the climate pattern. Higher temperatures tend to speed up evaporation in some regions and cause more precipitation in others. A warmer atmosphere retains more moisture and water vapour absorbs more radiant heat. Extra water vapour in the air will make more rain, and this cycle inevitably enhances the greenhouse effect (Falk & Brownlow, 1989; Bala, 1998).

The warming of the Earth's surface has a significant effect on the living creatures on Earth and as well as the structure of the atmosphere. Human health will be affected by the increased heat stress and widespread vector-borne diseases such as malaria (Houghton, 1997). Increasing global temperature warms and expands the oceans, melts polar ice caps and, in turn, raises sea levels. It is estimated that there will be an average increase in sea level of about 6cm per decade for a temperature rise of between 1.5 to

5.5°C (Falk & Brownlow, 1989). The sea levels are expected to rise by about 0.5m by 2100 (Houghton, 1997; Bala, 1998).

As sea levels rise, soil erosion, flooding and storm damage to some coastal regions will follow. Ecosystems at river mouths and the quality of fresh water are also affected. Reduced snow and ice will reflect less light back into space and produce even greater warming (Langston & Ding, 2001). High concentration of carbon dioxide in the atmosphere will also affect coastal ecosystem productivity (Bala, 1998).

The high concentration of carbon dioxide in the atmosphere also increases the rate of plant loss, that is, loss of biodiversity, another environmental problem that threatens human existence. Biodiversity refers to the variety of life of Earth. It is an important global resource and its existence has a close relationship with every aspect of human society. Its conservation must be treated as a matter of urgency as human populations are degrading the environment at an accelerating rate, destroying natural habitats and reducing it. According to Glasby (2002) the rate at which species are disappearing is about 1,000 to 10,000 times the normal rate and more than 25 percent of all species could disappear within the next two decades.

Biodiversity is important in many ways. First, it sustains food production. With an increasing rate of growth in world population, the demand for food becomes critical (Gilland, 2002). Second, species are the source of medicines to cure a range of known diseases, as well as for medical research and development (Bates, 1990; Wills, 1997; de Mendonca et al., 2003). Third, rainforests play an important role in the terrestrial recycling of carbon, nitrogen and oxygen by helping to regulate the greenhouse effect through absorbing carbon dioxide from the air, returning oxygen (Common, 1995; Pearce, 1998). Fourth, the planet is an interwoven ecosystem. The existence of one species is important to the existence of another. The extinction of one species may eventually lead to the loss of many others dependant upon it, which may result in an accelerated loss of important genetic information (Bates, 1990; Wills, 1997).

The loss of biodiversity may be caused by the expansion of human population and activities (Wills, 1997; Bala, 1998). The construction of facilities and extraction of resources can disturb natural land areas and thereby endanger sensitive ecosystems Flora and fauna destroyed through human activities may not fully regenerate. Population growth is clearly a major threat to the environment (Munda et al., 1998; Chew, 2001; Glasby, 2002) and there is no doubt that the human population has been putting increasing pressure on the ecosystem of the Earth for food, clean water and resources. It increases the pressure on renewable and non-renewable resources, reduces the amount of capital and productivity per worker, and increases the inequality of income.

According to a 1998 United Nations (UN) report, the global population will increase to eight billion in 2025 and nine billion in 2050 (Young, 1999; Reuveny, 2002). The annual increase in world population is approaching 80 million per year, approximately 90 percent of which is in the poorest countries. The fundamental reason for this increase is that life expectancy is extended as a result of the improvement and advancement of medicine. Population increases at an exponential rate, placing more demand on food production (Young, 1999; Chew, 2001). However, as Hopfenberg and Pimental (2001) state, the world human food availability continues to grow, but slower than the population rate. The shortage became more evident after the world food summit in 1996 where plans were prepared to reduce the number of under-nourished, estimated as 920 million, to half this level by 2015 (Young, 1999).

Population growth may also be associated with the world poverty level. Population growth may be a cause of poverty, particularly in the developing countries. In accordance to the World Development Report 2000/2001, 2.8 billion people are earning less than US$2 per day (Glasby, 2002) and the 1998 UN report states that about 25 percent of the world’s population live in absolute poverty (Young, 1999). By the end of this century, approximately eight out of nine people will live in poor developing countries compared with approximately one out of two in 1950 (Plant et al., 2000).

As population grows, greater demands are placed on land use, leading to deforestation, loss of biodiversity, water resource shortage, wasted natural resources, loss of soil fertility and increased soil erosion. This is especially serious in the developing countries where deforestation is at its highest. The depletion of soil fertility and water reserves is due to over farming and increased crop production. In order to maintain soil productivity, farmers have to use chemical fertilisers (Gilland, 2002). Crops, which are dependent on chemical fertilisers, tend to rob the soil of its fertility which, in turn, will require more fertilisers in succeeding years. As a result, after a number of years overall productivity may decline, and so even more fertilisers may need to be applied.

This increased fertilisation has further speeded up the rate of global warming in two ways. Fertiliser production involves mining and processing phosphate and nitrogen-bearing ores, and this process consumes fossil fuels increasing carbon dioxide production, methane and other greenhouse gases. Fertilisers also reduce the ability of soil microorganisms to remove carbon from the atmosphere.

The economic activities and population pressures on rural economies cause migration, especially the urban centres. In accordance with the World Health Organisation, the global urban population has increased from 32 percent in 1955 to 38 percent in 1975 and 45 percent in 1995 (Moore et al., 2003b). In 2002, the United Nations Environment Program predicted that the world's urbanisation would increase from 47 percent to 65 percent by 2015 (Moore et al., 2003b). The number of cities with a population greater than 1 million has increased from 90 in 1955 to 336 in 1995, representing an increase of 35 percent of the world's population situated in urban areas (Moore et al., 2003b).

This rapid urbanisation has caused further environmental problems through contamination of soils, surface water and aquifers from poor sanitation. The results are severe health hazards, especially due to crowding and a poor living environment. Inadequate quality water supply, air pollution, water pollution, poor sanitation services and solid waste collection (Chew, 2001; Moore et al., 2003b). The increase in diseases associated with these conditions is further evidence of a declining standard of living.

2.2.4 Summary

There is no doubt that resource depletion, pollution and population growth are seen as the main causes of biologically and ecologically destructive phenomena. The increase in the amount of human activities is responsible for the amount of pollutants dumped onto land, into water and the atmosphere, causing various pollution problems to the environment, hazardous wastes generated from economic activities and stratospheric ozone depletion from chlorofluorocarbons. Evidently the planet is in environmental crisis and these environmental problems are inter-related. The environment needs to be treated as a whole, rather than paying attention to its individual parts. The links between the environment and the economy established earlier also ensure that the environmental crisis is also an economic crisis. It is caused by economic activities and it undermines the very functions on which economy depends.

2.3. OVERVIEW OF ENVIRONMENTAL VALUATION TECHNIQUES

2.3.1 Introduction

The term ‘sustainable development’ is not a new concept. The debate about sustainability was activated by the Club of Rome’s report “The Limits to Growth” during the 1960s and 1970s (Harding, 1998; Boughey, 2000). The debate led to the First United Nations Conference on the Human Environment held in Stockholm in 1972 where the international agreement on desired behaviour and responsibilities to ensure environmental protection was discussed. The discussion was followed by the World Conservation Strategy in 1980 when the term ‘sustainable development’ was first expressed (Rees, 1999).

The concept of sustainable development was further discussed at the Earth Summit held in Rio de Janeiro in 1992 by the United Nations Conference on Environment and Development (UNCED, 1992). The Earth Summit was the first international conference attended by world leaders on environmental issues to promote international cooperation for global agreements and partnerships for environmental protection (Harding, 1998).

A number of important conclusions were reached at the Earth Summit and the Rio Declaration on Environment and Development set out 27 general principles for achieving sustainable development. The declaration was adopted in the Agenda 21 ‘policy plan for environment and sustainable development in the 21st century’ as an action plan to pursue the principles of sustainable development in this century (Langston & Ding, 2001; Bentivegna et al., 2002). The purpose of Agenda 21 is to balance environmental with economic development needs in this century (Postle, 1998). Sjöström and Bakens (1999) state that Agenda 21 provides an action plan for sustainable development including goals, commitments and strategic program areas. Following Agenda 21, the global concern about sustainability and the government's commitment requires the building sector to act differently from the conventional approaches (Langford et al., 1999). The Second Earth Summit was held in 1997 in New York and the progression of the commitments made at Rio five years earlier were assessed.

However, up until now, sustainable development is still a difficult notion to define as the concept is ambiguous, multi-dimensional and generally not easy to understand within the single issue of environmental protection (Lombardi, 1999).

2.3.2 The concept of sustainability

Sustainable development is a catchword that has been interpreted and discussed in all fields (Nijkamp et al., 1992; van Pelt, 1994; Hill & Bowen, 1997; Harding, 1998; Ofori et al., 2000). According to Pearce (1998), it is not the difficulty of defining sustainable development, but rather the difficulty of determining ways to achieve the goal. The concept of sustainable development has emerged to describe a new framework for development aimed at achieving economic and social balance whilst maintaining the long-term integrity of ecological systems. The concept is firmly embedded in government policy, legislation and in the environmental policies of private organisations (Harding, 1998).

According to Goodland and Daly (1995, cited in Herendeen, 1998), sustainability has three levels: weak, strong and absurdly strong. Weak sustainability requires that the total of the man-made and natural capital do not decline and are close substitutes (van Pelt, 1994, Herendeen, 1998; Victor et al., 1998). Strong sustainability is based on a disagreement of the degree of substitution and the natural and man-made capital is not substitutable but complementary in most production functions (Ekins & Jacobs, 1998;

Victor et al., 1998). Absurdly strong sustainability tends to stress limits to sustainability. Accordingly, non-renewable resources could never be used at all and renewable resources could only be harvested at the net annual growth (Ekins & Jacobs, 1998; Herendeen, 1998). With the three levels of sustainability, controversy about the meaning and definition of sustainable development is inevitable.

According to Cooper (2002), sustainable means capable of being maintained indefinitely within limits whilst development implies the pursuit of continuous growth. This appears contradictory, as development tends to destroy the ability to sustain. However, Ofori et al. (2000) suggest that as long as development is sustained, economic growth will continue and environmental issues will be dealt with through technology. Similarly, Boughey (2000) states that sustainability indicates economic activities which could continue without long-term damage to the natural environment or general human well-being. This viewpoint indicates that economic growth will continue to thrive whilst the environment will never be deprived, or even used, at all. However, it is highly unlikely that this will happen, as economic growth requires the consumption of environmental resources to sustain its activities.

The most used definition of sustainable development is derived from the Brundtland Commission on Environment and Development (WCED, 1987, p. 43): “development that meets the needs of present generations without compromising the ability of future generations to meet their needs and aspirations”. The four aspects as emphasised in the report are to: eliminate poverty and deprivation; to conserve and enhance natural resources; to encapsulate the concept of economic growth, social as well as cultural variations into a development; and finally, to incorporate economic growth and ecology in decision-making. This shows that many factors can contribute to achieving the goal of sustainable development.

Daly (1990) states that the Brundtland definition has made a great contribution by emphasising the importance of sustainable development, supported by van Pelt et al. (1995) who say that the interpretation of sustainable development in the Brundtland report is the clearest. Mitchell et al. (1995) describe the definition as being very much about quality of life and ecological integrity and Spence and Mulligan (1995) further state that the idea of sustainable development is well summarised in the report. The report also acknowledges that there are limits imposed by the ability of the biosphere to absorb the effects of human activities and advancements in technology and social organisation are needed to improve economic growth.

It is true that sustainable development is about imposing limitations on the use of scarce natural resources in the production and consumption process in order to ensure quality of life of present generations. In that way, sufficient resources may be reserved to allow future generations to have an acceptable level of welfare and quality of life. As the WCED definition appeals to many, it forms the guiding principle for the design of environmentally sound socio-economic policies. It is also clear from the report that unless decisions are taken now to address the deteriorating situation, future generations will not have the ability to correct them. Therefore there is an immediate need for an action for this crisis situation.

The general acceptance of the Brundtland definition of sustainable means it is regarded as representing an international consensus of the concept and conflicts between the demand for human development and future protection of environmental systems (Bentivegna et al., 2002). On the other hand, the definition is often considered to be too vague and therefore inadequate in practice (Daly, 1992; Hill, 1997; Elkington, 1997; Ofori et al., 2000; Bentivegna et al., 2002). Glasby (2002) says the Brundtland's definition fails to recognise the method and does not provide an agenda to achieve a sustainable society or, most importantly, of how to survive in an unsustainable world. Indeed, the Brundtland definition does not satisfactorily provide guidance on how to define sustainability or be measured in practice. For the principle of sustainable development to be achieved and practiced, a clearer and more precise definition is required for different sectors of society. A specific definition of sustainable development for the construction industry will be discussed in detail in Chapter three.

Since the publication of the Brundtland definition, over 160 definitions of sustainable development have been developed, used or interpreted by different groups to suit their own goals (Pearce et al., 1989; Elkington, 1997; Langston & Ding, 2001). According to Pearce et al. (1989), sustainable development requires future generations to be left no worse off than present generations, and if sustainable development is to be achieved, depreciation of natural capital must be zero since man-made capital does not provide adequate compensation for a reduction in environmental capital. Similarly, Daly (1992) suggests that an explanation of sustainable development has to satisfy three conditions. Firstly, the rates of use of renewable resources should not exceed the rates of regeneration. Secondly, the rates of use of non-renewable resources should not exceed the rate at which sustainable renewable substitutes are developed, and finally, the rate of pollution emission should not exceed the assimilative capacity of the environment. In addition to Daly's viewpoint, Moser et al. (1993, cited in Krotscheck & Narodoslawsky, 1996) believe that the natural variety of species and landscapes must also be sustained or improved so as to maintain the quality of life and the needs of successive generations.

Hill and Bowen (1997) describe sustainable development as that development effort which seeks to address social needs while taking care to minimise potential negative environmental impacts. Postle (1998) goes further, suggesting that sustainability, as a concept, has a far wider reach than the environment, encompassing a whole range of social and ethical factors such as employment, social welfare, culture, infrastructure and the economy. In other words, sustainability requires that all of the factors that contribute to long-term societal benefit be catered for in decision-making. Ball (2002) supports the idea that sustainable development is a broader concept than sustainability and includes issues on the quality of life and the integration of social, economic and environmental spheres of activity. Indeed, sustainable development need not always be seen as restrictive to making choices among the issues, but as an integrated approach to consider all the issues.

As described by du Plessis (1999), sustainable development initially only addresses the conflict between protecting the environment and natural resources, and answering the development needs of the human race. However, he believes that sustainable development would not be possible without tackling the problems of poverty and social equity both between people and between nations. Indeed, as Spence and Mulligan (1995) state, the only way to reduce environmental deterioration is to eliminate poverty by raising standards of living. This is particularly important in the developing countries as environmental degradation is closely related to rapid population growth, land degradation and loss of the tropical forest (Spence & Mulligan, 1995; Ofori, 1998; du Plessis, 2001). du Plessis (2001) further states that social responsibility as a principle of sustainability is achieved through sharing the benefits of wealth with the community. Therefore, development is guided by community interest, not individual profit.

From these discussions it is clearly shown that the means of achieving sustainable development deals with the concepts of environment, futurity and equity, with the emphasis that the welfare of future generations should be considered in the decision-making process. On the other hand, The International Institute of Sustainable Development (IISD)[1] stipulates that sustainable development should also simultaneously consider the improvement of the economy Beder (1996), Berggren (1999), Stigon (1999) and Rohracher (2001) all discuss the concept of sustainable development in the context of considering economic growth in addition to the social and environmental dimensions). Economic growth, with an emphasis on aspects such as financial stability and material welfare creation, is the ultimate goal for every government in order to secure rising standards of living and increase the capacity of providing goods and services to satisfy human needs.

In spite of differing perceptions about the precise meaning and the possible interpretation of the term ‘sustainable development’, it is widely accepted that for a development to be sustainable it must examine ecological, economic, social and ethical aspects of reality. It also places emphasis on the importance of combining economics and ecology in development planning (Tisdell, 1993; van Pelt, 1993b; Spence & Mulligan, 1995; Moffatt, 1996; Berggren 1999; Stigon 1999). The divergence of opinion relating to the term proves that sustainability is so broad an idea that a single definition cannot adequately capture all meanings of the concept. While there is little consensus about a definition for sustainable development, there are certainly commonly accepted principles that can be used to guide the process of development (du Plessis, 1999). Sustainable development is a continuous process of dynamic balance instead of a

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[1] IISD—http://www.iisd.org

fixed destination that must be reached at a certain time (Berggren, 1999; du Plessis, 1999).

In summary, the concept of sustainable development must consist of the examination of economic, social and environmental aspects of a development. In addition, sustainable development may not be viewed as one-dimensional, but consists of multiple facet of issues that concern people today and in the future. It is the concept of sustainable development on which this research is based to develop a sustainability index for project appraisal.

The Brundtland report, although it has been shown to be vague in its own way, provides sufficient explanation of what sustainable development may have meant. To this end, to find a precise definition of sustainable development that satisfies all needs may be difficult. It is more important to find ways to achieve sustainable goals in order to maintain and conserve the environment, so that future generations will not be disadvantaged. It is also difficult to derive a definition that applies to all sectors in the economy, therefore it is more realistic to define the concept of sustainable development with particular reference to each sector.

2.3.3 Environmental valuation techniques

Environmental valuation refers to the process of identifying environmental issues, the collection of information and incorporating the information into the decision-making process. Before a decision is made, all environmental effects are to be expressed in numeric form and then converted to a single unit of measurement that has a dollar value. Therefore environmental valuation is to put a monetary value on the environmental effects of economic decisions, and to provide a framework for comparing the environmental loss with economic gains (Herendeen, 1998; Boughey, 2000). Such monetary units offer consistency and direct access to policy-makers (van de Bergh, 1996). Winpenny (1991b) describes three reasons for valuing the environment. Firstly, it helps a better selection of projects as the environmental costs are considered. Secondly, it provides a measure of economic efficiency and finally, it offers a basis for resolving use conflicts and awarding compensation in a fairer distribution of wealth.

In Section 2.2, environmental problems are closely linked with the absence of market value for environmental goods and services (Harding, 1998). There is no pricing mechanism to acknowledge an ecosystem's value to the economy and to be included in the current gross domestic product (GDP) accounts (Alexander et al., 1998). The ecosystem is typically unpriced, or not priced correctly because of a lack of private and organised markets for such services. It is because most environmental services are considered 'free' goods, in that they are not marketed and so no price exists to assess their values. Omitting this environmental valuation can lead to an underestimation of environmental damage (van de Bergh, 1996; Alexander et al., 1998; Harding, 1998).

Over the years, attempts have been made to incorporate the value of ecosystems in the traditional GDP accounts: termed 'green' GDP (Pearce et al., 1989). In green GDP accounts the ecosystem services are treated as a stock of inputs, which are depreciated or depleted over time. However, according to Alexander et al. (1998) the green GDP fails to account for the productivity of ecological inputs and is, therefore, of little use. The United Nations has developed the Satellite System for Integrated Environmental and Economic Accounting (SEEA) as a way of expanding the overall scope of the national accounts, while leaving the core accounts undisturbed (Lintott, 1996; van den Bergh, 1996; Herendeen, 1998). Other attempts such as regulations or fiscal policies, introduction of tradable abstraction rights and pollution permits have been used to promote environmental protection (Field, 1996; Boughey, 2000).

Valuing environmental resources is using market forces to determine resource allocation and ensure less wasteful consumption. The approach helps to place an upper limit on resource usage and allowing a trade-off process to establish market prices by which these resources will be allocated (Boughey, 2000). According to Pearce and Turner (1990) the adoption of monetary valuation can help to stimulate environmental awareness, justify a decision, and evaluate regulation so as to indicate relevance to macroeconomic objectives and to determine compensation. However, the problem is that some potential consumers are not even born and cannot help to determine current prices.

There are several different ways to assign monetary values to environmental benefits or damages. In accordance with OECD (1995), the valuation techniques can be grouped into three main kinds namely market valuation of physical effects, stated preference and revealed preference methods as shown in Table 2.1. Market valuation of physical effects observes environmental changes in physical terms and the differences are estimated accordingly. Stated preference methods obtain values of environmental assets by asking people directly to place monetary values on environmental issues such as the value of preserving a forest. It is a questionnaire-based social survey to obtain individuals' willingness to pay for an environmental gain or to accept compensation for a loss (Turner et al., 1994). Revealed preference methods concern the examination of people's behaviour to the environment. It is based on surrogate markets, which act as a proxy for the missing environmental goods and services in the market (Turner et al., 1994).

Each valuation technique has strengths and weaknesses. Deciding which technique to use will depend on the nature of environmental goods. Therefore, these techniques should be considered as complementary rather than competitive; not substituting for one another, but valuing different aspects of a proposed project or change (OECD, 1994).

Table 2.1 Summary of environmental valuation techniques

Market valuation of physical effects	
Dose-response method	Based on developing a dose-response relationship between output level of economic activities and environmental qualities. This technique is used to identify the consequences of changes in environmental issues to the economic return. To assess the gain or loss of benefits resulting from such a change requires the analysis of biological process, technical possibilities and the effect of resulting production changes on consumer welfare (Hanley & Spash, 1993; Hoevenagel, 1994).
Damage functions	Uses dose-response data to estimate the economic cost of environmental change using the market prices of the units of output (OECD, 1995).
Production function approach	Estimates the change in the environment on output and valued at market prices (Winpenny, 1991b; Hanley & Spash, 1993; OECD, 1995).
Human capital methods	Cost estimated using the impact of workers' productivity in relation to bad health caused by environmental changes (Winpenny, 1991b; OECD, 1995).
Replacement cost method	Uses the cost of preventing or restoring environmental damages as a way to estimate the value of protecting the environment, such as the cost of pollution (Winpenny, 1991b; OECD, 1995; Anon, 1996).
Stated preference methods	
Contingent valuation method	It is a direct valuation method which determines a value by surveying people's 'willingness to pay' for an environmental gain or 'willingness to accept' compensation for a loss on a hypothetical market scenario (Cameron & Englin, 1997; Harding, 1998; Foster & Mourato, 2002). It was originally proposed by Davis in 1963 and has been widely used by resource economists (Hanley & Spash, 1993) that enable economic values to be estimated for a wide range of commodities not traded in the markets (Tunstall & Coker, 1992; Abelson, 1996).
Revealed preference methods	
Travel cost approach	Developed by Clawson in 1959, it is widely used to evaluate recreational benefits (Thampapillai, 1991; Hanley & Spash 1993; Anon, 1996; Harding, 1998). This approach has simple methodology and it is an indirect environmental valuation method, in which the costs incurred in visiting an area are taken as a proxy to value the site itself. Market-related prices are used to estimate the demand curve for non-market goods. The information is obtained through visitors' surveyed on the distance and costs of travel and the origin of each group, thus providing an indication of the cost of conversion to another use.
Avertive behaviour Defensive expenditure	Information is obtained on the cost of protecting people from potential harm caused by declining environmental quality (Hoevenagel, 1994; OECD, 1995; Langston & Ding, 2001).
Hedonic pricing technique	This is a form of revealed preference analysis attempting to assess the value of environmental assets by estimating the prices of their closest market substitutes such as house prices (Beder, 1996; Gilpin, 1995). Hedonic pricing technique seeks to find a statistical relationship between the levels of environmental services and the prices of the marketed goods using regression analysis (Hanley & Spash, 1993; Anon, 1996). The technique focuses on a single environmental factor such as noise levels or air pollution (Langston & Ding, 2001).

2.3.4 The limitations of environmental valuation techniques

The usefulness and accuracy of environmental valuation techniques is highly controversial. The complex nature of the ecosystem has made it difficult to ascertain the quantity of natural resources and the functions they perform in relation to our daily activities. Moreover, environmental effects have no natural units of measurement. Consequently, it is difficult to translate them into economic valuations and bring them into national account calculations (El Serafy, 1991). Foster and Mourato (2002) suggests that environmental valuation techniques need a unique ability to deal with situations as environmental damages are multidimensional and the trade-off between the dimensions is of particular importance. However as Prato (1999) states, most environmental valuation techniques are single-dimensional, therefore unsuitable for evaluating multifaceted ecological impacts. For a technique to be useful and adequately address environmental assets, it needs to be more diverse and embrace the complex nature of the environment. However as van de Bergh (1996) explains, no single valuation method yet exists that provides a satisfactory valuation across the full range of environmental goods and services. It is also argued that the benefit of the environment to society is too complex to be captured by a single dollar value and to attempt to do so is to underestimate the importance of the environment (Gregory et al., 1993; Harding, 1998). Indeed, shadow pricing method is particularly difficult and it becomes even harder as the valuation involves evaluating future demands over a number of generations and over different social groups (Harding, 1998). Consequently, environmental impacts are often ignored in the decision-making process.

According to Hanley and Spash (1993), the only inclusive method that can be used to value a variety of environmental resources is the contingent valuation (CV) method. Other methods are restricted to measuring a limited class of environmental impact. However the CV method's usefulness to value environmental services is debatable and must be viewed with caution (Gilpin, 1995). Gilpin (1995) further states that a willingness to pay might be overstated to encourage preservation of an area, or might be understated to minimise the possibility of a significant user charge or levy. The possibility of over or understatement in the CV method is a major problem in environmental valuations as it is unable to provide a true market value to be incorporated in the decision-making process (Hanley & Spash, 1993).

Another problem with survey-based approaches is that biases may arise (Hanley & Spash, 1993; Anon, 1996; Crookes & de Wit, 2002). The CV method is a typical example as it relies heavily on an individual's view rather than actual market behaviour, which is highly responsive to supply and demand theory. The sums of money stated may exceed the willingness to pay because the participants knew they would not really have to pay (Hanley & Spash, 1993; Anon, 1996; Prato, 1999). The biases may also be caused by the survey design (Abelson, 1996) or due to the hypothetical situation with which survey respondents are unfamiliar or lack of experience with the environmental resource being valued (OECD, 1995; Cameron & Englin, 1997) necessitating the provision of explicit background information about the resource.

Environmental valuation techniques also attract argument about the feasibility and desirability of converting all environmental benefits and costs into dollar values; the main argument being that ethical issues such as the worth of a human life is beyond any monetary valuation (van de Bergh, 1996; Prato, 1999; Hobbs & Meier, 2000). Many people dispute that it is possible to assign accurate economic values to aspects of the environment, which often do not have any direct use in the economy. Therefore they consider that it is morally unacceptable to attempt to estimate non-use values. Thus many natural resources are considered priceless and cannot be compared with ordinary market commodities (Abelson, 1996; Harding, 1998). Crookes and de Wit (2002) further state that if such an approach is incorrectly interpreted, unethical issues are attached. So far, trying to put a monetary value on environmental assets using environmental valuation is inadequate and undesirable.

Environmental valuation requires extensive information to be collected and analysed. Except for the travel cost method, most valuation methods require extensive data collection, which is lengthy, costly and time-consuming (Tunstall & Coker, 1992; OECD, 1995; Crookes & de Wit, 2002). Additionally, the information required for valuation by various methods might either not be available or only available in an elementary form. This is a particularly serious concern in developing countries (Tewari et al., 1990; Crookes & de Wit, 2002).

Each valuation method has its own methodological limitation. In the hedonic pricing technique, the proposition is simple but the application is complex (Gilpin, 1995) because using house prices as a proxy is highly unreliable as there are too many variables that may affect the price such as age, size, location, quality and layout. Therefore the selection process of which factors to be included will significantly influence the results (Hanley & Spash, 1993; Anon, 1996). Abelson (1996) further states that the whole of the environment is greater than the sum of its parts and it cannot be valued simply on the collection of separate pieces of real property.

The travel cost method is restricted to measuring a limited class of environmental impacts (Anon, 1996) and only direct use values of actual users are measured with this method (Hanley & Spash, 1993). In the dose-response method there may be problems of interdependence between causal variables and whether the alternative costs fully reflect the cost of the externality (Anon, 1996). Conducting a survey-based contingent valuation method could exaggerate the importance of the issue. The result depends on how well the study is designed, carried out and interpreted (Hanley & Spash, 1993; Gilpin, 1995). In avertive behaviour and defensive expenditure methods the problem of underestimating the damage has suffered due to imperfect substitutability is unavoidable in the evaluation (Hoevenagel, 1994).

Distribution problems are inherent in valuation techniques. Environmental assets in an area populated with wealthy people cannot be directly compared with poorer people in another without any income adjustment (Anon, 1996). As Abelson (1996) states, everyone has an equal right to natural environmental assets and therefore techniques that are based on income, such as the willingness to pay, are irrelevant and unfair.

2.3.5 Summary

The purpose of putting value on environmental assets is to limit environmental degradation and to promote its protection. However, as discussed in this section, putting a price on environmental quality is not useful for protection as the valuation techniques suffer from methodological limitations and cannot accurately value the environment. Furthermore, environmental issues such as biodiversity cannot be priced at all, since plants and animals have an intrinsic value that cannot be represented in dollars. However, even though the environmental valuation techniques are constrained, it will always be better to do something rather than nothing. If putting a price on the environment cannot save the environment, it at least allows the decision-maker and general public to realise the potential damage and, in the process, highlight the importance of environmental conservation and its incorporation into the decision-making process.

As has been shown, the concept of putting a dollar value on environmental assets is controversial and there is no doubt that the current environmental valuation techniques are deficient. Therefore, it is important to transfer the focus from pricing the environmental assets to evaluating them using a non-monetary approach such as multi-criteria analysis. It is the purpose of this research to examine the usefulness of a non-monetary approach to assess environmental values and to incorporate this into the decision-making process. The next section will present the concept of using such an approach to evaluate environmental assets.

2.4 COST BENEFIT ANALYSIS AND MULTI-CRITERIA ANALYSIS

2.4.1 Introduction

This section examines the usefulness of cost benefit analysis as an evaluation tool to assess environmental effects and the incorporation of these values into the decision-making process when appraising a project. It is argued that cost benefit analysis as a single dimensional tool is theoretically insufficient to consider environmental effects as they are unable to have a dollar value appended to them (details refer to Section 2.3). The issues raised in the literature have called for a review of the methodology and applicability of current project appraisal methods. The debates are working towards a complementary appraisal tool such as multi-criteria analysis.

Multi-criteria analysis does not require a dollar value to be appended to environmental effects, nor does it exclusively focus on efficiency measurement. This section provides a detailed discussion of the issues raised in the literature and the usefulness of both methodologies in environmental valuation.

2.4.2 Cost benefit analysis as an evaluation tool

The initial decision to proceed with a development rests with the financial viability of the proposal by maximising aggregate welfare with given available resources. This is often expressed by forecasting project benefits received from, and project costs incurred by, undertaking a project. The appraisal of the relationship between these two elements is vital to the decision-making process as it will identify if discounted project benefits exceed discounted project costs, making the project viable. If there are separate development proposals, the determination will rest on the option that exhibits the greatest net benefits. Lower ranked options or those showing negative benefits will be abandoned altogether.

Cost benefit analysis (CBA) is a single dimensional tool widely used in decision-making. It is based on weighing up costs and benefits associated with an action (Nijkamp et al., 1990; Janssen, 1992; Tisdell, 1993; van Pelt, 1993b). CBA captures the trade-off between the real benefits to society from a given alternative and the real resources that society must give up to obtain those benefits, using money as the universal unit. CBA is designed to help evaluate proposed projects in order that the best option is selected and resource efficiency and social welfare are promoted in a systematic manner. By assessing the costs and benefits of each alternative in monetary terms and ranking alternatives on the criterion of economic worth, society is able to identify the best allocation of scarce resources and therefore maximise social benefit.

CBA was adopted in the United States as early as 1808 when Albert Gallatin, US Secretary of the Treasury, recommended the comparison of costs and benefits associated with water-related projects (Hanley & Spash, 1993). This idea was adopted by the French engineer, Jules Dupuit, in the formulation of cost benefit analysis described in the 1844 publication 'On the Measurement of the Utility of Public Works'. Since then CBA has become established as the most popular technique for evaluating public projects (Hanley & Spash, 1993) and is now the primary technique used in the field of environmental economics.

CBA methodology, however, exhibits some conceptual and practical difficulties (van Pelt, 1993a; Abelson, 1996; Ding, 1999a; Crookes & de Wit, 2002), which means that its effectiveness as a decision tool may be questioned. The current focus on sustainable development highlights some of the difficulties of relying on CBA as the sole consideration for project choice (Tisdell, 1993; Joubert et al., 1997). As Joubert et al (1997) state, the inclusion of equity and sustainability in decision-making has made the flaws in the theoretical foundations of CBA less easy to accept.

2.4.3 The limitations of cost benefit analysis in environmental valuation

The concepts of potential Pareto welfare improvement and the Kaldor-Hicks compensation principle are at the heart of CBA framework, which favours projects that exhibit the greatest net present value (NPV) (Hanley & Spash, 1993; Sinden & Thampapillai, 1995; Joubert et al., 1997). These principles ignore equity issues and conflict with the ultimate goal to allow for efficient allocation of scarce resources and to promote social welfare. In other words, while more people win than lose, the losers may be made a great deal worse off and this will not matter so much as long as they are in the minority. Compensation is theoretically provided from the winners, but this does not usually happen unless a particular compensation plan is built into the successful proposal.

Farrow (1998) explains that the concern for the distribution of benefits and who incurs costs can be viewed as an unplanned rejection of the Kaldor-Hicks criteria. CBA treats gainers and losers equally and is unconcerned about who gains and loses from a project.

Hanley (1992) argues that a project, which yields negative NPV, should still be considered if it exhibits better distribution, but this is disputed.

The general approach of CBA is to value all project costs and benefits in monetary terms based on market prices. This limits the scope of any analysis to consideration of only those factors that are the subject of market transactions. Other factors such as environmental features, risks or externalities that may be relevant to a social CBA including all public goods in the global commons and all environmental impacts, can hardly be valued in money terms (Joubert et al., 1997). Most often these costs (or benefits) are neither recorded nor incorporated in the project cash flow. The Department of Finance (1997, p.82) states that "the use of the money yardstick for measuring costs and benefits lends a false accuracy to the result of a cost benefit analysis". This means that social CBA results may not reflect the true benefits of a project if intangible values are present. Double counting of benefits is also a common pitfall.

As with the potential Pareto welfare improvement and the Kaldor-Hicks compensation principle, concepts of welfare and the compensation principle suffer because they ignore equity issues that conflict with the goal of CBA to promote social welfare (Nijkamp et al., 1990; Hanley & Spash, 1993; Abelson, 1996; Joubert et al., 1997; Department of Finance, 1997). This equity issue is particularly important for future generations who can have no say in current decision-making processes. Their interests rely totally on the considerations of the present generation. The definition of sustainable development as defined in the Brundtland report strongly advocates that future generations should have equal opportunity and right to cast their votes on the decision of project developments which may have long-term affects on their living environment (WCED, 1987). Even though equity can be introduced in CBA by means of income distribution weighting, this is rarely used in practice (Joubert et al., 1997).

Distribution issues are normally ignored in CBA since only the sum of monetarised effects is taken into consideration. In reality, either the welfare benefits are not equitable or governments may not be able to distribute income. The combination of high levels of poverty, unequal distribution of income, and ineffective income redistribution policies led to the growing importance of intratemporal equity as an appraisal criterion for development projects (Dasgupta & Pearce, 1972; van Pelt, 1993a, Sinden & Thampapillai, 1995; Abelson, 1996; Crookes & de Wit, 2002). Sustainability-oriented project appraisals should address environmental issues at the project level, as well as at the national and international level (van Pelt, 1993b). Future generations cannot cast their votes, so project appraisal techniques must encompass this issue. Certainly equity issues cannot be upheld for future generations without undertaking a distribution analysis, which is overlooked in many studies.

Under the principles of CBA, no concern is given as to who gains and who loses from a project; as long as the total benefits outweigh the total costs therefore the option with the greatest positive net benefit is selected. A project that generates net benefits to the rich has opportunity equal to that of a project that generates net benefits to the poor. However, a project that yields benefits to the poor has a desirable distribution impact (van Pelt, 1993b). Equity is not generally a criterion for consideration within the CBA framework and largely weakens the effectiveness of CBA when applied in social contexts (Hanley & Spash, 1993; Perkins, 1994).

The outcomes of CBA may be manipulated to suit private purposes and may be less useful where political decisions dominate (Perkins, 1994). These outcomes may be influenced in various ways, e.g., by the adoption of particular values, shadow prices or discount rates in order to produce a pre-determined result. This is actually in direct conflict with the welfare objective of CBA as it may lend support to less desirable alternatives that suits private purposes rather than promoting options that are more resource efficient and socially desirable.

Market failure is another limitation of CBA (Nijkamp et al., 1990; Hanley & Spash, 1993; Abelson, 1996). One of the fundamentals of CBA is the assessment of project costs and benefits at local market prices, and as a result the outcome of CBA relies heavily on prevailing market valuations. However, markets may be distorted by a number of factors such as government intervention, interest rates, balance of payments deficit and foreign exchange rates (Perkins, 1994). Such market failure can lead to an incorrect set of prices, which inaccurately measures marginal social costs and benefits, and therefore an inefficient allocation of resources. In addition, environmental effects are not recorded in any market systems, as no property rights exist for many environmental goods and services.

Another concern is the use of discounted cash flow analysis as part of the methodology. Discounting is the process by which costs and benefits that occur in different time periods may be compared. CBA is involved in predicting the future and dealing with uncertain interaction between human activities and ecosystems. Crookes and de Wit (2002) state that CBA is insufficient to assess environmental variations as the traditional CBA values impact within the lifetime of the project but environmental impacts may extend beyond that lifetime. In the long term, it is possible that the discount rate might play a critical role in the intertemporal decision concerning the use of environmental resources for sustainable development. High discount rates discriminate against future generations. Many environmentalists argue that discounting violates the rights of future generations (Martin, 1993). Although the discounting philosophy is conceptually acceptable, its application to social and environmental issues is debatable and may lead to an undervaluing of these costs and benefits (Hanley & Spash, 1993). The choice of discount rate is also controversial, particularly where high rates are chosen that rapidly disadvantage future cash flows rendering them irrelevant to the decision. Besides, risk and uncertainty are also difficult to handle in CBA and other environmental valuation techniques (Crookes & de Wit, 2002).

Because public participation in the decision-making process is gaining strength (Mitchell et al., 1995; Joubert et al., 1997; Curwell & Cooper, 1998), the usefulness of CBA as a primary tool in decision-making is highly questionable. As Joubert et al. (1997) describe, CBA may no longer be appropriate as a decision-making tool if externalities are part of the consideration in project appraisal within a participatory democracy.

Given the limitation of CBA in accounting for environmental goods and services, Postle (1998) argues that in order for the goals of sustainable development to be realised, environmental and other social impacts should be properly taken into account in the decision-making process. This can only be achieved through quantification and full valuation. Placing values on the environmental goods and services in the projects appraisal stage may enhance their importance and the awareness among people (Pearce & Turner, 1990). However, over the years, monetary evaluation approaches have received harsh criticism (Nijkamp et al., 1990; Hobbs & Meier, 2000).

Pearce et al (1989) suggest that the use of CBA as a project selection methodology should be modified to make allowance for sustainability considerations. They further state that CBA should only be used in appraising a project providing that net environmental damage for projects selected is zero or negative. That means it is only useful in the situation where projects that are environmentally enhancing compensate for environmentally damaging projects. The argument gives a picture that solely relying on net benefits to decide whether a project is viable is inadequate if environmental values are also considered since environmental values are difficult to monetarise.

While CBA is an important tool in decision-making and its systematic arrangement of information enhances the decision-making process, its limitations are serious and cannot be neglected. There is a wide range of valuation techniques that can be used to incorporate environmental effects in the CBA framework. One modification is to extend the current CBA methodology to encompass any environmental cost or benefit (Azqueta, 1992; Powell, 1996). However, as Tisdell (1993) comments, it is a brave attempt to introduce sustainability considerations into the current CBA framework as there are often limitations in its methodology in measuring all relevant impacts of a project in money units (Nijkamp et al., 1990). It is, indeed, difficult to put all the complexities of ecological systems into a common measure and the price mechanism is an inappropriate method for attempting to control environmental process. Prices may be rather bad indicators of the real scarcities and pertaining social evaluations in the economy (Nijkamp et al., 1990; Common & Perrings, 1991; Moffatt, 1996).

Nijkamp et al (1990) further explain that although many efforts have been undertaken to arrive at values for intangibles and externalities it is, in practice, almost impossible to place anything more sophisticated than arbitrary numerical values on such effects. However, even if it may be possible to adopt the advanced cost benefit methodology to evaluate all the impacts in terms of monetary units, this approach still suffers from the drawback that the potential cost of the impact will vary with different outcomes of concern (Lee et al., 2002).

Powell (1996) argues that it is not necessary to assign monetary values to environmental effects in order to determine the viability of a decision. The CBA framework can be supplemented by adopting other techniques such as effectiveness analysis and multi-criteria analysis, which may help to produce a better evaluation tool (Nijkamp et al., 1990; van Pelt, 1993b; Powell, 1996). Various methods have been proposed to solve these evaluation problems, but these alternatives may often give rise to different outcomes, making them unstable to use.

Social CBA has been developed and includes adjustment for biased income distribution patterns. However, van Pelt (1993b) argues that social CBA cannot cover all equity issues and may only consider income distribution among target groups by using the income generated from a project for either consumption or savings. He further states that both economists and policy makers may find that social CBA is a rather inaccessible technique to deal with enormous data requirements and the need to explicitly express value judgements in the framework. When economists have been confronted with the requirement to monetarise all relevant effects and the difficulties in collecting data on several types of effects, they have frequently failed to incorporate all the costs and benefits of development projects.

The above problems and limitations of the market price approach gave rise to a search for alternative evaluation approaches to completely replace CBA, for example, cost effectiveness analysis (CEA) and environmental impact assessment (EIA). Such techniques identified environmental effects but did not require that these effects be monetarised. Sagoff (1988) argues that CBA should be replaced as a tool for project appraisal by the normal democratic process. Publicly elected politicians always make the final decisions based on the argument that they are the representatives of the citizens and should be delegated with rights to make decisions on their behalf. Interest groups may participate in the decision-making process to lobby in favour of particular alternatives (Norton & Hannon, 1997).

CEA is a variation of traditional CBA which is useful for public sector projects. This technique assumes a common level of social benefit and therefore focuses on measuring the costs. CEA is used in lieu of CBA when the project benefits are not readily measurable in monetary terms. Instead, benefits are expressed in physical units while project costs are expressed in money terms (Department of Finance, 1997). CEA is based on the acceptance of a target and only the cost of achieving the target is sought, so it is also known as a least-cost approach. As the benefits are equal they cancel out and can, essentially, be ignored. However, only indirect project benefits are measured. The difficulty in estimating externalities is also largely obviated by this approach. CEA substitutes non-monetary effectiveness indicators for a monetary estimate of social benefits. CEA examines the cost to achieve results on the assumption that there is a positive net benefit (Harlow & Windsor, 1988; Department of Finance, 1997).

EIA resembles CEA as only the damage side of a project is considered. The main problem of EIA is its incompatibility with other approaches. EIA originated from a very different theoretical framework as a way for the treatment of externalities and public goods to be measured in a situation characterised by the absence of markets for some commodities (Azqueta, 1992; Gilpin, 1995). However, as Joubert et al. (1997) suggest, EIA offers no structure and provides no guidelines to the decision-maker whose aim is a rational assessment of the impacts and trade-offs involved.

Azqueta (1992) suggests using extended CBA, which integrates EIA and social project appraisal into the same framework. However Pearce et al. (1990), argue that the extended CBA suffers from serious shortcomings as the two streams are based on different theoretical backgrounds implying different social objectives.

2.4.4 The principles of multi-criteria analysis

Project appraisal techniques are often employed by decision-makers to structure the complex array of data relevant to a project into a manageable form and provide an objective and consistent basis for choosing the best solution for a given situation. In CBA, much effort has been put into assessing the input costs and output benefits by means of a market approach. With the increasing awareness of possible negative external effects and the importance of distribution issues in economic development, CBA's usefulness in this respect is increasingly controversial. Consequently, in the past decade much attention has been paid to multi-dimensional evaluation approaches (Nijkamp et al., 1990). One such approach is known as multi-criteria analysis (MCA).

The identification of value for money on construction projects is clearly related to monetary return. But some other issues are becoming increasingly significant, particularly for social infrastructure projects. For example, issues such as welfare enhancement and resource efficiency are vital to the assessment of environmental impact in the wider social context. Since no single criterion can adequately address all the issues involved in complex decisions of this type, a multi-criteria approach to decision-making offers considerable advantages.

Traditional CBA uses price as the main tool to evaluate projects, based on market transactions. However, as has been shown, over the past decade criticisms of CBA have been many, and relate mainly to attempts at putting the underlying welfare economic theory into practice. It is often difficult, or even impossible, to improve social welfare in a society if the natural environment continues to be abused and depleted. Goulder and Kennedy (1997; cited in Prato, 1999) state that CBA is not a sufficient criterion for evaluating natural resource investments. Joubert et al. (1997) also argue that CBA is not an appropriate tool to evaluate investments that generate social and environmental externalities. Indeed, within the CBA framework, environmental assets are often ignored or under-estimated as there are frequently considerable difficulties in measuring all relevant impacts of a project in monetary units (Abelson, 1996).

Ecologically sustainable development (ESD) is now a constant focus for the mass media and a matter for widespread public concern (Joubert et al., 1997). As a consequence, intangibles and externalities have become major issues in project development. The presence of externalities, risks and spillovers generated by project development often preclude the meaningful and adequate use of a market-based methodology. When the analysis turns to assessment of environmental quality or loss of biodiversity, it is rarely possible to find a single variable whose direct measurement will provide a valid indicator of the severity of these effects.

The need to incorporate environmental issues into the project appraisal process is becoming increasingly apparent, and as it does, applying market prices to these factors becomes more and more questionable.

Apart from replacing CBA with techniques like CEA or EIA as discussed previously, others have suggested supplementing CBA with a technique that can measure environmental costs in terms other than monetary (Nijkamp et al., 1990; van Pelt, 1993b; Hanley, 1992; Abelson, 1996; Joubert et al., 1997). MCA is now widely accepted as a non-monetary evaluation method to aid decision-making when dealing with environmentally sensitive projects. As Joubert et al. (1997) describe, CBA is a well-established decision tool as long as there are no ‘externalities’ involved. MCA thus emerges as a technique to appraise projects with a potential environmental impact. As Diesendorf and Hamilton (1997) state, MCA is a useful technique for drawing together all of the complex information. As discussed previously, CBA equity issues are insufficiently addressed in the CBA framework. MCA can directly address equity issues by using improvement in income or non-income equity as project selection criteria. The equity issues can be measured on an interval or preference, rather than a monetary scale as in the CBA method.

2.4.5. Multi-criteria analysis—a non-monetary appraisal technique

Non-monetary evaluation techniques originated in operational research and developed in response to criticism of monetary methods (Janssen, 1992; Powell, 1996). Since the 1970s, a number of non-monetary evaluation techniques have been developed under MCA system. These techniques aim to provide a method for the systematic appraisal and incorporation of a number of alternative projects involving a range of different criteria into the decision-making process (Voogd, 1983; Janssen, 1992; Powell, 1996; Postle, 1998). Most of the differences between the various multi-criteria evaluation methods arise from the arithmetic procedures used as a means to aggregate information into a single indicator of relative performance. The use of such mathematical models to predict impact on each of the attributes lies at the heart of the MCA process (Voogd, 1983).

MCA has, in the past decade, become one of the most powerful methodologies in optimisation analysis (Nijkamp et al., 1990). It serves to enhance decision-making quality by providing a thorough methodological platform for decision analysis and an operational framework. MCA techniques offer the possibility of accounting for non-efficiency criteria as well as non-monetary project impacts, and can address subjective views of various parties in society (van Pelt, 1994; Hobbs & Meier, 2000).

MCA is designed to value two or more criteria for project selection, which include efficiency, equity and meeting a sustainability constraint. It is particularly useful for those environmental impacts that cannot easily be quantified in terms of normal market transactions. MCA transfers the focus from measuring criteria with prices, to applying weights and scores to those impacts and to determine a preferred outcome thus avoiding the ethical debates surrounding the issues of monetary valuation as environmental matters are largely priceless and unique (van Pelt, 1993b).

MCA as a utility approach has been structured in such a way that public participation can be readily included in terms of criteria selection, alternative evaluation and weighting assignments through questionnaires. Stakeholder groups may participate to review the results and identify areas of agreement and disagreement (Hobbs & Meier, 2000). In addition, MCA contains tools that facilitate the decision-making process by displaying trade-offs between criteria and improving the decision-maker’s ability to assess those trade-offs. (Joubert et al., 1997; Hobbs & Meier, 2000). Total scores are used in MCA to rank project alternatives to indicate the best option.

MCA is a more flexible methodological approach as it can deal with quantitative, qualitative or mixed data for both discrete and continuous choice problems and does not impose any limitation on the number and nature of criteria (van Pelt, 1993a). However, CBA is limited to quantitative data for discrete choice problems. As a result, MCA is a more realistic methodology in dealing with the increasingly complex nature of building development.

Despite its flexibility, MCA may also have limitations. Its usefulness is governed by an explicit view on the relative priorities in terms of weights, and stakeholder groups' priorities may fail to reflect the values of the community at large. It would be more useful if MCA was used to appraise several alternatives since the decision on a single alternative is either "rejected" or "approved" (van Pelt, 1993a & 1994; Hobbs & Meier, 2000).

As Hobbs & Meier (2000) state, with the amount of data generated in the MCA methodology concerning the performance of alternatives on numerous criteria, there is a possibility that stakeholders may not be easily able to digest. The true preferences of the stakeholders may be distorted and lead to inconsistencies across jurisdictions regarding value judgements (van Pelt, 1993b; Hobbs & Meier, 2000). In addition, there are so many techniques to choose from that confusion may result and different MCA techniques may be improperly applied to a particular problem resulting in the different outcomes. The problem of method uncertainty deserves specific attention and it may require applying several MCA techniques to a particular problem to test the results (van Pelt, 1993b).

Finally, even though equity and sustainability issues are difficult to fully evaluate in a broad sense, measurable sub-criteria using methods other than market transaction may indicate at least relative movement towards these goals. The debate on conventional versus modern evaluation analysis tends to regard CBA and MCA as complementary tools rather than as competitive tools (Watson 1981; Jones, 1989; Nijkamp et al., 1990; Gregory et al., 1993; van Pelt, 1993b; Powell, 1996; Joubert et al., 1997; Mirasgedis & Diakoulaki, 1997; RICS, 2001).

The methodology of supplementing traditional CBA with MCA is no doubt an improvement, but may still fall short of the requirements, as issues are either monetarised or scored. A methodology that quantifies economic and environmental effects using the method of measurement that best suit their nature and characteristic may be required. Some effects such as energy consumption may be better measured rather than rated in relative terms. The sustainability index as developed in this research is a way to address multiple criteria in relation to project decision-making and the economic and environmental effects are quantified as much as possible. Using a sustainability index will greatly enhance the assessment of external effects generated by construction activity, realise sustainable development goals and thereby make a positive contribution to the identification of optimum design solutions. The discussion of such a model will be detailed in Chapters Four and Five in this thesis.

2.4.6 Summary

Cost benefit analysis is a systematic and consistent method of project appraisal widely used by developers, investors, governments and international funding agencies. All project development, policies and programs will have different approaches or proposals in order to achieve the same objectives. Projects need to be properly evaluated before a decision is made to proceed. The approach used in project appraisal, therefore, becomes important in choosing the best option from the available alternatives.

Economic or social CBA are tools used to assist decision-makers to compare alternatives by applying economic theory. The main theme of CBA is to monetarise and weight the total flow of costs of proceeding with a project against the total flow of benefits obtained from it, and to rank the options. Alternatives with a net positive benefit are acceptable, whereas alternatives showing negative outcomes should be abandoned. The higher the NPV the better, given a reasonable benefit-cost-ratio (BCR) and an acceptable level of profit and risk contingency.

But the technique is not without its problems, and for public projects where externalities and intangibles are common, the calculated outcomes may be highly questionable. Much advantage lies in the rigour of the technique itself and the ability to evaluate different scenarios using a range of variables that are significant to the analysis. In a sense, the greatest benefit of CBA is its ability to allow for social and environmental issues objectively, and yet this is also its greatest weakness.

Building development involves complex decisions and the increased significance of external effects has further complicated the situation. Society is not just concerned with economic growth and development but is also conscious of the long-term impacts on living standards for both present and future generations. Sustainable development is now an important issue in project decisions. Ecologically sensitive projects require a different approach to appraisal than most traditional projects. The engagement of a conventional single dimensional evaluation technique such as CBA in assisting decision-making is no longer relevant and a much more complicated model needs to be developed to handle multi-dimensional arrays of data. Multi-disciplinary appraisal teams and an overall methodology are essential to uphold the goal of a sustainable development.

2.5. CONCLUSION

There is no doubt that the environment is closely linked to economic growth and the continued depletion of environmental assets will be detrimental to the well-being of mankind. As such, much research has been undertaken to evaluate environmental values and their incorporation in project appraisal. This chapter summarises the current environmental problems that are experienced around the world and their impacts on present and future generations. The techniques that are available in the valuation of environmental assets are also discussed but as this chapter described, they suffer from serious methodological shortcomings. These are closely related to the single-dimensional nature of these techniques which have restrictive methodology in assessing the complex nature of the natural world. This chapter also discussed the emergence of valuing the environment using a non-monetary approach in lieu of the conventional market-based approach of valuing costs and benefits in dollar values.

This chapter, whilst discussing the issues on a global viewpoint, has laid down the fundamental platform for the discussion of the impact of the construction industry and its related activities on the environment in the following chapters.

CHAPTER
THREE

THE CONSTRUCTION INDUSTRY AND THE ENVIRONMENT

3.1 INTRODUCTION

Construction projects differ widely in type and size. They can be as small as a simple domestic renovation or as large as a transnational infrastructure project such as the Channel Tunnel, requiring the collaboration of several countries. Construction is not limited to buildings but includes civil engineering and mining projects, transportation and energy generation projects, maintenance of existing facilities and developing new technologies.

A project is defined as "a discrete package of investments, policy measures, and institutional and other actions designed to achieve a specific development objective within a designated period" (van Pelt, 1993b, p.41). Indeed, projects can be in the form of physical developments, government policies, community activities and welfare programs. Projects are often conceived in response to particular problems. The project is designed to change an undesirable existing condition into a desirable new condition within a stated period of time and within budget limits. Project development involves systematic analysis of prioritised development objectives to facilitate efficient resource allocation. A project may also be defined in the broader sense of any use or saving of resources, such as health, social services and environmental control projects (OECD, 1994; Abelson, 1996).

A project is regarded as successful if it is completed within the imposed constraints of quality, cost and time and achieves its designated purpose. This involves the fundamental processes of selecting the right project, constructing it according to specification at reasonable cost and within minimum time. Project selection often involves choosing the best option from a range of possible ideas.

The purpose of a project is derived from a prescribed set of objectives. The objectives of a private development may be to maximise current profit, efficiency, yearly turnover or employment. In society's view, the ultimate goal of a project may be to improve social welfare or quality of life, or provide enjoyment. From an environmental viewpoint, however, more project development means more damage to the natural world and depletion of scarce renewable and non-renewable resources. In this way, people tend to go to one of two extremes, either focusing on project development without any consideration of the environment, or criticising almost any kind of new development in society. Nevertheless, going to either extreme is not an ideal circumstance and an effective balance needs to be struck.

The objective of this chapter is to review the relationship between construction activities and environmental issues. To study this, the literature review has focused on the impacts of the construction industry on the environment and the importance of environmental management systems in enhancing sustainable goals in the construction industry. In addition, this chapter also evaluates the importance of energy consumption in the built environment. To provide information for the study, the energy analysis has been carried out based on a life cycle approach where both embodied and operational energy were examined.

3.2 SUSTAINABLE CONSTRUCTION AND ENVIRONMENTAL ISSUES

3.2.1 Introduction

In the late 1960s and early 1970s people started to worry about the ability of the ecosystems to support ever-increasing economic activities (Azqueta, 1992). Throughout the world, the building industry is responsible for high levels of pollution as shown in previous research resulting from the energy consumed during raw materials extraction, processing and transportation. Industrialised building methods, based on the widespread use of high energy materials such as aluminium, cement, concrete and steel, must now comply with new directives for the protection of the environment. The construction industry, whilst important for every society, is also responsible for environmental protection.

3.2.2 The construction industry and its impacts on the environment

Concern is growing about the impact of building activities on human and environmental health. It is clear that actions are needed to make the built environment and construction activities more sustainable (Hill & Bowen, 1997; Barrett et al., 1999; Cole, 1999a; Holmes & Hudson, 2000; Morel et al., 2001; Scheuer et al., 2003). The construction industry and the environment are intrinsically linked and it is inevitable that it has found itself at the centre of concerns about environmental impact. According to Levin (1997), buildings are very large contributors to environmental deterioration. Kein et al. (1999) describe the building industry as uncaring and profit motivated, and the members as destroyers of the environment rather than its protectors. Indeed, the construction industry has a significant irreversible impact on the environment across a broad spectrum of its activities during the off-site, on-site and operational activities, which alter ecological integrity (Uher, 1999).

Construction activities affect the environment throughout the life cycle of a development from initial work on-site through to the operational period and to the final demolition when a building comes to an end of its life. Even though the construction period is comparatively short in relation to the other stages of a building’s life, it has various significant effects on the environment. Therefore the analysis of the impact of the construction industry on the environment may need to look at a ‘cradle to grave’ viewpoint (Ofori et al., 2000).

The construction industry is one of the largest exploiters of both renewable and non-renewable natural resources (Spence & Mulligan, 1995; Curwell & Cooper, 1998; Uher, 1999). According to Worldwatch Institute (2003), building construction consumes 40 percent of the world’s raw stones, gravel and sand, and 25 percent of the virgin wood per year. It also accounts for 40 percent of the energy and 16 percent of the water annually. According to Levin (1997), in the USA construction uses 30 percent of raw materials, 40 percent of energy and 25 percent of water. In Europe, the Austrian construction industry has about 50 percent of material turnover induced by the society as a whole per year (Rohracher, 2001) and 44 percent in Sweden (Sterner, 2002). It relies heavily on the natural environment for the supply of raw materials such as timber, sand and aggregates for the building process. This extraction of natural resources causes irreversible changes to the natural environment of the countryside and coastal areas, both from an ecological and a scenic point of view (Curwell & Cooper, 1998; Ofori & Chan, 1998; Langford et al., 1999). The subsequent transfer of these areas into geographically dispersed sites not only leads to further consumption of energy, but also increases the amount of particulate matter in the atmosphere.

Raw materials extraction and construction activities also contribute to the accumulation of pollutants in the atmosphere. According to Levin (1997), in the USA construction is responsible for 40 percent of atmospheric emissions, 20 percent of water effluents and 13 percent of other releases. Dust and other emissions include some toxic substances such as nitrogen and sulphur oxides. They are released during the production and transportation of materials as well as from site activities and have caused serious threat to the natural environment (Spence & Mulligan, 1995; Ofori & Chan, 1998; Rohracher, 2001). Other harmful materials, such as chloroflucarbons (CFCs), are used in insulation, air conditioning, refrigeration plants and fire-fighting systems and have seriously depleted the ozone layer (Clough, 1994; Langford et al., 1999).

Pollutants have also been released into the biosphere causing serious land and water contamination, frequently due to on-site negligence resulting in toxic spillages which are then washed into underground aquatic systems and reservoirs (Kein et al., 1999). According to Langford et al (1999), about one third of the world's land is being degraded and pollutants are depleting environmental quality, interfering with the environment's capacity to provide a naturally balanced ecosystem. If the construction industry continues to overuse these natural resources, a limit on economic growth will eventually emerge. In other words, the destruction of the environment will inevitably affect the construction industry.

The construction industry produces an enormous amount of waste. A large volume results from the production, transportation and use of materials (Ofori & Chan, 1998; Kein et al., 1999). Construction activity contributes approximately 29 percent of waste in the USA, more than 50 percent in the UK and 20–30 percent in Australia to the overall landfill volume (Teo & Loosemore, 2001). According to Levin (1997), in the USA construction contributes 25 percent of solid waste generation. In the European Union, the construction industry contributes about 40–50 percent of wastes per year (Sjöström & Bakens, 1999; Sterner, 2002).

Most construction waste is unnecessary according to Sterner (2002) who says that many construction and demolition materials have a high potential for recovery and reuse. However, due to the economic nature of the building industry, every stage of the construction period is minimised. In addition, time and quality are crucial and virgin materials are considered superior to second hand products for these reasons alone. Screening, checking and handling construction waste for recycling are time consuming activities and the lack of environmental awareness amongst building professionals may create significant barriers to the usefulness of recycling (Langston & Ding, 1997d). The depletion of natural resources by the building industry is a topic of serious discussion as most of the recyclable material from building sites ends up in landfill sites. Sterner (2002) states that implementing a waste management plan during the planning and design stages can reduce waste on-site by 15 percent, with 43 percent less waste going to the landfill through recycling, and it delivers cost savings of up to 50 percent on waste handling.

Besides generating waste, building activities also irreversibly transforms arable lands into physical assets such as buildings, roads, dams or other civil engineering projects (Spence & Mulligan, 1995; Langford et al., 1999; Uher, 1999). The loss of agricultural land is mainly found along coastal areas where soil fertility is most suited to crops and other agricultural production. According to Langford et al. (1999), about 7 percent of the world’s cropland was lost between 1980 and 1990. Arable land is also lost through quarrying and mining the raw materials used in construction. Construction also contributes to the loss of forests through the timber used in building and in providing energy for manufacturing building materials. Both deforestation and the burning of fossil fuels contribute directly global warming and air pollution.

The building industry is also considered to be a major consumer of energy and the use of finite fossil fuel resources for this purpose have contributed significantly to carbon dioxide emissions (Clough, 1994; Spence & Mulligan, 1995; Ofori & Chan, 1998; Langford et al., 1999; Uher, 1999). Building material production consumes energy, the construction phase consumes energy, and operating a completed building consumes energy for heating, lighting, power and ventilation. In Europe, construction activities have consumed about 40 percent of total energy production (Sjöström & Bakens, 1999; Rohracher, 2001; Sterner, 2002). The energy consumption and the construction sector will be discussed in greater detail in Section 3.3 in this chapter.

3.2.3 The concept of sustainable construction

Sustainable construction is considered as a way for the construction industry to contribute to the effort of achieving sustainable development. It is also a way to portray the construction industry's responsibility towards protecting the environment (Pitney, 1993; Spence & Mulligan, 1995; Hill & Bowen, 1997; Bourdeau, 1999; Ofori & Chan, 1998; Ofori et al., 2000; Zhang et al., 2000).

One view considers that the construction industry plays an important role in the world economy through creating man-made capital, a significant contributor to maintaining economic growth and quality of life. Hill and Bowen (1997) state that about 10 percent of the global economy is dedicated to constructing, operating and equipping homes and offices. This activity accounts for approximately 40 percent of materials flowing into the world economy (Hill & Bowen, 1997). In the European Union, the construction sector contributes about 10–12 percent of gross national product (GNP) to the economy each year (Sjöström & Bakens, 1999). It is also a main supporter of economic development by providing infrastructure and buildings. Therefore, continuing and increasing levels of construction activity are essential to all aspects of development.

However, the alternate view is that the construction industry has a significant impact on resources such as land, materials, energy and water and, therefore, also shares responsibilities of working towards a sustainable future through limiting the environmental impact of building activities. The total environmental damage can be significantly reduced if the construction industry takes proper actions to improve its environmental performance (Miyatake, 1996; Ofori & Chan, 1998; Ball, 2002) and this potential damage has to be analysed when considering sustainable development (Bourdeau, 1999).

There is still no consensus agreement of what sustainable construction really means (Ofori, 1998). According to Kibert's presentation in the First International Conference on Sustainable Development in 1994, sustainable construction is defined as the creation and responsible maintenance of a healthy built environment based on resource efficient and ecological principles (cited in Bourdeau, 1999). Bourdeau (1999) states that this has provided a broad definition that forms a starting point for defining sustainable construction. The definition of sustainable construction includes the concepts of construction that prevents environmental degradation and utilises resources efficiently so that the environmental, economic and social benefit justify the environmental degradation created throughout the building life cycle (Najjar, 1994; Guy & Kibert, 1998; Ofori et al., 2000).

Spence and Mulligan (1995) state that restricting the total amount of construction in order to achieve the principle of sustainable development is not essential. Construction development is interwoven with economic growth, and economic growth is about improving standards of living. du Plessis (1999) suggests that social impacts should have a role in accomplishing sustainable construction. He points out that social achievement through improving the quality of life is the motivation for many actions and it follows that the more development, the more growth, leading to improved standards of living. Therefore, sustainable construction is not just about saving the world, but also about maintaining a comfortable environment for mankind. This view supports the idea that sustainable construction does not imply a complete halt to irreversible change in the natural environment. Some conversion of natural into man-made capital is acceptable providing that the depletion rate of the world's natural capital does not exceeds the rate of accumulation of man-made capital of lasting value (Spence & Mulligan, 1995; Curwell & Cooper, 1998). Unfortunately this is currently not the case. The consumption rate of the world's natural resources is much faster than the regeneration rate and waste production has already breached the assimilative capacity of many ecosystems (Rees, 1999).

Hill and Bowen (1997) state that sustainable construction starts at the planning stage of a building and continues throughout its life to its eventual deconstruction and recycling of resources to reduce the waste stream associated with demolition. They go on to describe sustainable construction as consisting of four attributes: social, economic, biophysical and technical. These four attributes form a framework for achieving sustainable development that includes an environmental assessment during the planning and design stages of projects, and the implementation of environmental management systems.

The continuing confusion about concepts and lack of agreement on causes and effects have reduced the ability to provide guidance based on well-accepted and understood concepts for good practice in construction (Bröchner et al., 1999). With regards to the existing definition of sustainable construction, it is important to note that even if the principle of sustainable construction is attained, construction operations would continue to have environmental impacts, but at a reduced rate (Ofori et al., 2000).

3.2.4 ISO14000 and environmental management systems in construction

Improvements in environmental performance are often seen as a cost burden. At the same time, because the construction industry is fragmented and because much of what it produces has cultural significance, it is particularly slow to change and to embrace environmentally friendly practices (Teo & Loosemore, 2001; Ball, 2002). With the widespread publication of environmental problems, there has been an increasing force for the construction industry to take a more responsible attitude towards the environment. In particular, understanding the impact of the construction sector on the global environment is still unclear (Bourdeau, 1999). Teo and Loosemore (2001) describe how attitude and conventional behaviour have hindered changes in the construction industry.

Bourdeau (1999) argues that it is important for the construction industry to realise the nature and extent of environmental impacts caused by its activities so that solutions will be developed. Construction companies' current corporate practices may need to respond to the requirements of sustainable development. Environmental management systems are considered as a way for construction to minimise environmental effects (Kein et al., 1999; Ofori et al., 2000, Zhang et al., 2000). They are tools that help to make a trade-off between economic growth and the sustainability of the environment. ISO14000 has environmental management systems and it includes a standard for organisations to implement these systems into their practices. The ISO14000 series of standards provides a framework for construction companies to manage their operations in order to improve the environmental performance and to achieve tangible results without compromising their corporate goals.

The International Standards Organisation (ISO) developed ISO14000 in 1996 in accordance with the results of a 1993 study of major international standards for environmental management systems by the Technical Committee (TC 207) (Ofori et al., 2000). The main objective of the study was to develop a uniform international environmental management system standard to be used as an environmental management tool. Apart from environmental management systems, ISO14000 has four other standards: environmental auditing, environmental labelling, environmental performance evaluation and life cycle assessment. The development of ISO14000 supports the view of sustainable development as minimising harmful effects on the environment through construction activities (Ball, 2002).

Zhang et al. (2000) state that ISO14000 brings environmental issues into an organisation's decision-making process, integrating sustainable development principles with business practices. Fundamentally, ISO14000, even though voluntary, has provided a framework to link the concept of sustainable development with the construction procurement process. Environmental management systems as defined in ISO14001 are part of the overall management system which includes the organisational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining a company's environmental policy (Kein et al., 1999).

Environmental management systems have many benefits for the construction industry assisting improved its environmental performance. Zhang et al. (2000) state that such systems can help to reduce environmental damage and improve environmental performance in the construction industry. Ofori et al. (2000) state that they are a set of management tools enabling companies to protect the environment from the potential impacts of its activities, products and services. They also provide a means to manage the processes and procedures to avoid adverse effects to the environment, and to comply with environmental regulations. Kein et al., (1999) and Ofori et al., (2000) nominate other key benefits of environmental management systems for the construction industry as:

- enhanced image and credibility,
- lower operating costs from resources conservation and waste minimisation,
- minimised risk of violating environmental legislation and regulations,
- reduced environmental risk,
- improved customer trust and satisfaction leading to improved competitiveness,
- improved business expansion potential where environmental management capability is needed, and
- enhanced employee involvement and education in environmental matters.

Conversely, Kein et al. (1999) and Ofori et al. (2000) also nominate some drawbacks from implementing environmental management systems in the construction industry. The environmental management system as an ongoing activity may add a short-term financial burden from employing environmental consultants and setting up the required structures and training for the firm's personnel. Nevertheless, the additional cost may be offset by the long-term benefits that may accrue from implementing the system. The diversity of construction techniques and individuality of each project also make it difficult to employ environmental management systems. Therefore, environmental impacts and measures can be difficult to assess and quantify.

The process of incorporating ISO14000 into company practices may require further investigation to minimise adverse effects during implementation. Implementing ISO14000 has short-term adverse effects on company practices and may well be offset by improvements gained through proper management of building activities such as lower energy and maintenance costs, and a reduction in employee absenteeism as a result of healthier buildings. However in the long term, ISO14000 seems to be a way of directing the construction industry towards improved environmental performance (Ball, 2002). Nevertheless the biggest problem remains the low level of environmental awareness and lack of interest by the construction industry (Kein et al., 1999; Ofori et al., 2002).

3.2.5 A way forward

Environmental protection is effected by implementing resource-efficient sustainable practices, preserving ecosystems and maintaining the carrying capacity of the planet. According to Ofori and Chan (1998), sustainable construction can be achieved by the clients and contractors forming a team to manage environmental issues. It is important that every development includes environmental protection to the list of project objectives which traditionally include only time, cost and quality considerations (Ofori et al., 2000). Bourdeau (1999) believes that sustainable construction can be achieved through the cooperation of various parties in the construction industry. Building clients and developers can promote sustainable construction since they represent the demand of the building sector. The development of environmentally aware processes, and the consideration of proficiency in formulating, evaluating and verifying relevant environmental requirements to include these aspects, is crucial to development (Ofori, 1998; Ofori et al., 2000; Sterner, 2002). In addition, it is also important for clients to set up an environmental policy for each project and to consider environmental track records when selecting consultants and contractors (Ofori et al., 2000).

For building designers it is important to show environmental consciousness in their design (Ofori, 1998). Bourdeau (1999) suggests that a more integrated approach to design be adopted to consider the fundamentals of sustainable building design and environmental labelling. Bourdeau (1999) continues, suggesting that building designers should work together with manufacturers to create new designs which facilitate material recycling. The environmental qualities of construction materials may be considered as fundamental to the design and life cycle assessment models may be used to facilitate product development. However, life cycle analysis in its present form is too complex for efficient use and the input data is not sufficient for a complete assessment of building products since there are over 40,000 products on the market with new products in the pipeline (Sterner, 2002). Therefore, it will take a long time for a life cycle assessment to be carried out on all products on the market. Nevertheless, it is important for contractors to adopt environmentally conscious techniques in construction methods on-site (Ofori, 1998).

In addition to design teams incorporating environmentally sensitive initiatives, there are other important factors. In order to achieve sustainable goals in construction it is also important to improve land use by controlling the rate of conversion of agricultural lands to support development of human settlements and urbanisation (Ofori, 1992; Bourdeau, 1999; Zhang et al., 2000). At the same time, it is important to extend the life and reuse of existing buildings (Spence & Mulligan, 1995; Kohler, 1999) reducing the resources required to construct new facilities. However, current practices frequently result in buildings designed with a very limited life expectancy (Spence & Mulligan, 1995; Kohler, 1999) because the natural capital used is not considered to have any significant value leading to abuse of these resources. So far, the cost of rectifying environmental damage from the extraction of resources has not yet been properly recognised as part of the cost of those resources to society and is therefore not included in the price paid by those using the product.

The waste generated from construction activities is also a target for change and this is particularly important for avoidable waste. Teo and Loosemore (2001) state that the wasteful practices in the construction industry are due to the convenient and cost-effective solution provided by landfill sites. They further state that construction waste has a residual value and is avoidable by adopting an effective waste management system. Spence and Mulligan (1995) suggest that the increased use of mineral, agricultural and demolition wastes in construction would reduce the impact of construction on the natural environment. It would also reduce the environmental impact associated with the disposal of those mineral wastes. Considerable research and development work has been devoted to minimise construction waste and recycling methods that put them back into the production process (Tränkler et al., 1996; Lowton, 1997; Poon et al., 2001; John & Zordan, 2001; Klang et al., 2003). However, John and Zordan (2001) state that there are many barriers to recycling beyond the technical difficulties, including economic, geographic, legal, social, time and informational barriers, all of which have hindered the full potential of promoting recycling in the construction industry.

There are many other ways to change current construction activity to become less environmentally damaging. Research and development has already been carried out in response to the environmental challenge including:

- preparation of pre-construction environmental impact appraisals (Pitney, 1993; Spence & Mulligan, 1995),
- improvements in the total life-cycle energy efficiency of buildings (Ofori, 1992; Zhang et al., 2000),
- sustainable use of non-renewable resources (Zhang et al., 2000), and
- increased control of the atmospheric and water pollution consequences of construction (Ofori, 1992; Spence & Mulligan, 1995; Zhang et al., 2000).

3.3 ENERGY AND THE BUILT ENVIRONMENT

3.3.1 Introduction

Present day buildings tend to depend on energy, such as that provided by fossil fuels, to such an extent that should those fuels become unavailable, buildings would become inoperable or uninhabitable. Energy is the major aspect in the day-to-day operation of the community and business, even an individual's domestic life (Blowers, 1993; Treloar, 1997, Hammond, 2000).

Energy is used primarily for heating, ventilation, cooling and lighting buildings and for vertical transportation via elevators. Since energy plays such an important part in our daily life, energy efficiency and energy management become vital design criteria in buildings. Energy is also important to economic growth and without fuel to make energy, transport and living standards in industrialised countries would be considerably jeopardised.

At present, most of the world's energy is supplied by coal, oil, natural gas, nuclear power and hydropower. Since the energy crisis of the 1970s, there has been growing concern about the world's stock of natural resources, in particular non-renewable resources, and the adverse affects on the environment through the combustion of fossil fuels and the use of biomass (Ellis, 1987; Cole & Rousseau, 1992; Johnson, 1993; Baird et al., 1994; Brown & Herendeen, 1996; Pierquet et al., 1998). Coal production could be increased, but at great cost, damaging human health and the environment. Hydropower is increasing in popularity, but its supply capacity is around 20 percent of the world's total electricity (Lauge-Kristensen, 2001). Oil and natural gas are clean and easy to deliver, but world reserves for both oil and natural gas are in great doubt and new oilfields need to be discovered in order to cope with present consumption. It has been estimated that oil production will peak early this century and then fall rapidly. New sources of energy need to be developed to bridge the gap of world energy needs and reserves (World Bank, 2000).

New renewable energy sources such as solar, wind, wave, tidal, ocean thermal and nuclear power are now being used to supplement fossil fuels. However, these energy sources would be more useful if this energy could be stored economically on a large scale (Baird et al., 1984; Lauge-Kristensen, 2001).

The production and use of energy has become a growing source of environmental concern and research has demonstrated that the production of energy is closely related to the degradation of the environment (Cole & Rousseau, 1992; Brown & Herendeen, 1996; Fay & Treloar, 1998; Hammond, 2000; Tiwari, 2001). The wide use of fossil fuels, to some degree, has polluted the atmosphere (Hodgson, 1997). Electricity generation from conventional coal-fired power plants accounts for environmental deterioration through atmospheric emissions and other effluents, and these impacts are not sufficiently taken into consideration in making energy decisions (Johnson, 1993; Hammond, 2000). Currently, companies and governments involved in energy production do not properly consider the implied costs imposed on society such as damage to human health, and the natural and social environment (such as crop failure, forest destruction, various pollution, contamination of buildings and archaeological monuments).

Air pollution contributes to premature death, chronic bronchitis and other respiratory illness and early childhood death, particularly in developing countries. It is estimated that air pollution has caused economic loss of approximately US$350 billion per year amounting to about 6 percent of the gross nation products (GNP) of developing countries (World Bank, 2000).

Energy production and use also contributes to global climate change through carbon dioxide, methane and nitrous oxide emissions from the combustion of fossil fuels. Approximately 80 percent of greenhouse gas emissions from human activities are related to the production and use of energy (Norgard & Christensen, 1994; Hall & Peshos, 2000). The blanket-like gases around the earth trap heat emitted from the earth’s surface, causing average global temperature to increase by 0.3 to 0.6 degrees Celsius over the past century. The Intergovernmental Panel on Climate Change (IPCC) predicts that global temperatures will rise a further one to 3.5 degrees Celsius by the year 2100 (World Bank, 2000). This global temperature change consequently causes a rise in the sea level adversely affecting human health, ecosystems, agricultural, water resources and human settlement (Hodgson, 1997; World Bank, 2000).

Considering the urgency of saving the world’s energy reserve, studies on the total energy use during the life cycle of a building are crucial. Previous research has mainly focused on the energy used during the occupancy stage of a building, such as space heating, hot water and the need for electricity. However, embodied energy usage during the life cycle of a building is largely ignored (Cole & Rousseau, 1992; Treloar & Fay, 1998; Pullen, 2000b; Treloar et al., 2001a; Chen et al., 2001). Energy-conscious buildings are becoming an important part of design helping to minimise demands on non-renewable resources while providing better natural ventilation than was previously possible (Baird, et. al., 1984, Brown & Herendeen, 1996).

3.3.2 Energy and the construction industry

Buildings consume energy and other resources at each stage of development from design and construction through to operation and final demolition (Cole & Rousseau, 1992; Hui, 2001). At each stage buildings consume different amounts of energy and generate pollutants accordingly. This is particularly serious when fossil fuels are involved (Fay & Treloar, 1998; Pullen, 2000a). Improving energy efficiency alone may not result in the maximum potential reduction in energy consumption, because there is a substantial portion of energy trapped in the upstream and downstream production of goods and services (Treloar, 1997).

According to the World Resources Institute (2001), the world's commercial energy production has increased by 15 percent in the last decade and mainly produced by burning fossil fuels (e.g. oil, gas and coal).

Construction is one of the largest consumers of commercial energy in the form of direct fossil fuel burning or the use of electricity (Spence & Mulligan, 1995). Energy use in buildings accounts for almost 50 percent of carbon dioxide emissions in the UK and building material production accounts for 8 percent and 20 percent in the UK and Australia respectively (West, 1995). Construction also contributes greatly to the depletion of non-renewable materials and fossil fuel, and the emission of greenhouse gas and other pollutants (Fay & Treloar, 1998; Morel et al, 2001).

The environmental problems associated with energy consumption have extended from a local scale of urban and indoor air pollution through to a global scale of contributing to climate change and stratospheric ozone depletion. Consequently, reducing energy-based fossil fuels to provide thermal comfort, lighting, hot water and other services, and to minimise energy consumption to reduce environmental degradation has been the focus of much research and development activity (Fay & Treloar, 1998).

Over the entire life span of a building it is maintained, refurbished, extended and finally demolished. The use of energy at various stages is largely influenced by how the building was constructed and how the energy is used (Spence & Mulligan, 1995; Morel et al., 2001). Baird et al. (1984) state that assessment of energy performance is important at all stages. Such assessments may be used to check the design or as a basis for relevant standards.

Construction consumes energy in two principal ways. Firstly, it consumes energy through the construction of buildings and related facilities. In general the energy is used to produce building materials and their subsequent on-site assembly at their final destination. Secondly, it consumes energy in the later use of these buildings and related facilities in the form of heating, ventilation and cooling, lighting, hot water, and appliances and equipment.

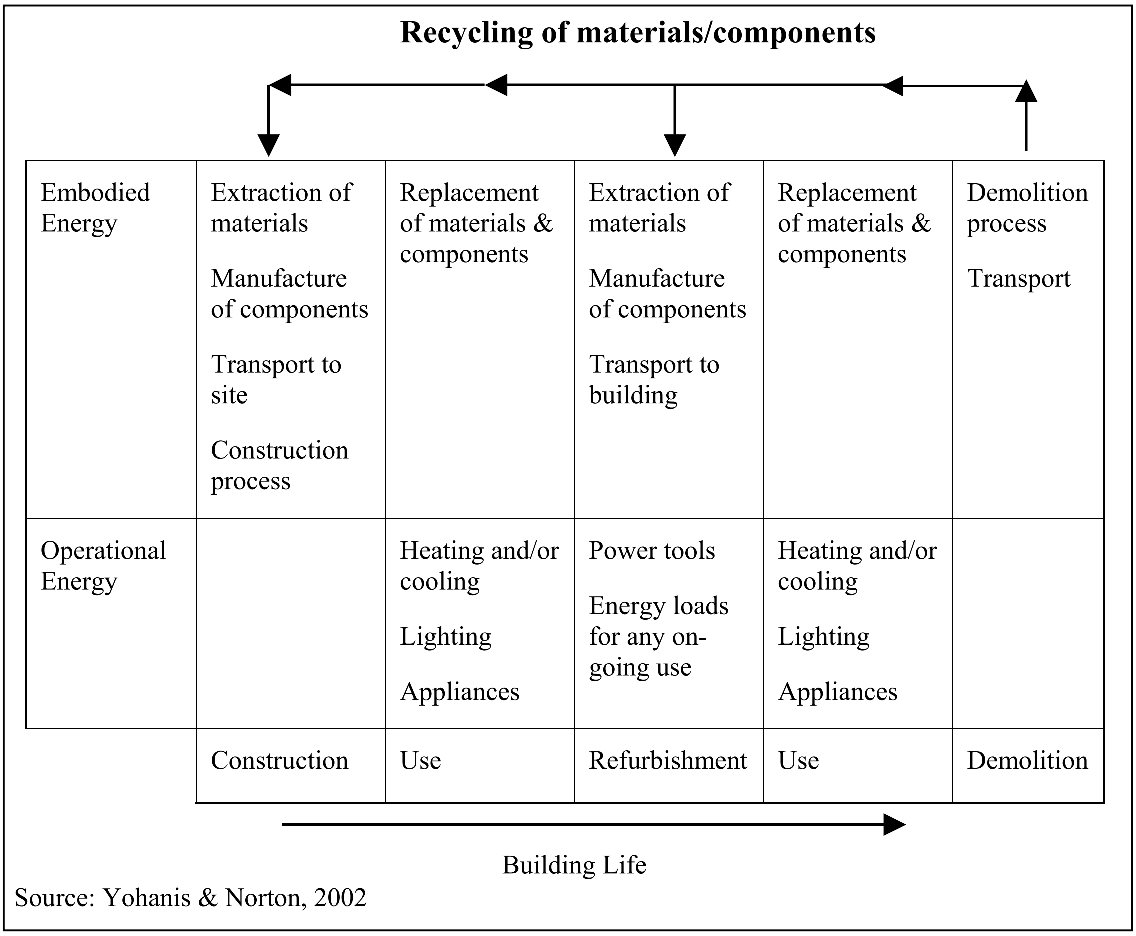
The actual amount of energy consumed by buildings depends on many factors such as the design of the building fabric, orientation, outside temperature, window areas, light systems, air conditioning and ventilation, level of insulation and the thermal characteristics of walls and roofs. The impact of buildings on the environment is based on the whole-of-life assessment of many variables such as fossil fuel based energy, and other non-renewable resource requirements and various emissions to soil, water and air.

Besides consuming energy during and after the construction of buildings, the process of manufacturing building materials also contributes to the carbon dioxide (CO_2) emissions that play a major role in global warming. In the UK, the building and construction trades account for over 50 percent of total CO_2 emissions (Weir & Muneer, 1998). Commonly used building materials, such as structural steel, reinforced concrete and aluminium, release CO_2 during the production process therefore research into new material production, manufacturing methods, recycling of building materials and using low embodied energy materials has become extremely important (Weir & Muneer, 1998).

Total energy usage is based on a building's life-cycle analysis (Figure 3.1). There are four distinct categories of a building's life-cycle energy use (Pullen & Perkins, 1995; Cole & Kernan, 1996; Yohanis & Norton, 2002):

1. The energy initially used to produce building materials and components. This is usually described as **initial embodied energy** and is derived from the recovery of raw materials and the manufacturing of building materials together with on-site construction energy.
2. The **recurring embodied energy** is the energy used to refurbish and maintain a building over its effective life. It is measured during the building's economic life after occupancy. It also refers to the embodied energy used to produce materials and components for replacement, repair and maintenance during the building's life.
3. The **energy used to operate the building** is the energy needed for heating, cooling, ventilation, and lighting during its effective life cycle.
4. The **energy used to demolish and dispose of the building** at the end of its effective life

Figure 3.1 The components of life cycle energy analysis



Embodied Energy	Extraction of materials Manufacture of components Transport to site Construction process	Replacement of materials & components	Extraction of materials Manufacture of components Transport to building	Replacement of materials & components	Demolition process Transport
Operational Energy		Heating and/or cooling Lighting Appliances	Power tools Energy loads for any on-going use	Heating and/or cooling Lighting Appliances	
	Construction	Use	Refurbishment	Use	Demolition

Source: Yohanis & Norton, 2002

The kind and amount of primary energy used in the production of building materials, and the handling of the building materials after demolition of the building, can affect the flow of greenhouse gasses (GHG_s) to the atmosphere in different periods of time. This is, indeed, an area worth researching in order to protect the environment.

3.3.3 Life-Cycle Energy Analysis

Life-cycle analysis (LCA) is a methodology used to assess a product's, process's or activity's overall environmental impact throughout its life cycle (Scheuer et al., 2003). Life-cycle analysis is also known as the "cradle to grave" assessment of a product (or service) from the initial extraction and processing of raw materials to final disposal (Blowers, 1993; Ayres, 1995; Bennetts et al., 1995; Weir & Muneer, 1998; Scheuer et al., 2003). This method has been widely used in Europe and the United States initially for product comparison, but its current application has been extended to include government policy, strategic planning and product design. LCA permits an evaluation of how impacts are generated and distributed across various processes throughout the life cycle.

LCA methodology was originally developed by the Society of Environmental Toxicology and Chemistry (SETAC) to improve the science, practice and application of reducing resource consumption and environmental burdens associated with products, packaging, process or activities (Weir & Muneer, 1998; Johnstone, 2001). LCA has four stages (Ayres, 1995; Miettinen & Hämäläinen, 1997; Weir & Muneer, 1998):

1) **Goal definition and scoping**—defining study objectives, products and their alternatives, system boundary choice, environmental parameters and data collection strategy.
2) **Inventory analysis**—data collection and treatment, quantifying materials, energy inputs and waste emissions, and preparing inventory tables where system's material and energy balance is calculated.
3) **Impact assessment**—classifying the inventory table into impact categories, aggregation within the category, normalisation, weighting different categories where the system's potential environmental impacts are evaluated.

4) **Improvement assessment**—sensitivity analysis, improved prioritisation and feasibility assessment to reduce the environmental burden are pursued.

LCA methodologies have complicated and sophisticated in assessment processes, so computer software has been developed as an aid. Products such as LISA and SimaPro are widely used to apply LCA for environmental impact assessment of products or materials (Department of the Environment and Heritage, 2001).

LCA has been extensively used in energy analysis since the 1960s. During early studies, energy consumption and efficiency were the main focus and energy-related waste emissions were not considered (Ayres, 1995). Since the early 1970s, waste emissions generated by the production processes were taken into account and life-cycle energy analysis became an important tool for assessing environmental impact based on energy uses (Fay & Treloar, 1998; Treloar et al., 1999). Treloar et al. (1999, p.404) defines life cycle energy analysis as "the initial and recurring embodied energy plus the operational energy and any energy required for decommissioning". Indeed, life cycle energy analysis enables assessment of the effects that products, processes and activities have on local, regional or global environments.

Life cycle energy analysis provides a complete means of analysing the energy requirement and environmental impact of buildings. The analysis includes the energy required to construct the building, the energy used during occupancy and the energy used to maintain, renovate and eventually demolish the building (Bennetts et al., 1995).

3.3.4 The importance of embodied energy

In many industrialised countries, the construction industry is largely factory-based with much of the building manufacturing process occurring away from the building site. Site work consists mainly of component assembly such as precast concrete panels and structural steel. There is a growing awareness of environmental impact in the choice of building materials. The designer should not only consider the traditional requirements of the owner and occupants of the building, but also the resource base and the effects on the environment of extraction, manufacture and processing of the building materials (Börjesson & Gustavsson, 2000; Venkatarama Reddy & Jagadish, 2003).

Recent research has shown that energy used to manufacture building components off-site accounts for over 75 percent of the total embodied energy in buildings (Spence & Mulligan, 1995). Tucker et al. (1994, cited in Treloar et al, 2001a) explain further that in Australia the energy embodied in construction can represent up to one-fifth of national energy consumption. However, the energy embodied in manufacturing of building materials is not included in the calculation of total energy consumption of buildings. In the past, the common view was that embodied energy is almost negligible compared with operational energy over the life of a building. However this view is now hotly contested (Lawson, 1996b; Pullen, 2000b).

Researchers have estimated the embodied energy intensity of building materials since the 1970s (Boustead & Hancock, 1979; Baird et al., 1984 & 1994). These studies have included the calculation of atmospheric pollutants associated with fossil fuel burning such as CO_2, ozone depletion and acid rain throughout the life cycle energy requirements of buildings (Baird et al., 1994; Pullen & Perkins, 1995; Ayres, 1995; Lawson, 1996b; Alcorn, 1998; Pullen, 2000a; Treloar et al., 2001a).

Embodied energy comprises the energy consumed during the extraction and processing of raw materials, transportation of the original raw materials, manufacturing of the building materials and components and energy use for various processes during the construction and demolition of the building (Baird, 1994; Edwards & Stewart, 1994; Howard & Roberts, 1995; Lawson, 1996b; Cole & Kernan, 1996). Embodied energy is defined by Tucker et al. (1993, cited in Edwards et al., 1994, p. 318) as “the total energy consumed from all sources in creating that product … it includes energy consumed in the winning (e.g. mining), transporting and processing of raw materials, to the final delivery of the product; plus the energy of all intermediate manufacturing and transporting processes, and a share of all energy required to provide the capital infrastructure which enable the product to be produced”.

Treloar et al. (2001b) state that embodied energy is significant because it occurs immediately and the total energy consumed in the production of building materials can be equal, over the life cycle of a building, to the temporary requirements for operational energy. The study of energy use in buildings has already captured the interest of many researchers and, together with increasing awareness of the surrounding environment, there is little doubt that embodied energy will be an area of major focus in further research of energy efficiency. Knowledge of embodied energy can stimulate the development of products with low embodied energy content, using reduced quantities of energy and contributing fewer amounts of greenhouse gases to the atmosphere in their use phase.

Embodied energy is an area that attracts attention around the world as one of the main aspects of green building design and is the focal point of energy management in building construction (Stein et al., 1976; Lawson, 1996; Pears, 1996; Aye et al., 1999; Pullen, 2000b and Treloar et al., 2001b). Indeed, embodied energy is within the construction industry's control. Fully identifying the nature and extent of embodied energy intensity will allow designers, builders and building materials manufacturers to improve production processes to minimise energy consumption (Edwards & Stewart, 1994). Embodied energy is divided into direct and indirect energy, which is consumed throughout the life cycle of a building (Treloar, 1997).

Table 3.1 (see next page) summarises the results of previous studies on the initial embodied energy of various types of building from different sources and different countries. The embodied energy per square metre varies widely. In residential buildings the embodied energy per square metre of gross floor area ranged from 3.6 to 8.76 GJ/m^2 whilst for commercial construction the range is from 3.4 to 19 GJ/m^2. The university building in South Australia is recorded as 11 GJ/m^2 which is in the mid range between residential and commercial construction.

Table 3.1 Summary of initial embodied energy studies per unit quantity of gross floor area

Embodied energy (GJ/m^2)	Building type	Sources
3.6	Residential	Hill, 1978 (cited in Pullen, 2000b)
3.9	Residential	Edwards et al., 1994
4.3-5.3	Residential	D'Cruz et al., 1990 (cited in Pullen, 2000b)
4.9	Residential	Pullen, 1995
5.0	Residential	Lawson, 1992 (cited in Pullen, 2000b)
5.9	Residential	Pullen, 2000b
6.6	Residential	Ballantyne et al., 2000 (cited in Pullen, 2000b)
6.8	Residential	Treloar, 1998
8.76	Residential	Treloar, 1996b
3.4-6.5	Commercial	Honey & Buchanna, 1992 (cited in Pullen, 2000c)
4.3-5.1	Commercial	Cole & Kernan, 1996
5.5	Commercial	Oppenheim & Treloar, 1995
8.0-12.0	Commercial	Oka et al., 1993 (cited in Pullen, 2000c)
8.2	Commercial	Tucker & Treloar, 1994 (cited in Pullen, 2000c)
10.5	Commercial	Yohanis & Norton, 2002
18.6	Commercial	Stein et al., 1976 (cited in Pullen, 2000c)
19.0	Commercial	Tucker et al., 1993 (cited in Treloar, 1996b)
11.0	University	Pullen, 2000c

There are various reasons for the wide range of embodied energy consumption. The high figures presented in the table may be due to shifts in building performance and materials production efficiencies over the past 20 years (Cole & Kernan, 1996). In addition, it is not clear whether this data is based on a primary or delivered energy basis. This is important as research indicates that the primary energy may be three to four times more than the delivered energy (Fay & Treloar, 1998; Pullen, 2000c).

Furthermore, the exact boundary of the studies is unclear without investigating their methodology in detail. Some studies may not include energy used in furniture and fittings, on-site construction processes and demolition which may result in greater differences in the total embodied energy calculation. It is also impossible to draw universal conclusions based on buildings categorisation in terms of number of storeys and types of principal structure. Finally, the magnitude of these values depends, among other factors, on the method of construction employed and on materials selection.

The research may also be based on different sources of information. The most important one is the embodied energy coefficient. Some researchers may derive their own embodied energy coefficient in their studies, but others may just adopt information from current literature. However, there is much debate about the current methodology in the compilation of embodied energy coefficients. This will be discussed in greater detail in the latter part of this section.

As stated by Kohler (1991), there is no absolute or correct energy intensity of a material because a stated value is a direct function of what was included and what was excluded from its derivation. Therefore, it is difficult to arrive at universally applicable embodied energy values because of the large variations in the values of embodied energy available to date.

3.3.5 Embodied energy modelling

Some recent research has suggested that the criteria for embodied energy consumption in buildings includes the energy required to manufacture building materials and components, the energy required to transport building materials and components to and from the building site during construction, renovation and demolition, and the energy used in various processes such as crane lifting and smoothing of soil during the construction and demolition of the building (Adalberth, 1997a; Chen et al., 2001).

The embodied energy estimation can be separated into 'initial' and 'recurrent energy' (Pullen, 2000b). The initial embodied energy refers to the total energy used to produce building materials, including extracting and then transporting raw materials to factories and then the finished products to the site, and the on-site operation energy. Recurrent energy measures energy use during the operational life of a building. This includes the energy use for the production of materials or components for renovation, repair and routine maintenance during the life spans of a building.

Initial embodied energy

Energy is needed to manufacture building materials and components. It would be very useful and provide significant data if each manufacturer recorded the energy used associated with their particular product. Such information would ensure that more specific energy requirement data for each type of construction material would be available. At the same time, the information may also be fed back into the assessment loop to monitor and adjust product design development (Adalberth, 1997a). Improved materials manufacturing technologies may reduce energy consumption.

Energy is needed to transport the building materials and components. Transporting materials is a major factor in the cost and energy of a building. The transportation distance may vary depending upon the location of construction activities and from project to project. Energy is required whenever building materials and components are to be moved from one location to another at different stages in the process, including transporting raw materials from the place of extraction to the place of component manufacture. Further energy is consumed in delivering the manufactured components to the site (Miller, 1996; Adalberth, 1997a; Chen et al., 2001). The energy requirement will increase if the materials or components are imported.

Past research on transportation energy shows that this is often assessed using generalised assumptions (Miller, 1996; Adalberth, 1997a; Chen et al., 2001). Adalberth (1997a) states that transportation energy represents approximately 5–10 percent of the manufacturing energy for each building material. However Miller (1996) identifies transportation energy at around 0.8MJ/t/Km and approximately 6 percent of the total initial embodied energy of materials and components used to construct a building. It is difficult to compare research results since the mode of transportation and the distance travelled is crucial to the calculation but remains largely unknown. It is necessary to set up a boundary of studies for the energy consumption of transportation. The more imported raw materials required to manufacture building materials and components from abroad, the higher the embodied energy consumption.

The energy efficiency of different means of transport is significant. Locally made materials should be preferred to those transported long distances, including imports and, where possible rail transport is preferable to road transport (Lawson, 1995b).

Energy is needed in the on-site construction process. On-site construction energy plays an important part when calculating embodied energy (Stewart et al., 1995; Pullen, 2000b). When erecting a building, energy will be needed for a variety of processes such as off-site manufacture, delivery, assembly, operation, demolition or re-cycling phases. On-site construction may require direct electrical energy or fuel to operate tower cranes, power tools, trucks and generators. All this equipment will have an indirect embodied energy impact arising from the share of all the energy inputs necessary to produce that equipment originally, to get it to the site, and to maintain it in service.

This energy consumption is often ignored because accurate information is difficult to obtain or unavailable. This energy consumption is also considered to be small compared with the embodied energy used to manufacture building materials (Pullen, 2000b). Nonetheless, Tucker et al. (1993, cited in Stewart et al., 1995) argue that the energy required to construct a 150m^2 house is about equal to the energy required over nine years to heat it.

Table 3.2 summarises the percentage allowance of on-site construction energy in relation to the total embodied energy information gathered from the literature. The allowance ranges between 6 and 15 percent. With such a wide range, it is important to note that only the percentages derived from the data of Stewart et al's (1995) and See's (1998, cited in Pullen, 2000b) research work were based on actual monitored on-site activities starting with site levelling through to carpet laying. The results obtained from Stewart et al. (1995) and See (1998, cited in Pullen, 2000b) appeared to be consistent.

The research details of the other percentage allowances in Table 3.2 (see next page) were unknown and no information is provided as to whether the energy term is based on delivered or primary energy. Therefore the figures can only be treated as a rough guide for calculating total embodied energy in the assessment of on-site construction energy. There is no doubt that the amount of energy consumed on-site is important when calculating embodied energy and further research is required to examine the accuracy of these allowances. However, on-site construction energy is difficult to measure accurately as it is affected by site location and topography, site management, outdoor climate and the duration of construction.

Table 3.2 Summary of percentage allowance of on-site construction energy

On-site construction energy (%)	Building type	Sources
6	Residential	Stewart et al., 1995
6.5	Residential	See, 1998 (cited in Pullen, 2000b)
7-10	Unknown	Cole & Rousseau, 1992; Lord, 1994 (cited in Pullen, 2000c)
10-15	Unknown	Lawson, 1996b
10	Office	Treloar et al., 1999
10	Unknown	Christophersen et al., 1993 (cited in Pullen & Perkins, 1995)
11	Residential	Ballantyne et al., 2000 (cited in Pullen, 2000b)
15	College	Baird et al., 1994

Apart from allowing energy for site processes, construction materials will also be wasted during construction. Such wastage should also be considered when estimating embodied energy (Chen et al., 2001). The waste factor varies from material to material and from site to site. Building materials fabricated on-site may have more wastage than pre-fabricated components. There is no research, so far, on the energy of material wastage on-site. Since there are so many variables, researching on-site material wastage would be challenging.

Recurrent embodied energy

Recurrent embodied energy accounts for the changes in embodied energy associated with building up-keep and improvements. Recurrent embodied energy includes the energy consumption of building materials used during building maintenance and repair over its effective life; energy to produce the materials consumed (light bulbs, cleaning fluids, paint, etc.); and a share of the energy used to manufacture the maintenance tools, ladders, etc. Therefore the longer the life span, the more **recurrent embodied** energy is used during occupancy, and the less annualised **initial embodied** energy is used (Edwards & Stewart, 1994; Adalberth, 1997a; Chen et al., 2001).

Energy use at this stage starts when the building is finished and occupants start to move in. At this stage, there will be two main uses of energy: that required for heating, cooling, lighting and hot water supply, which is considered as the operational energy and will be dealt with later in this section; and energy required to manufacture materials or components used for renovation, repair and routine maintenance. The embodied energy calculation should now also include providing building materials and components for maintenance and replacement during the entire life span of the building. The building's needs for maintenance during its life span depends on the type of materials, the climatic conditions, the location of components, anticipated life span of materials and components, frequency of maintenance, type of construction and pattern of occupants' energy consumption. Some components may require more frequent maintenance, for example, woodwork will require repainting every three to five years but masonry may only require cleaning once during the life of the building. All these materials should be taken into consideration when calculating recurrent embodied energy (Adalbertha, 1997a). The internal finishes and components, which represent only a relatively small portion of the initial embodied energy, dominate the recurrent embodied energy during the building life cycle.

The internal partitions, doors, finishes and building services are replaced, refurbished and maintained more frequently than the structure and the building envelope comprises the majority of the initial embodied energy. Some building components such as floor coverings may need replacement from time to time in order to maintain the normal functioning of a building. The average life span of materials or components varies in accordance with the types of product and the life expectancy. Components may require replacement due to wear and tear, or changes in style. Relevant data on the replacement cycles of building components is difficult to obtain and even though the data is available, the validity of these data may require investigation before they can be used. In order to calculate energy use during this stage, some assumptions regarding the lifespan and maintenance cycles of materials or components may have to be made (Adalberth, 1997a; Pullen, 2000b; Johnstone, 2001).

Recurrent embodied energy plays an important part when calculating total embodied energy. Treloar (1996a) suggests a further 50 percent of initial embodied energy is required for maintenance. Cole and Kernan (1996) further estimate that recurrent embodied energy is equivalent to about 130 percent of the initial embodied energy. Fay and Treloar (1998) found that the recurrent embodied energy is 32 percent of the initial embodied energy and Pullen (2000c) had similar results where recurrent embodied energy of approximately 37 percent of the initial embodied energy is required for replacement, repair and maintenance activities. Table 3.3 summarises the current research results of recurrent embodied energy in buildings.

Table 3.3 Summary of recurrent embodied energy per unit quantity of gross floor area

Recurrent embodied energy (GJ/m^2)	Building type	Sources	Life span
6.32	Office	Yohanis & Norton, 2002	50
6.5-6.8	Commercial	Cole & Kernan, 1996	50
10.2-20.4	Commercial	Howard & Sutcliffe, 1994 (cited in Cole & Kernan, 1996)	60
9.9	Residential	Pullen, 2000b	50

Table 3.3 shows that recurrent embodied energy ranges from 6.32 to 20.4 GJ/m^2 with a life span of 50 to 60 years. The wide range of recurrent embodied energy reveals that differences life expectancy assumptions, maintenance and refurbishment frequency and climatic conditions may affect the calculation. Research suggests that the recurrent embodied energy may be greater than the initial embodied energy depending on the number of years involved (Cole & Kernan, 1996).

Embodied energy in building services

The next significant component of total embodied energy calculation is the embodied energy of building services such as electrical, plumbing, mechanical and water supply. This component is the most difficult to assess according to Cole and Kernan (1996). Most of the information found in the literature is based on a percentage allowance of the total embodied energy. In some embodied energy calculations, building services have been disregarded, as the level of information in the design and construction is largely unknown or unavailable at the time of the research. In addition, the embodied energy coefficients for the materials and components used in building services are insufficient in that there are not enough of them to be used. More work needs to be done in this area in order to allow an accurate measurement of embodied energy of building services. Table 3.4 (see next page) summarises the percentage allowance of embodied energy of building services in the literature.

Table 3.4 Summary of percentage allowance of embodied energy of building services

Embodied energy of building services (%)	Building type	Sources
19	Residential	Treloar, 1996a
20	University	Pullen, 2000c
20-25	Commercial	Cole & Kernan, 1996
22.8	Office	Yohanis & Norton, 2002

Building services must also be repaired, maintained and replaced at regular intervals making them one of the most significant categories of recurrent embodied energy (Cole & Kernan, 1996). Kirk and Dell'Isola (1995) contend that building services are required to be maintained yearly and replaced every five to 35 years.

Embodied energy in furniture and fittings

Embodied energy research has typically focused on the structure and finishes of a building. Not much study has been carried out on furniture and fittings and, typically, embodied energy calculations do not include the initial and recurrent embodied energy of furniture and fittings (McCoubrie & Treloar, 1996; Treloar et al., 1999). This is because there is a large variety of furniture and fittings used in buildings and there is insufficient information on the embodied energy coefficient for the calculation. However, in accordance with Treloar et al. (1999) furniture and fittings are significant when estimating embodied energy.

Furniture and fittings are often used in the initial construction and fit-out of a building. Furthermore, they are often consumed several times over during the life of a building. Compared with other building elements, furniture and fittings have high replacement rates and that may contribute significantly to the calculation of recurrent embodied energy over the life of a building (Treloar et al., 1999).

Treloar et al. (2001a) state that while the initial embodied energy in furniture and fittings was small (around 10 percent of the initial embodied energy of the building), the energy embodied in furniture and fittings used over the building's life cycle represented about the same amount as the life cycle operational energy. Treloar et al.

(1999) calculate the life span of furniture and fittings as approximately five to seven years. That means that for a 40-year life span, the churn rate for furniture and fittings would be approximately 560 percent. Treloar et al. (1999) also found that the initial embodied energy for furniture and fittings is approximately 1.5 GJ/m^2 of gross floor area, and the recurrent energy added further 8.4 GJ/m^2 to the total embodied energy calculation. The initial and recurrent embodied energy of furniture and fittings are, thus, equivalent to about 31 percent of the total life cycle delivered energy of a building (McCourbie & Treloar, 1996; Treloar et al., 1999).

These results are stunning, showing that around one third of the total building energy is consumed by the furniture and fittings alone. However, the results are only based on a single scenario and on contentious assumptions. For example, the direct energy of the manufacturing process was based on an allowance of 15 percent of the total embodied energy, an assumption that needs validation by further research. Additionally, the life cycle of furniture and fittings varies greatly according to the type of furniture, the way the furniture is used and changes in fashion. These are critical in the calculation of replacement rates. Most furniture can also be re-used or refurbished making energy-implication modelling very difficult. The research needs to be updated to include a greater number of case studies to further improve the analysis results. In addition, the idea of replacing furniture and fittings every five years appears peculiar because their life span varies greatly between different furniture items.

Owing to the high replacement rates, even though the research is primitive, the importance of the embodied energy of furniture and fittings cannot be denied. Further research is required to break down the furniture and fittings into their respective basic elements and to collect data on the direct energy consumption of furniture manufacturing processes such as administration, storage and transport. The outcome, whilst important for facilities managers and building owners who select items for fit-out, is also critical for furniture designers. If furniture is designed to be more durable there are potentially large savings through reduced replacement rates.

Energy use during the demolition

At the end of the useful life of a building, energy is used for demolition and transport. This energy is another significant part of life-cycle energy analysis. Current demolition practice is a high energy user and landfill supplier. It is difficult to estimate the energy used during demolition as predicting such energy consumption is approximately 50 or more years in the future. It is also difficult to predict the useful life of a building (Yohanis & Norton, 2002). The method of demolition, the energy implication of any materials or components' re-use or recycling and the importance of salvaging of materials at a future date are difficult to assess at the present time.

Published figures on the actual amount of energy associated with demolition and recycling capability are limited. Christophersen et al (1993, cited in Pullen & Perkins, 1995) state that demolition energy is about 2 percent of the total initial embodied energy. Cole and Kernan (1996) suggest about 1–3 percent of the total initial embodied energy. However, these figures are highly uncertain, as details of what is included in the demolition process and whether transportation is included in the calculations are not provided.

Due to the high degree of uncertainty surrounding demolition processes and the numerous unknown variables, demolition energy was not considered in most of the research studies of embodied energy (Cole & Kernan, 1996).

3.3.6 Embodied energy measurement tools

Calculating embodied energy intensity is an enormous task, which involves using the data from input-output tables and other national and international studies (Treloar, 1997; Tucker et al., 1998; Treloar, 2001b). Recently, information technology has been used to enhance the study of embodied energy with CAD-based embodied energy modelling underway since 1993 (Edwards & Stewart, 1994). Embodied energy consumption and other atmospheric emissions are demonstrated and measured using three-dimensional CAD models, which drastically simplifies the work of estimating embodied energy (Edwards et al., 1994; Ambrose, 1997; Tucker et al., 1998; Johnstone, 2001). A CAD based modelling approach is becoming more attractive as this evaluation technique is easy to use, quick to apply and reliable. Three-dimensional CAD modelling enables embodied energy impacts to be quantified as a total for the building, per element, per square metre of floor area and for each type of construction material. It will also facilitate comparisons between the embodied energy impacts of alternative construction materials, aiding design decision-making.

APDesign is one of the popular three-dimensional CAD packages used in Australia. It is designed to allow the calculation of embodied energy values, building mass data and atmospheric emissions from the three-dimensional CAD drawings (Tucker et al., 1998). Another is Ecotech[2], a conceptual environmental design tool for a three-dimensional geometric modelling of initial capital and running costs of projects which also provides life-cycle assessment of materials throughout the design stage.

A further package, LCAid[3], was developed in Australia by the Department of Public Works and Services (now known as Department of Commerce) Environmental Services and is designed to evaluate the environmental performance and identify environmental impacts over the building life cycle. It is particularly useful for measuring embodied energy, and the data library contains the up-to-date embodied energy intensity of building materials and their components (Hall & Peshos, 2000). LCAid also provides an integration of environmental software such as Ecotect and the Boustead Model, and can input material data from most CAD models.

ENVEST[4] was developed by the Building Research Establishment in the UK as a software tool to assess life cycle energy consumption of buildings, the system uses ecopoints for measurement. However, as Scheuer et al. (2003) state, the software has limited usage in assessing the environmental impacts from a life cycle perspective due to the continuing data limitations and a large variety of construction techniques and materials choices.

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[2] Ecotech—http://fridge.arch.uwa.au/ecotect

[3] LCAid—http://asset.gov.com.au/dataweb/lcaid

[4] Envest—http://www.bre.co.uk

Energy Express[5] was developed by the CSIRO Energy and Thermofluids Engineering in 2003. The tool is designed to quantify the thermal performance of commercial, industrial and domestic buildings and is now at the beta testing stage. There are many similar systems such as SimaPro and LISA, which are also widely used in this respect.

LCAid is the chosen tool used to measure total embodied energy consumption of the sample of 20 high school projects examined in this research because the different manufacturing processes for materials, components, and fuel types makes the UK-developed ENVEST software less useful for Australian projects. At the same time, Energy Express is only at the beta testing stage and full development is not yet available. As LCAid was developed for an Australia context and has a comprehensive data library which will be a useful tool to measure embodied energy.

3.3.7 **Critique of current methods used to measure embodied energy**

Calculating total embodied energy involves estimating the quantities of materials to be used in a building. Traditionally, calculating total embodied energy consumption can be estimated using a bill of quantities which normally breaks down building works by trades (Edwards & Stewart, 1994; Treloar et al., 2001a). Embodied energy intensity can be inserted into the relevant location in accordance with the trade breakdowns and the total embodied energy can then be summed. However, this method may not be practical as all the items may need to be converted to per unit mass of materials as most embodied energy values are expressed as Megajoules or Gigajoules per unit mass. This is a time-consuming and labour intensive approach. Furthermore, a copy of the bill of quantities may not always be available as using bills of quantities in the building trade is declining in some countries (Edwards & Stewart, 1994). Computer software may help to reduce the overall workload of measuring total embodied energy, but may not always be available or may be too expensive to use.

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[5] Energy Express—http://www.cmit.csiro.au

Calculating an embodied energy coefficient[6] is important in the life cycle energy analysis of buildings. Nevertheless the accuracy of embodied energy coefficient is highly controversial (Pears, 1996; Pullen, 2000a; Treloar et. al., 2001b). Embodied energy intensity varies over different countries and years due to variations in raw material quality, climate, manufacturing processes, fuel types and distance from markets. These will all contribute to variations in calculating the results (Cole & Rousseau, 1992; Edwards & Stewart, 1994; Lawson, 1996b; Pears, 1996; Pullen, 1996).

Pears (1996) states that most publications and computer software used to calculate embodied energy in building materials and components are based on a single source of information. This single source of information may represent the national averages or just simply be based on a single supplier. Hence, the accuracy and reliability of embodied energy coefficients are very much in doubt.

Pears (1996) goes on to explain that variations may occur from different research methodologies, dissimilar production processes and sources of information. He states that based on the sources of information, calculating embodied energy coefficients using primary energy is different from a calculation which uses secondary energy with results that may end up approximately 30 to 40 percent apart.

Pullen (1996 & 2000a) explains the possible errors that may occur in the use of different methods when measuring embodied energy values. If process analysis is used in the calculation, only direct energy consumption will be included for manufactured building materials or components, unless a very extensive analysis has been undertaken. This method can be significantly incomplete due to the extreme complexity of the upstream requirements for goods and services (Cole & Rousseau, 1992; Lenzen & Dey, 2000; Treloar et al., 2001a).

In process analysis indirect energy, such as upstream energy used to extract, prepare and transport all the raw materials and downstream energy used to transport the finished product to the market place, are not included in the embodied energy coefficient

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[6] Embodied energy coefficient is defined as a numerical expression of the energy directly and indirectly to manufacture a product or component. It is usually expressed as GJ or Mk per unit element.

calculation. Energy used to manufacture the production plant and other equipment may also not be included in the calculation using process analysis (Pullen, 2000a; Treloar et al., 2001b). Nevertheless, the process method can be very accurate but it is only relevant to the particular system considered and can be subject to substantial inconsistencies (Treloar et al., 2001a).

Pullen (1996 & 2000a) explains that input-output analysis is also adversely affected by the incomplete methodology used to calculate embodied energy values. Input-output analysis is based on government data sources and is used to measure both direct and indirect energy consumption. Nevertheless, this methodology requires a significant number of assumptions to be made about the energy tariffs and material prices in the conversion of the economic data to energy data. Some manufacturing sectors will pay different prices for energy and as this information is often confidential, it cannot be used in the calculation (Lenzen & Dey, 2000; Pullen, 2000b). The widely differing production processes may also contribute to the variations of embodied energy values and are not reflected in this method (Pullen, 2000a; Treloar et al., 2001b). However, the results of input-output analyses are representative of the national average and are considered to represent a consistent approach across the range of building materials (Pullen, 2000b; Treloar et al., 2001a).

Hybrid analysis combines the benefits of both process analysis and input-output analysis to measure embodied energy intensity. Nevertheless, this method also suffers the same incompleteness and limitations of the other two methods (Treloar et al., 2001b). The hybrid method is, however, complementary, reducing the errors associated with both techniques so that uncertainty in the estimate of the total energy requirement for a large electricity plant can be reduced to less that 10 percent (Lenzen & Dey, 2000).

Cole and Rousseau (1992) state that the differences in the energy intensity values may be due to a lack of clear definitions and system boundaries in relation to calculating energy intensity values. Current embodied energy values are calculated on the use of energy sources based on fossil fuels. Renewable energy sources such as solar, wind and wave power are not presently considered in embodied energy impact studies (Edwards

& Stewart, 1994) because they only occupy a small portion of energy production. They may become more important in the future but in the meantime, there is no way to check and no information available on which to base calculations.

Pullen (2000a) says the factors affecting embodied energy values include:

- different locations and possible variations in the production processes,
- possible improvement in process efficiency over time,
- different methods of estimating embodied energy,
- some estimates that do not consider all of the energy inputs to the production process,
- whether the values are based on delivered or primary energy, or
- whether the fuel value of the product is included as part of the embodied energy.

Such deviations in embodied energy intensity calculations may provide misleading data on the low energy materials and components and may also distort the results obtained for a building's life cycle energy analysis. It is therefore important to determine a set of guidelines, or methodologies, to monitor calculations of embodied energy values and the type of materials to be included (Pears, 1996). However, such a methodology which prefers one environmental material over another may lead to conflict or confusion amongst material manufacturers and consumers. Treloar (1996b) suggests a technique which breaks down the input-output model into embodied energy pathways. This way, the errors of double counting and assumptions made when calculating embodied energy coefficients can be minimised (Treloar et al., 2001b). The purpose of breaking down the input-output model is to determine the viability of validating embodied energy paths that represent 90 percent of the overall energy intensity of the residential building sector (Treloar et al., 2001b).

The total embodied energy usage will be calculated for a sample of 20 high school projects and included in a sustainability index developed for this research. Computer software called SINDEX, based on the concept of a sustainability index, has been developed in this research to include embodied energy in the decision-making process. Detail development of SINDEX is included in Chapter Nine of this thesis.

3.3.8 Operational Energy

Operational energy is the main focus of energy efficiency studies (Howard & Roberts, 1995). Operational energy is also called 'in-use' energy consumption, which refers to the energy used for heating, cooling, ventilating, lighting, powering appliances and equipment. The main purpose of operational energy usage is to provide thermal and non-thermal comfort for building occupants.

Operational energy usage starts when a building is completed and occupants start to move in. It will continue until the building is finally demolished. Operational energy is an important area of lifetime energy consumption. The longer the life span of a building the more in-use energy is required. In addition, the operational energy consumption multiplies as the building gets older due to systems becoming inefficient.

Operational energy usage varies considerably with building use patterns, prevailing climate and season, and the building's efficiency and its systems. It is also directly affected by the way the building is used and managed (Cole & Kernan, 1996; Lawson, 1996b). The varying climate from location to location throughout the year will lead to considerable differences in energy use in heating and cooling between different buildings. Routine maintenance and repair will also affect energy. The level of energy used relies heavily on system efficiency which itself depends on adequate maintenance. Inadequate maintenance will jeopardise a building's normal functions over its physical lifetime and can drastically increase energy consumption.

The total operational energy consumption also depends on the building's life expectancy. There is no doubt that the energy used to operate a building is by far the largest component of life-cycle energy analysis and is probably the reason why it has attracted most research attention. In addition, building designers can contribute to the planned objective of energy conservation (Lawson, 1996b).

Operational energy is usually expressed in terms of energy per unit of floor area per annum ($MJ/m^2/year$). It is calculated by multiplying the energy use per year by the life span of a building (e.g. 50 years) to derive the total operational energy. There are usually two approaches to estimate operational energy. The first is collecting data on energy usage based on the energy bills for electricity and gas. An average energy consumption of various fuel types is usually used in research studies. However, operational energy estimated using this approach may be based on delivered energy instead of primary energy. Researchers regard the use of primary energy as a better representation of energy used (Cole & Kernan, 1996; Fay & Treloar, 1998; Pullen, 2000b).

Besides collecting actual energy consumption from energy bills, computer software is also used to estimate the energy costs to heat and cool the building. Computer software such as NatHERS, CHEETAH, TEMPZON, TRNSYS, BUNYIP, DOE2 and CHEENATH are commonly used in operational energy studies (Fay & Treloar, 1998; Department of the Environment and Heritage, 2001; Matthews & Treloar, 2001). The computer simulation programs are complex, making them difficult to use and are incapable of modelling complex human behaviour. The results from computer software may be used as indicative only and manual adjustment may be required to tailor the program to allow for relevant variations in a particular project or particular environment (Fay & Treloar, 1998). Despite these limitations, computer simulations allow large numbers of variables to be modelled and their impact evaluated for a building that is going to be built or refurbished (Fay & Treloar, 1998; Tucker et al., 1998; Karlsson et al., 2000).

A number of studies have been carried out on different types of buildings to estimate the annual operational energy consumption based on gross floor area. Tucker et al. (1998) suggest that the annual energy usage of a typical house is 157.30 GJ/m^2 with heating and cooling loads the most significant contributor.

However, Pullen (2000b) estimates the average annual energy usage of 25 houses in Adelaide to be 0.8 GJ/m^2 (approximately 132 GJ) based on energy bills. A primary energy factor was applied to convert the figure into primary energy terms. The figure is lower than the figure suggested by Tucker et al. (1998), but compares well with the research carried out by Williamson et al. (1993, cited in Pullen, 2000b) which found the figure of 0.7 GJ/m^2. Unfortunately, the detail of the research study of Williamson et al.

such as system boundary and research methodology was not available in the literature for further comparison. These figures are higher than the research carried by Treloar et al. (1999) who suggest the figure is 0.4 GJ/m^2.

In commercial construction, Oppenheim (1995) finds the operational energy to be 0.65 GJ/m^2 for an office building in Canberra. Cole & Kernan (1996) state that the annual operational energy per square metre of gross floor area is in the range of 0.96 to 1.64 GJ/m^2. These figure are high side when compared with the Building Owners and Managers Association of Australia's target figure in 1994 (cited in Pullen, 2000c), which is in the range of 0.5 to 1 GJ/m^2.

For higher education buildings, Pullen (2000c) studied a university campus in South Australia and arrived at a figure of 0.5 GJ/m^2 for a 60-year life span. This figure was in the mid range of the figure provided by a survey of higher education carried out by the Queensland University of Technology, Brisbane in 1999 (cited in Pullen, 2000c) of 0.3 to 1 GJ/m^2.

The variations in the operational energy consumption can be partially explained by the unclear nature of the energy terms used, i.e. whether these figures are based on delivered, or primary, energy. Additionally, some of the results are derived using computer simulation whilst others are based on the average annual energy consumption from energy bills. The difference in the methodological approach may contribute to the wide range of research results.

Energy usage is directly affected by the use pattern. With commercial usage, full heating/cooling loads may be expected in daytime during the week for the whole year whilst for domestic usage full loads may only apply to nights and weekends. For higher education, the full load of energy usage may only be relevant to daytime during the week for about 40 weeks of the year. These differences in the usage pattern may make comparative analysis extremely complex.

The facilities that are available in different types of building may also contribute to different energy consumption. In domestic usage, only basic facilities such as cooking appliances and electrical goods (such as white goods, air-conditioning, etc.) are required. However for commercial and higher education use buildings, more complex facilities are required such as chiller plants, generators and lifts. These differences in the annual operational energy result per square metre of gross floor area obtained from the literature make them difficult to compare. Nonetheless, the building industry has recognised the high energy usage in buildings and has focused its efforts for the past 20 years on conserving energy in order to reduce building operational energy consumption.

3.3.9 Embodied energy versus operational energy

Operational energy is always the main focus of reducing energy consumption in buildings (West, 1995; Treloar & Fay, 1998; Pullen, 2000b; Treloar et al., 2000b; Chen et al., 2001). Over the last decade, knowledge of global warming and depletion of non-renewable resources has encouraged a more comprehensive approach to life cycle energy analysis and it has become a major interest to researchers in minimising total energy use in buildings (Fay & Treloar, 1998; Pullen, 2000b). As part of life cycle analysis, indirect energy use through building materials manufacture is gaining increasing attention and is considered to be an important issue in environmental-friendly developments (Pullen, 2000b). Pierquet et al. (1998) state that the embodied energy in construction materials can add up to many years' worth of operational energy in an energy efficient house.

Environmental impact from energy use ensures that the energy embodied in building materials has now become of prime importance (Weir & Muneer, 1998; Treloar et al., 2001b). As Pears (1996, p.15) states:

> … much work on embodied energy aims to specify representative embodied energy values for different materials produced or supplied in a given country or region, so design can choose environmentally-preferred materials, or to assess the embodied energy associated with various activities.

The knowledge of energy embodied in building materials can help designers to choose low embodied energy materials. Edwards and Stewart (1994, p.22) suggest that:

> … embodied energy impacts are best studied at an early stage in the design process of buildings, when the effect of using alternative materials … can be investigated, preferably before any major design decisions are taken.

Research by Pullen and Perkins (1995), investigating the embodied energy of 10 brick veneer houses in Adelaide, revealed that embodied energy was about 85 percent of the heating and cooling requirement and 23 percent of the total operational energy over an 80-year life cycle.

In another study carried out by Oppenheim and Treloar (1995) on the embodied energy in the office building materials, the total embodied energy was estimated to be equal to around 21 to 37 years of the operational energy of those buildings. Cole and Kernan (1996) also undertook a study on office buildings using three different kinds of materials, namely timber, concrete and steel. They discovered that the total embodied energy of a timber building is equivalent to approximately 34 years of operational energy. The same building constructed using concrete or steel will definitely have higher embodied energy consumption as both are high energy intensity materials.

Furthermore, other research estimates that the total embodied energy consumption can correspond to around 15 to 20 years of operational energy (Treloar, 1996b; Pullen, 2000a). Tucker et al. (1998) state that buildings have a significant impact on the environment due to the energy embodied in construction materials. These studies provide very similar results with a significant portion of total energy consumption of buildings embodied in the material.

A further complication when comparing operational energy and embodied energy is that it is not always certain whether energy estimates have been expressed in terms of the delivered or primary forms of energy (Pullen, 2000b). Taking into account these research results, embodied energy cannot be ignored in the energy management of buildings. Consideration should be given to the specification of materials with low embodied energy as a contribution to reducing total energy consumption and greenhouse gas emissions (Pullen, 2000a).

The energy required to manufacture building materials and components is rarely revealed in marketing energy efficiency during the operational phase. In contrast, in economic evaluation, both the capital cost and operating costs are taken into account in life cycle costing (West, 1995; Treloar & Fay, 1998). Further, research on increasing operational energy efficiency alone, such as heating or cooling buildings, may not result in minimum energy consumption in an overall life cycle sense as additional embodied energy may be required through additional thermal insulation, for example. Energy efficiency should be considered in a life cycle energy analysis in which initial and recurrent embodied energy both play a role.

3.4 CONCLUSION

This chapter presented a literature review of the relationship between construction and the environment. The literature has revealed that the construction industry undoubtedly shares the responsibility of conserving natural resources and protecting the environment. The principle of sustainable construction, even though it is vague in its definition, is still the goal. The future direction for construction is a more responsible attitude and more environmentally friendly practices.

A further issue with environmental degradation is the context of energy consumption by the built environment. From the literature review it is clear that energy consumption is a significant field of research as it relates to depleting non-renewable resources and contributing to environmental pollution. It is particularly important for construction as it is the major consumer of global energy sources. For the goal of sustainable construction to be achieved, life cycle energy analysis of built projects and facilities is essential.

The literature review highlights a number of issues surrounding sustainable construction and energy consumption. The information provided in this chapter provides the platform for further research on the conceptual development of the sustainability index for project appraisal which follows in the next chapter.

CHAPTER FOUR

CONCEPTUAL FRAMEWORK OF A SUSTAINABILITY MODEL FOR PROJECT APPRAISAL

4.1 INTRODUCTION

Construction has been beset with problems ranging from excessive consumption of global resources, both in terms of construction and building operation, to the pollution of the surrounding environment (Spence & Mulligan, 1995; Uher, 1999). As suggested in the previous chapter, the construction industry is closely related to environmental degradation. Solutions are already being researched with goals such as minimising the impact of construction on the environment, recycling building materials to reduce natural resource depletion, and reducing construction wastage from on-site processing (Uher, 1999).

Research on green building design and using building materials to minimise environmental impact is also underway. However, relying on the design of a project to achieve the goal of sustainable development, or to minimise impacts through appropriate management on site, is not sufficient to handle the current problem. The aim for sustainability assessment goes even further on a project and it is essential to consider its importance at an early stage, before any detailed design or even before a commitment is made to go ahead with a development. However, little or no concern has been given to the importance of selecting more environmentally friendly designs during the project appraisal stage; the stage when environmental matters are best incorporated (Lowton, 1997). The goal of ecologically sustainable development should be considered as soon as possible in a project's life in order not to waste time, effort, money and resources.

The main objectives of this chapter are to investigate the current methods used to assess the environmental performance of buildings and to present the concept of a new, multi-dimensional approach to assess sustainability. This research firstly examines the development, role and limitations of current methods in ascertaining building sustainability, then the new approach will be discussed. The final section of this chapter presents the concept of developing a sustainability model for project appraisal based on the multi-dimensional approach discussed earlier, that will allow alternatives to be ranked. The mathematical model for the sustainability index is discussed in detail in the next chapter.

4.2 ENVIRONMENTAL BUILDING ASSESSMENT METHODS

4.2.1 Introduction

There is now concern being expressed about how to improve construction practices in order to minimise their detrimental affects on the natural environment (Cole, 1999a; Holmes & Hudson, 2000). The environmental impact of construction, green buildings, designing for recycling and eco-labelling of building materials have captured the attention of building professionals across the world (Johnson, 1993; Cole, 1998a; Crawley & Aho, 1999; Rees, 1999). In addition, building performance is now a major concern of professionals in the building industry (Crawley & Aho, 1999) and environmental building performance assessment has emerged as one of the major issues in sustainable construction.

According to Cole (1998a), the definition of building performance varies according to the different interest of parties involved in building development. For instance, a building owner may wish his building to perform well from a financial point-of-view, whereas the occupants may be more concerned about indoor air quality, comfort, health and safety issues. Therefore, an ideal environmental building assessment will include all the requirements of the different parties involved in the development. However, using a single method to assess a building’s environmental performance and to satisfy all needs of users is no easy task. Building performance assessment methods are currently one of the emerging areas in research and development (Cole, 1998a; Cooper, 1999; Holmes & Hudson, 2000).

4.2.2 An overview of environmental building assessment methods

Building designers and occupants have been concerned about building performance for a long time (Cooper, 1999; Kohler, 1999). Considerable work has gone into developing systems to measure a building's environmental performance and physical facilities over its life cycle. Separate indicators, or benchmarks based on a single criterion, have been developed to monitor aspects of building performance such as air quality and indoor comfort. In spite of this, a comprehensive assessment tool is essential to provide a thorough evaluation of building performance against a broader spectrum of environmental criteria. The release of the Building Research Establishment Environmental Assessment Method (BREEAM) in 1990 was the first comprehensive building performance assessment method. In this research some of the popular environmental building assessment methods were examined in detail and they are broadly divided into two categories, local and international methods.

Environmental building assessment methods used locally

BREEAM—BREEAM was the first environmental building assessment method in the world to be developed and remains the most widely used (Larsson, 1998). The Building Research Establishment developed the system in 1990 in collaboration with private developers in the UK. It was launched as a credit award system for new office buildings. A certificate of the assessment result is awarded to the individual building based on a single rating scheme of fair, good, very good or excellent. The purpose of this system is to set a list of environmental criteria against which building performances are checked and evaluated. This system can be carried out as early as at the initial stages of a project. The results of the investigation are fed into the design development stage of buildings and changes can be made accordingly to satisfy pre-designed criteria (Johnson, 1993).

Since 1990, the BREEAM system has been constantly updated and extended to include assessment of such buildings as existing offices, supermarkets, new homes and light industrial buildings (Yates & Baldwin, 1994). Crawley and Aho (1999) suggest that the system is successfully alerting building owners and professionals to the importance of environmental issues in construction. BREEAM has been adopted worldwide, with Canada, Australia, Hong Kong and other countries developing their own environmental building assessment methods largely based on the BREEAM methodology.

BEPAC—The Building Environmental Performance Assessment Criteria (BEPAC) were developed by the University of British Columbia in 1993. BEPAC is a more detailed and comprehensive assessment method than BREEAM, but its use is limited to the evaluation of new and existing office buildings (Cole, 1994 & 1998a). It is similar to BREEAM as it evaluates the environmental merits of buildings using a point system (Crawley & Aho, 1999). It has a set of environmental criteria related to interior, local and global scales based on objective performance standards. A certificate of design and management performance is offered to the building on completion of the assessment.

LEED—In 2000, the US Green Building Council developed LEED, Leadership in Energy and Environmental Design[7] through a consensus process (Crawley & Aho, 1999). It is a green building rating system for commercial, institutional and high-rise residential new construction and major renovation in five areas of sustainability: water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. It adopts a whole-building approach that encourages and guides a collaborative, integrated design and construction process. It is also a voluntary and market-based assessment method that is intended to define a green building and is very simple to use. However as Larsson (1999) states, while it is widely accepted and used by the community of building owners and managers because of its simplicity, its completeness in assessing building performance is in doubt.

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[7] LEED—http://www.usgbc.org

EPGB—The Environmental Performance Guide for Building (EPGB)[8] was developed by the Policy Services Division of the NSW Department of Public Works and Services (now the Department of Commerce) in Australia. The framework is largely based on the Green Building Challenge (GBC) performance assessment framework (described later in this section) by using a rating method to assess buildings. The guidelines cover the areas of resource consumption, environmental loadings, quality of internal environment, functionality and wider planning issues.

NABERS—The Department of Environment, Australia is developing the National Australian Building Environmental Rating System (NABERS)[9] as a performance-based approach to promote sustainability in the built environment during operation. It provides an assessment tool allowing comparisons to be drawn between different designs and investment options, and assesses a building's operational environmental impact.

The system evaluates things such as energy and water efficiency, site conservation and biodiversity, indoor air quality, efficiency of resource use and other relevant environmental factors.

ENER-RATE—Soebarto and Williamson (2001) developed ENER-RATE software to be a designer-oriented environmental performance rating tool. It is intended to assist designers to test their strategies against different sets of criteria. The system adopts a multi-criteria decision-making approach to assess energy use, indoor air quality, thermal comfort, operating plant load, cost and other environmental degradation. The design proposals are compared with an automatically generated reference building, based on the principle rules of ASHRAE 90.1. The software is still in a developmental stage. However, once it is completed it will be the only software that can be used to consider sustainability issues at the design development stage (Soebarto & Williamson, 2001).

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[8] EPGB—http://www.asset.gov.com.au

[9] NABERS—http://www/ea/gov.au/industry/waste/constructing/index.html

CPA—Comprehensive project evaluation (CPA) is an assessment methodology that embraces all economic, social and environmental costs and benefits in project appraisals developed by the Royal Institution of Chartered Surveyors (RICS) and the Environment Agency. CPA is an appraisal framework which enables sustainable development issues to be incorporated into the development evaluation process. CPA is different from a building performance method as it is used to assess projects during the development process using a combination of financial and economic appraisals to provide monetary values where possible, and scoring and weighting techniques for measuring impacts (Woolley et al., 1999). CPA provides a mechanism to evaluate the nature of the impacts, select the most appropriate analysis method, incorporate local sustainability priorities into the analysis, and a framework to select the best development option (RICS, 2001). The framework uses a multi-criteria analysis approach to assess environmental and social impacts.

CPA is a checklist type evaluation framework that requires an independent assessor to undertake the assessment. Subjectivity is inevitable but it is a limitation in most of the environmental building assessment methods. CPA is more useful than most environmental building assessment methods as cost is measured based on the technique of cost benefit analysis. However, energy and other social and environmental issues are only scored by the assessor. Any assessment method that does not quantify criteria as much as possible is potentially problematic. Energy consumption, for instance, is important as it reflects resource allocation and there are methodologies readily available for such measurement. CPA does not allow other parties to participate in the evaluation process, except when determining priorities, which is another shortcoming of the methodology. CPA's usefulness may be to provide an additional service area for the planners, chartered surveyors and others in the construction industry, but may not be useful to assess a building's environmental performance.

Other systems such as the Total Quality Design and Assessment System of Austria, ESCALE of France, EcoProfile of Norway; Eco-quantum of the Netherlands and HK-BEAM of Hong Kong are based on the BREEAM model (Davies, 2001; Todd et al., 2001; Lee et al., 2002).

Environmental building assessment method used internationally

GBC—Since 1995, the environmental building assessment method has moved towards an international collaborative effort to develop an environmental building assessment tool for international purposes. Known as the Green Building Challenge (GBC), thirteen countries collaborated to take a comprehensive look at environmental issues within buildings (Larsson, 1998; Rohracher, 2001). GBC's objectives are to establish international benchmarks for building performance and to offer participating countries help in developing regionally sensitive assessment models (Kohler, 1999). Some aspects of BREEAM also served as a model for the GBC framework (Todd et al., 2001). GBC developed through different stages from GBC 98 to GBC 2000 (Cole, 1998a; Larsson & Cole, 2001). Initially, GBC was difficult to use as a design tool because of its complexity and the data entered into the GBTool were not clearly linked to the scoring system (Todd et al., 2001; Soebarto & Williamson, 2001). In order to simplify the process, GBC was implemented through software called GBTool.

BEQUEST—The Built Environment Quality Evaluation for Sustainability through Time (BEQUEST) system was an international project funded by the Research and Technical Development Directorate of the European Commission through the Fourth Framework Programme in 1997. The project's main objective was to identify a common language and framework to assess and implement urban sustainability (Cooper, 1999; Deakin et al., 2002).

The BEQUEST represents a similarly successful international research project to GBC for creating greater collaboration of international partners at a multi-disciplinary level using the BEQUEST Extranet as the communication network. The research project combines the diverse knowledge and expertise of a wide range of environmental researchers, professionals, infrastructure providers and managers to produce a framework, directory of assessment methods and set of procurement protocols which are linked together in the form of a tool-kit (Curwell et al., 1998). The vision of the BEQUEST is to enhance sustainability issues in urban decision-making.

The framework of the BEQUEST is different from the existing environmental building assessment methods such as BREEAM for assessing individual building sustainability. Instead, the BEQUEST aims at advising users on incorporating sustainability in urban design. As Kohler (2002) suggests, the BEQUEST is a framework for the preparation of projects for the 'City of Tomorrow'. Indeed, the successful implementation of the BEQUEST will no doubt enhance the sustainable development concept in urban development.

The principle of BEQUEST is based on the four principles of sustainable development identified by Mitchell et al (1995): to embrace environment, futurity, equity and public participation. However, as Cooper (2002) describes, there is a lack of a clear definition of sustainable urban development and its implementation process. Kohler (2002) further states that the problem of valuing the different aspects of sustainable urban development has not been explicitly identified. Thus no clear basis for future discussions and implementation exists.

4.2.3 <u>The role of environmental building assessment methods in the construction industry</u>

As the problems of natural resource depletion and global environmental degradation become evident, building performance has become a matter of public concern. Most building evaluation methods are concerned with a single criterion such as energy use, indoor comfort or air quality to indicate the overall performance of a building (Cooper, 1999; Kohler, 1999). As environmental issues become more urgent, a more comprehensive building assessment method is required to assess building performance across a broader range of environmental considerations.

An environmental building assessment method reflects the significance of the concept of sustainability in the context of building design and its subsequent construction work on site. Designers aim to improve the overall performance of buildings in relation to their effects on both the natural and man-made environments. The primary role of an environmental building assessment method is to provide a comprehensive assessment of the environmental characteristics of a building (Cole, 1999a). It is undertaken by providing a common and verifiable set of criteria and targets for building owners and designers to achieve higher environmental standards.

Additionally, the assessment method helps to define the direction for a project and provides information on which to make informed design decisions at all stages and to plan effective environmental design strategies. The development of an environmental building assessment method lays down the fundamental direction for the building industry to move towards environmental protection and achieving the goal of sustainability. It also provides a way of structuring environmental information, an objective assessment of building performance, and measure of progress towards sustainability.

Assessment methods act as a bridge between environmental goals and strategies and building performance during the design and occupancy stages of a building. They comprise a set of environmental criteria that are relevant to buildings, and are organised and prioritised to reflect the performance of a building. The environmental assessment methods satisfy three major aspects: global, local and indoor issues. They also include a set of standard guidelines for how individual buildings are assessed and evaluated. They are prepared in order to provide a methodological framework to assess building performance in a broad context of decision-making, where environmental issues have a significant role (Yates & Baldwin, 1994; Cole, 1998a; Cooper, 1999; Crawley & Aho, 1999).

Environmental building assessment methods do not just provide a methodological framework for assessing building performance but also collect useful information to form guidelines for remedial work in order to meet pre-designed criteria. The collected data can also be used as feedback information for planning future projects of similar design while offering the same level of service and amenity. The accumulated knowledge and expertise of environmental building design contributes to the greater consideration of environmental issues within the decision-making process, thus minimising the environmental impacts of a building in the long term.

Environmental building assessment methods also enhance the environmental awareness of building practices, highlighting concerns about the design and construction of more environmentally oriented projects. Crawley and Aho (1999) state that environmental assessment methods might provide a means for incorporating more holistic environmental performance requirements in national building regulations, which again aim to significantly reduce the environmental impact of new construction. They go on to state that although largely different from each other and designed around different indicators, these systems nevertheless have a positive impact on reducing environmental stress in the short term. However, work is needed to develop a universal life cycle assessment system based on internationally agreed absolute indicators of environmental performance (Uher, 1999).

4.2.4 Critique on the environmental building assessment methods

As stated by Cole (1998a), environmental building assessment methods contribute significantly to the understanding of the relationship between buildings and the environment. However, the interaction between building construction and the environment is still largely unknown. The assessment methods have limitations that may hamper their future usefulness and effectiveness in the context of assessing environmental performance of buildings as discussed below.

Environmental building assessment methods used as a design tool

Environmental building assessment methods are most useful during the design stage when any impairment for the pre-design criteria may be assessed and incorporated at the final stage of design development. Incorporating environmental issues can be achieved in the design process which can minimise environmental damages. Even though these assessments are not originally designed to serve as design guidelines, it seems that they are increasingly being used as such (Crawley & Aho, 1999; Cole, 1999a).

The more effective way of achieving sustainability in a project is to consider and to incorporate environmental issues at a stage even before a design is conceptualised. It is important to separate project design and project assessment as building design takes place at an early stage and most of the outcomes of the design have already been established and incorporated into the final design. However, the assessment process works the opposite way around, thus may not be useful as a design tool (Crawley & Aho, 1999; Soebarto & Williamson, 2001). Therefore, in order for environmental building assessment methods to be useful as a design tool, they have to be introduced as early as possible to allow for early collaboration between the design and assessment teams. However, apart from ENER-RATE which has been particularly designed to assist the design process, the other assessment methods were not designed for this purpose (Soebarto & Williamson, 2001).

Some environmental building assessment methods may be used to assess existing buildings, such as BREEAM 4/93: An Environmental Assessment for Existing Office Buildings. However, the usefulness of the environmental building assessment method in this respect is doubtful as the remedial work needed to make a completed building comply with the environmental criteria may be too extensive, too costly and time consuming (Lowton, 1997; Crawley & Aho, 1999). For example, remedial work to existing buildings may be impracticable or difficult to facilitate, e.g. replacing an existing ventilation system with a more environmentally friendly system or installing more windows to allow for natural ventilation. This assessment system has predominantly been applied to new construction, but refurbishment and maintenance of existing buildings are also an important part in future construction activities.

Project selection

Environmental building assessment methods are less useful for project selection as they are used to evaluate building design against a set of pre-designed environmental criteria. Environmental issues are generally only considered at the design stage of projects where the effect of different development options or locations of development are required to be considered at the feasibility stage.

Project selection starts at an earlier stage and it is at this stage that environmental issues are best considered and evaluated (Lowton, 1997). A project may have various development options and choosing the option that minimises detrimental effects to the environment plays an important role in achieving sustainable goals. Lowton (1997) argues that environmental matters are to be considered as early as possible. If they are not dealt with before and during the appraisal stage of a project, later alterations to the brief will cost money and cause annoyance. Sustainability should be considered as early as possible in the selection phase in order to minimise environmental damage, maximise natural resources and reduce remedial costs. According to Crookes & de Wit (2002), environmental assessment is most efficient during the identification and preparation stages of a proposed project but current environmental assessment methods are designed to evaluate building projects at the (later) design stage to provide an indication of the environmental performance of buildings. However, by this stage it may be too late to consider environmental issues, as changing the design to meet full compliance with the environmental criteria may be costly.

Financial issues

Environmental building assessment methods focus on the evaluation of design against a set of environmental criteria broadly divided into three major categories: global, local and indoor issues. These tools assess several main issues including resource consumption (such as energy, land, water and materials), environmental loading, indoor comfort and longevity. Some assessment tools such as BREEAM, BEPAC, LEED and HK-BEAM do not include financial matters in the evaluation framework. This may contradict the ultimate principle of a development, as financial return is fundamental to all projects because a project may be environmentally sound but very expensive to build. Therefore the primary aim of a development, which is to have an economic return, may not be fulfilled making the project less attractive to developers even though it may be environment friendly. Environmental issues and financial considerations should go hand in hand as parts of the evaluation framework when making decisions. As stated in Larsson (1999), the revised GBC model will include economic issues in the evaluation framework. This is particularly important when the decision-making process starts from the outset at the feasibility stage where alternative options for a development are assessed. As shown, both environmental and financial aspects should be considered when assessing environmental concerns.

Regional variations

Most environmental building assessment methods were developed for local use and do not allow for national or regional variations. To a certain extent, weighting systems can offer opportunities to revise the assessment scale to reflect regional variations and criteria order. However, regional, social and cultural variations are complex and the boundaries are difficult to define. These variations include differences in climatic conditions, income level, building materials and techniques, building stocks and appreciation of historic value (Kohler, 1999).

Many countries have adapted the BREEAM system for their own use giving rise to new systems such as HK-BEAM and Total Environmental Assessment of Buildings in Australia. Adjustments to customise the system include cultural, environmental, social and economic considerations. It is unlikely that a set of pre-designed environmental criteria could be prepared for worldwide use without further adjustments.

The GBC is the first international collaborative effort to develop an international environmental assessment method. The prime objective of the GBC was to overcome the shortcomings of the existing environmental assessment tools. The Green Building Tool (GBTool) has been developed to embrace the areas that have been either ignored or poorly defined in existing environmental building assessment methods for evaluating buildings throughout the world. However, GBTool suffers from other shortcomings. Crawley and Aho (1999, p.305) state that “one of the weaknesses of the GBTool is that individual country teams established scoring weights subjectively when evaluating their buildings”. They further state that “most users found the GBTool difficult to use because of the complexity of the framework”. GBTool is the first international environmental building assessment method and it is unlikely it will be used as intended without incorporating national or regional variations. Curwell et al. (1999) think that the approach of the GBTool has led to a very large and complex system causing difficulties and frustration for over-stretched assessors rather than a global assessment method as intended.

Complexity

Environmental issues are a broad area and difficult to capture by using a set of criteria. Consequently, environmental building assessment methods tend to be as comprehensive as possible. For example, the BEPAC comprises 30 criteria, C-2000 comprises 170 criteria and GBTool comprises 120 criteria (Cole, 1999a, Larsson, 1999). This approach has led to complex systems which require large quantities of detailed information to be assembled and analysed. Typically, they tend towards generalisation in order to capture most environmental criteria within their evaluation framework. However, this may jeopardise their usefulness in providing a clear direction for making assessments cumbersome. Striking a balance between completeness in the coverage and simplicity of use will be one of the challenges in developing an effective and efficient environmental building assessment tool.

Evaluation of quantitative and qualitative data

The assessment system accommodates both quantitative and qualitative performance criteria. Quantitative criteria comprise annual energy use, water consumption, greenhouse gas emissions etc., whereas qualitative criteria include the ecological value of the site, local wind effects, and so on.

Quantitative criteria can be readily evaluated based on the total consumption level and points awarded accordingly. For example, in BREEAM 8 credit points are given for CO^2 emissions between 160-140kg/m^2 per year and more points are awarded if CO^2 emissions are further reduced (BREEAM’98 for Office). However, environmental issues are mainly qualitative criteria, which cannot be measured and evaluated using market-based approaches within the existing environmental assessment framework. They can only be evaluated on a ‘feature-specific’ basis where points are awarded for the presence or absence of desirable features (Cole, 1998a). This may largely undermine the importance of environmental issues within the decision-making process. The accurate assessment of environmental issues involves a more complex and operational framework in order that they can be properly handled.

Weighting

Weighting is inherent to the systems but not explicitly and, as such, all criteria are given equal weights (Todd et al., 2001). The GBC framework provides a default weighting system and encourages users to change the weights based on regional differences. However, since the default weighting system can be altered, users may manipulate the results to improve the overall scores in order to satisfy a specific purpose (Larsson, 1999; Todd et al., 2001).

There is insufficient consideration of a weighting system attached to the existing environmental building assessment methods. The overall performance score is obtained by a simple aggregation of all the points awarded to each criterion. All criteria are assumed to be of equal importance and there is no order of importance for criteria. Cole (1998a) states that the main concern is the absence of an agreed theoretical and non-subjective basis for deriving weighting factors. It is currently dependent on the in-depth understanding of the environmental impact of building. The relative importance of performance criteria is an important part of the decision if the stated objectives are to be achieved, for example, the public sector's opinion will definitely differ from that of the private developer. Therefore, weighting environmental criteria should be derived on a project-by-project basis and should reflect the objective of a development. The absence of any readily used methodological framework has hampered existing environmental assessment methods in achieving sustainability goals.

Measurement scales

Measurement scales are also based on a point award system and the total score obtained for the evaluation reflects the performance of a building in achieving sustainable goals in the industry. However, there is no clear logical or common basis for the way in which the maximum number of points is awarded to each criterion. Most building environmental assessment methods award their own points to environmental criteria. Using consistent measurement scales facilitates more comparable assessment results across countries. Benchmarking the baseline performance for assessment is another difficult area to accurately assess in the existing assessment tools.

4.2.5 Summary

Construction is one of the largest end users of environmental resources and one of the largest polluters of man-made and natural environments. The improvement in the performance of buildings with regard to the environment will indeed encourage greater environmental responsibility and place greater value on the welfare of future generations. There is no doubt that environmental building assessment methods contribute significantly in achieving the goal of sustainable development within construction. On one hand, it provides a methodological framework to measure and monitor environmental performance of buildings, whilst on the other it alerts the building profession to the importance of sustainable development in the building process.

However, existing environmental building assessment methods have their limitations as examined in this section reducing their effectiveness and usefulness. There is a requirement for greater communication, interaction and recognition between members of the design team and various sectors in the industry to promote the popularity of building assessment methods. The inflexibility, complexity and lack of consideration of the weighting system are still major obstacles to the acceptance of environmental building assessment methods.

4.3 THE CONCEPTUAL DEVELOPMENT OF A SUSTAINABILITY MODEL FOR PROJECT APPRIASAL

4.3.1 Introduction

Ecologically sustainable development is the central concern of people from all disciplines (Cole, 1999a; Holmes & Hudson, 2000). The concept of sustainability in the context of construction is about creating and maintaining a healthy built environment and at the same time focusing on minimising resources and energy consumption, thereby reducing damage to the environment, encouraging reuse and recycling, and maximising protection of the natural environment. These objectives may be achieved by considering the most efficient option amongst competing alternatives through the process of project appraisal at an early stage.

Following the thorough discussion on the usefulness of environmental building assessment methods in the construction industry in achieving the goal of sustainable development, this section sets out to conceptualise the development of a model that can be used in project sustainability appraisals. It is argued in this section that a multiple criteria approach may be considered in the development of a sustainability model.

4.3.2 Single or multiple dimensional assessment approaches

The decision-making process frequently involves identifying, comparing and ranking alternatives based on multiple criteria and multiple objectives. This process frequently occurs without conscious consideration in our daily life (Tabucanon, 1988; Nijkamp et al., 1990). Decision-makers often emply project appraisal techniques to structure a complex collection of data into a manageable form in order to provide an objective and consistent basis for choosing the best solution for a situation. However, for big decisions where millions of dollars may be involved, there is a tendency to simplify the objectives of the project into a single decision criterion (Tabucanon, 1988). Single criterion evaluation techniques have dominated project appraisal since World War II and they were mainly concerned with economic efficiency (Zeleny, 1982; Nijkamp et al., 1990; Tisdell, 1993; van Pelt, 1993b; Burke, 1999).

Cost benefit analysis (CBA) is the leading tool in this respect and it is a well respected appraisal technique widely used in both private and public development to aid decision-making (Harvey, 1987; Tisdell, 1993; Perkins, 1994; van Pelt, 1994; Joubert et al., 1997). Everything is converted into dollars, at least where possible, and the decision is based on finding the alternative with the highest net monetary value (Hanley & Spash, 1993; Perkins, 1994; Abelson, 1996). Often financial return is the only concern in project development, but the project that exhibits the best financial return is not necessarily the best option for the environment. In addition, many environmental and social considerations underlying sustainable developments cannot be monetarised (Tisdell, 1993; Hobbs & Meier, 2000; RICS, 2001) significantly reducing CBA's usefulness.

Other single criterion evaluation techniques focus on energy efficiency such as energy rating. NATHERS and ASHRAE Standard 90.1 are used to simulate energy consumption to estimate the performance of proposed building as an aid to decision-making (Lord, 1994; Fay & Treloar, 1998; Pullen, 2000b; Soebarto & Williamson, 2001). These methods are mainly focused on operational energy in relation to indoor air quality and user comfort.

However, in reality, decision-making is rarely based on a single dimension. Janikowski et al. (2000) argue that using only one assessment criterion cannot be regarded as a correct approach. They go on to advocate that it is necessary to accept a multi-criteria perspective that takes into account a spectrum of issues regarding a development. Since the end of the 1960s it has been gradually recognised that there is a strong need to incorporate a variety of conflicting objectives. An increasing awareness of externalities, risk and long-term effects generated from development, and the importance of distributional issues in economic development (Zeleny, 1982; Nijkamp et al., 1990) fostered this new perspective. Thus single dimensional appraisal techniques are increasingly controversial (Zeleny, 1982; Nijkamp et al., 1990; van Pelt, 1993b; Tisdell, 1993; Abelson, 1996).

The strong tendency towards incorporating multiple criteria and objectives in project appraisal has led to a need for more appropriate analytical tools for analysing conflicts between policy objectives (Moffatt, 1996; Powell, 1996; Popp et al., 2001). Multi-criteria analysis (MCA) provides the required methodology to evaluate multiple criteria and objectives in project appraisal (Voogd, 1983; Nijkamp et al., 1990; Janssen, 1992; van Pelt, 1993b).

The multi-dimensional framework incorporates the consideration of environmental issues in a development and it will take an important role in the evaluation approach. Sustainability, as defined by Young (1997), is a measure of how well the people are living in harmony with the environment taking into consideration the well-being of the people with respect to the needs of future generations and to environmental conservation. Young (1997) goes on to describe sustainability as a three-legged stool, with a leg each representing ecosystem, economy and society. Any leg missing from the ‘sustainability stool’ will cause instability because society, the economy and the ecosystem are intricately linked together. Indeed, Young (1997) explains clearly that a measurement of sustainability must combine the individual and collective actions to sustain the environment as well as improve the economy and satisfy societal needs.

Elkington (1997) expands the concept of sustainability to be used in the corporate community, developing the principle of triple bottom line. Triple bottom line refers to the three prongs of social, environmental and financial performance, which are directly tied to the concept and goal of sustainable development. They are highly inter-related and are of equal importance (Cooper, 2002). It is a term that is increasingly accepted worldwide within the corporate community, and as a framework for corporate reporting practices.

The triple bottom line concept focuses not just on the economic value as do most of the single criterion techniques, but equally on environmental and social values. For an organisation to be sustainable it must be financially secure, must minimise the negative environmental impacts resulting from its activities, and must conform to societal expectations (Elkington, 1997; Roar, 2002). The triple bottom line concept underlies the multiple dimensional evaluation process of development. To conform with the concept, a business to be sustainable, must deliver prosperity, environmental quality and social justice. Further, the triple bottom line concept has been expanded and used as an audit approach for sustainable community development (Rogers & Ryan, 2001).

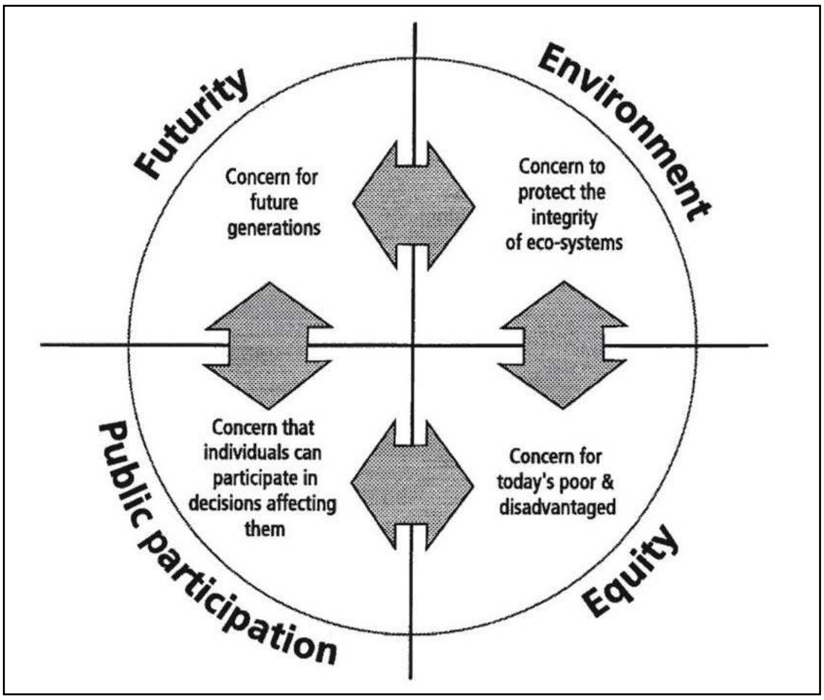
Kohler (1999), states that a sustainable building has three dimensions: ecological, cultural, and economic sustainability. Young's (1997), Elkington's (1997) and Kohler's (1999) frameworks to measure sustainability have many similarities but Kohler (1999) also emphasised the importance of cultural considerations. The assessment of a sustainable building has to make explicit the particular cultural expectation which the development has been designed to maintain (Kohler, 1999; Cooper, 1999).

Apart from this three-dimensional concept of sustainability, Mitchell et al. (1995) describe four separate principles: equity, futurity, environment and public participation, which underpin sustainable development, known as the PICABUE (see Figure 4.1).

Equity deals with the principle of fair shares, both locally and globally, among the current generation. The principle of futurity is to ensure intergenerational equity within which a minimum environmental capital must be maintained for future generations. The integrity of the ecosystem should be preserved, and its value recognised and respected, in order not to disrupt the natural processes essential to human life and to protect biodiversity. The fourth principle recognises the importance of public participation in decisions concerning them and the process of sustainable development (Mitchell et al., 1995; Curwell & Cooper, 1998).

PICABUE is a methodological framework designed to develop sustainability indicators. Its name is derived from the seven steps used to develop sustainability indicators to enhance quality of life (for details refer to Mitchell et al., 1995). Cooper (1999) further proposes that the principles of PICABUE should be addressed when environmentally assessing buildings or cities. The PICABUE model of sustainable development has also been adopted by the BEQUEST as the basic principle of development (Bentivegna et al., 2002). The four principles were used to define common understanding and terminology for sustainable development in the BEQUEST network (Cooper, 2002). Cooper (1999) further states that only the environment directly deals with ecology whilst the other three principles are political and socio-economic issues that are concerned with resource allocation and the decision-making process.

Figure 4.1 The PICABUE principle



Source: Mitchell et al., 1995

Most building performance assessment methods only tackle the principle of economics and are inadequate in addressing the concept of sustainability (Curwell & Cooper, 1998). The public participation factor is only found in the PICABUE model and it concerned with the general public's participation in the decision-making process. This is a significant part of the process as it is the public that will suffer any long-term effects arising from decisions about developments. Indeed, the requirement for public participation is increasing (Joubert et al., 1997) and is also in line with Principle 10 of the Rio Declaration on Environment and Development (Curwell & Cooper, 1998).

Other concepts of multi-dimensional approaches are developed on the same basis. The four system conditions as described in the Natural Step[10] have also gained significant attention. Karl-Henrik Robért developed Natural Step in 1989 to address environmental issues. The first three conditions provide a framework and a set of restrictions for

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[10] Natural Step—http://www.naturalstep.org

ecological sustainability. The fourth condition formulates an international turnover of resources for society, ensuring that human needs are met worldwide (Herendeen, 1998; Chambers et al., 2000). The Natural Step has provided a good sustainable development business philosophy, and has been widely applied in the business and industrial sectors (Bentivegna et al., 2002).

Giarni and Stahel developed another concept, the ‘service economy’ which seeks more cyclical industrial and economic processes, rather than the current linear process of production, consumption and waste (Bentivegna et al., 2002). Reusing, refurbishing and recycling materials and components form a feedback loop in the process, aiming to considerably reduce material flows by increasing resource utilisation efficiency and by extending product life (Curwell & Cooper, 1998; Bentivegna et al., 2002).

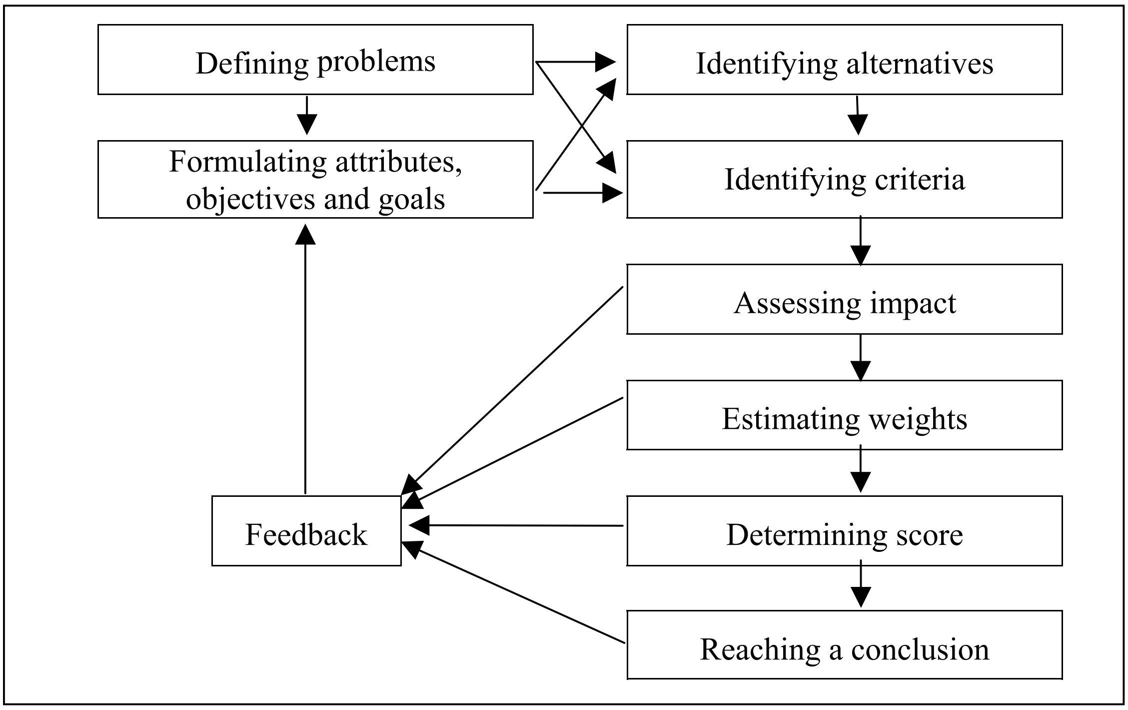
From the above discussion, it is clear that project appraisal is multi-dimensional and the aspects, as described in the PICABUE and others, have summarised the essential components to be assessed in a development.

4.3.3 The multiple dimensional model of project appraisal

Given the previous discussion of an increased tendency to consider multiple criteria in project appraisal, it is necessary to develop a model to facilitate multiple dimensional assessment of criteria to aid decision-making. A sustainability index for project appraisal is designed to bridge the gap between the current methodology which uses a single objective approach, and the need for a multiple criteria approach in order to incorporate environmental issues in the decision-making process. It is based on a multiple dimensional model that embraces economic, social and environmental values. The criteria included in the sustainability index are based on an absolute assessment approach and are combined into a composite index to rank options for projects at the feasibility stage. The purpose of this research is to develop a mathematical model yielding a single index allowing development alternatives to be ranked.

In this respect, project appraisal may be considered as a continuous process, which takes place during the early stages of a development. No matter what size of development, there are always many possibilities during the decision-making process that must be assessed and judged. Generally, project evaluation goes through several distinctive, inter-related stages. The literature describes many models for this process but most of them use similar and, as discussed, flawed, approaches (Nijkamp et al., 1990, Janssen, 1992; van Pelt, 1993b; Hobbs & Meier, 2000; RICS, 2001). Figure 4.2 shows the model adopted in this research. The evaluation process for a project will not be seen as a simple linear process but follows a cyclic nature (Nijkamp et al., 1990, Janssen, 1992; Bentivegna et al., 2002; Ding, 2002b). Each stage can supply additional information participate in the feedback loop to provide further information for a more precise consideration for the forthcoming stage or stages (Nijkamp et al., 1990; Ding, 2002b).

Figure 4.2 Multiple dimensional decision model of project appraisal



Source: Adopted from Nijkamp et al., 1990

i) Defining problems

Project appraisal usually starts by defining a problem then formulating project attributes, objectives and goals (van Pelt, 1993b; RICS, 2001). The project problem is structured to provide adequate specification of objectives, and so that attributes can be identified. In addition, project constraints such as financial, political and external will also be investigated (Nijkamp et al., 1990). Financial constraints relate to the availability of scarce resources for a development; political constraints have to be considered when public funds are to be used; and external constraints refer to the external effects generated through development upon the man-made and natural environment. These constraints often govern the compilation of alternative criteria sets in a development. Early identification of project constraints is critical to develop a more precise set of alternatives to optimise the best solutions, or acceptable compromise solutions, to problems (Nijkamp et al., 1990).

ii) Identifying alternatives

The next step is to identify alternatives, based on the decision problem's structure. Alternatives may include design alternatives, location options, technology and development options. They are usually derived from observing the project problem and through screening and scoping a number of possible solutions (van Pelt, 1993b; Hobbs & Meier, 2000). At this stage, the list of possible alternatives concerns objectives which include maximising utilities, optimising renewable and non-renewable resources, and minimising disturbance to the environment. There is no limit to the number of alternatives, but policy makers tend to reduce the total number in order to facilitate decision-making. A recommended number is approximately seven because an increase in number can create confusion and uncertainty (van Pelt, 1993b).

iii) Identifying criteria

Evaluation criteria are defined following the identification of development alternatives. Criteria are reflections of objectives to be achieved and can be used as guidelines to analyse impacts from each alternative (Nijkamp et al., 1990; van Pelt, 1993b; Hobbs & Meier, 2000). Criteria about environmental effects will also be formulated and may result in a special environmentally focused analysis of alternatives at a later stage. The list of criteria should be sufficiently precise and comprehensive to cover the full range of issues, but should also be limited to around eight criteria as this is the maximum number from which most people can make meaningful and reasonable judgements (Voogd, 1983; Nijkamp et al., 1990; van Pelt, 1993b). The decision model will focus only on the aspects that are salient and eliminate those that are less attractive. If the number of criteria cannot be reduced, a hierarchy of criteria may need to be established to categorise them (Saaty, 1994). However, in such a situation is less than ideal, causing the decision process to become more complicated.

iv) Assessing impact

The previously identified criteria may contain objective and subjective issues. For objective issues, such as financial obligations and energy flows, there may be techniques that are readily applicable for their quantification. The main difficulty at this stage is to quantify subjective issues which are largely social and environmental matters. Therefore, at this stage of the impact assessment, different methodologies may be engaged to evaluate satisfactorily each criterion.

Detailed analysis of each criterion is an important step in determining the score in relation to a development's impacts. It involves expressing impacts in numeric terms and information may be presented in an evaluation matrix with alternatives set against criteria in a spreadsheet (Voogd, 1983). Each criterion is measured using the most appropriate method for its nature to reflect its relative importance against each alternative. Each criterion can be measured in either a quantitative method or on a qualitative scale.

A quantitative scale is expressed in monetary or physical units such as dollar or Gj/m^2. However, qualitative scales are much more difficult to handle and may be expressed in three different ways (van, Pelt, 1993b), through:

- an ordinal[11] ranking expressed as 1, 2, 3, … or + + +,
- a nominal scale which reflects the characteristics of alternatives such as type of colour, or
- a binary scale that contains only two answers such as yes or no.

Whenever a qualitative measure is involved, the measure must be converted to numerical data (Nijkamp et al., 1990).

This is the stage when the public can participate. Local inhabitants can be consulted to identify likely impacts from a development that may affect them and the community. This process may ensure that not just the technical or financial criteria will be considered but, within the multi-criteria project appraisal model, the social and environmental criteria will also be considered.

v) Estimating weights

In any list some items are likely to be more important than others. For example, in a public project the social and environmental issues may have more weight than the financial aspects. However, the situation may be the reverse in a private development as financial return is the crucial driver for private projects. It is only a rare scenario when all criteria carry equal weights, such as the PICABUE, triple bottom line, and environmental stool concepts (Mitchell et al., 1995; Elkington, 1997; Young, 1997).

In a project appraisal, choosing an option from a list of alternatives means that priorities must be set and weights assigned to each criterion, reflecting each criterion's priority. Nijkamp et al (1990) suggest various methods to estimate criteria weighting. These are broadly divided into two main approaches: direct and indirect estimation.

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[11] It is noted that the author has used the term 'ordinal' in a manner that is not strictly the meaning accorded it by the Concise Oxford Dictionary 3rd Ed. s.v. 'ordinal'.

Direct estimation of criterion weights refers to the expression of relative importance of the objectives or criteria in a direct way through questionnaire surveys. Respondents are asked questions within which their priority statements are conveyed in numerical terms. Respondents can be members of the design team, representatives from the client, local council and the public (Seabrooke et al., 1997). This is another opportunity for the increasing demand for public participation in the decision-making process (Joubert et al., 1997; Price, 2000).

Direct estimation method techniques come in various forms:

- The trade-off method where the decision-maker is asked directly to place weights on a set of criteria to all pairwise combination of one criterion with respect to all other criteria.
- The rating method where the decision-maker is asked to distribute a given number of points among a set of criteria to reflect their level importance.
- The ranking method where the decision-maker is asked to rank a set of criteria in order of their importance.
- The seven-points (or five-points) scale which helps to transform verbal statements into numerical values.
- The paired comparison, which is similar to the seven-point scale, obtains the relative importance of criteria by comparing all pairs of criteria on a non-points scale.

However, all these methods run into trouble when the number of objectives becomes large (van Pelt, 1993b; Hobbs & Meier, 2000). When this happens, objectives may have to be structured in a hierarchical model to separate objectives into different levels (Saaty, 1994).

The indirect approach is based on investigating the actual behaviour of respondents in the past. Weights are obtained through estimating actual previous behaviour derived from ranking alternatives or through an interactive procedure of obtaining weights by questioning the decision-maker and other involved parties. Hypothetical weights may also be used in some projects. Here, the analyst prepares weights to represent the opinion of specific groups in the community, then policy-makers may comment accordingly. Each approach has restrictions and limitations in terms of accuracy and cost. Their usefulness strongly depends on the time required and the attitude of respondents (Voogd, 1983; Nijkamp et al., 1990; Hobbs & Meier, 2000).

vi) Determining score

A total may be obtained by amalgamating the assessment scores of criteria and their related weights using combined methods, because criteria may contain objective and subjective issues. Therefore, this stage may involve the use of multi-criteria analysis to bring the values together for each alternative to aid decision-making. Since criteria may be measured using different units, standardisation may be required to convert these criteria into a common basis (Voogd, 1983; Nijkamp et al., 1990; Janssen, 1992). As mentioned, the purpose of this research is to develop a mathematical model to produce a single index that allows alternatives to be ranked. The model for the sustainability index will be significant for the use of multi-dimensional approach in project appraisal.

vii) Reaching a conclusion

Finally, a conclusion can be drawn and decisions made according to the score of each alternative. In accordance with the concept of the sustainability index, the higher the score the better will be the option for a development. Evaluation may be considered as a continuous activity in a planning process as evaluation feedback loops can take place in different routes at different stages, providing further information to define alternatives and/or criteria to satisfy the ultimate objectives to be achieved.

4.3.4 Summary

This section presented the literature review and a discussion on conventional single criterion models and the multiple dimensional approaches for project appraisals. This section also presented a framework as adopted from Nijkamp et al. (1990) for the conceptual development of a sustainability model that can be used to evaluate projects. This model is based on a multiple dimensional concept that encompasses economic, environmental and social/cultural aspects in the evaluation process. Combining these criteria into a single decision tool is fundamental to decision-making and will be the focus of investigation in the next chapter. The project appraisal model, as discussed in this section, represents a systematic and holistic approach to making a decision. It uses the concept of multi-criteria analysis and this concept will be further extended in the development of a sustainability index for project appraisal in the next chapter.

4.4 CONCLUSION

This chapter summarised the aspects of environmental building assessment methods that have been used by many countries to assess environmental performance of both new and existing buildings. The environmental building assessment methods have escalated from local programs into an international agenda. The importance of environmental building assessment is well recognised as a way for promoting environmental awareness among building professionals. However, as discussed in this chapter, the usefulness of environmental performance of buildings can be extended from a checklist-type single evaluation method, to a multiple criteria framework that includes physical quantification of criteria for project appraisal.

This chapter also presented a conceptual framework for such a multiple criteria approach to project appraisal. The discussion in this chapter has laid down a platform for the development of a sustainability index, which will be discussed in detail in the next chapter. The next chapter will focus on identifying project appraisal criteria to be included in the sustainability index. Time, cost and effort do not permit the evaluation of every criterion that relates to project appraisal. It is, therefore, critical to identify those criteria that are important in project appraisal. An extensive questionnaire survey is used to identify these criteria. A mathematical model for the sustainability index will also be presented and discussed in the next chapter.

CHAPTER
FIVE

THE DEVELOPMENT OF A SUSTAINAILITY INDEX FOR PROJECT APPRAISAL

5.1 INTRODUCTION

The previous chapter reviewed the literature on environmental building assessment methods, their development, role, and limitations in promoting ecological sustainable development in construction. Following the conceptual development of a sustainability model for project appraisal in Chapter Four, this chapter sets out to identify economic and environmental criteria to be incorporated into the new model.

Study data was collected via an industry questionnaire. Its main aim was to survey professional opinions on ranking the economic and environmental criteria identified in previous chapters. The survey was sent to building professionals currently practising in construction. The procedure and results are discussed and presented in this chapter which has been divided into two main sections. The first section details the process of identifying project appraisal criteria. It includes the introduction, research design of the questionnaire survey, questionnaire structure and presentation of survey results. The second section presents the rationale for the development of a sustainability index for project appraisal. The conceptual framework, together with the mathematical model of the sustainability index, are presented and discussed.

5.2 IDENTIFYING PROJECT APPRAISAL CRITERIA

5.2.1 Introduction

Following the discussion on current environmental building assessment methods and the evaluation of their usefulness in promoting ecological sustainable development in construction, this section sets out to develop a project appraisal model which incorporates environmental values in the decision-making process. A questionnaire is used to investigate project appraisal techniques commonly used in construction and identify the most important attributes in the sustainability assessment of built projects and facilities. The collected data and the results are analysed and presented in this section. A copy of the final version of the questionnaire and a summary of the survey result are included in Appendix A and B at the end of the thesis.

5.2.2 Research methodology

A survey was used to identify the sustainable determinants to be included in the decision-making model for project appraisal. It was based on the literature review carried out in Chapters Two to Four. Economic and environmental factors were identified from the literature that merit consideration during the process of project selection. These factors were highlighted and ranked by building professionals in the survey. The outcome aided the development of a decision-making model, which will encapsulate the essential components of project appraisal and environmental matters that are part of the decision-making process. The questionnaire was carried out in two stages, an initial pilot study followed by an extensive survey amongst building professionals.

Due to time and cost constraints, the target population of the study is confined to professionals currently involved in construction in New South Wales. They include architects, engineers, quantity surveyors, contractors, building developers, planners, project managers and environmentalists. Bias is inherent in all research and is an inevitable in such a survey work (Leedy & Ormrod, 2001). There is no doubt that the survey results will be biased, particularly through the selection of the sample for the study. In order to minimise the level of bias, it was decided to use composite samples to improve precision and reliability of the data collected. A composite sample is, therefore, obtained from each respective profession for the study; the respective sample size can be found in Section 5.2.4.

Both the public and private sectors were included in the study since differences in the achievements in, and attitudes towards, ecologically sustainable construction was expected. In the public sector, professionals from the Department of Public Works and Services (now the Department of Commerce), Department of Housing and local councils were invited to participate.

The survey was mailed to each participant, together with a self-addressed, stamped envelope to improve the response rate. Non-respondents also received a reminder note. The sample of each professional sector was compiled by contacting the respective professional institutes or organisations. The required sample size in each category was selected using a random sampling method.

5.2.3 Pilot study

Based on the literature review and an initial consultation with industry representatives, a questionnaire was designed to identify consultants', developers', government agencies' and planners' views on economic and environmental impacts in developments.

Before the full survey was carried out, a pilot study was conducted to test the questionnaire. The aim of the pilot study was to highlight problems and also test the viability of the questionnaire amongst a small group of people qualified to be part of the survey. The pilot questionnaire was sent out in September 1999, to 25 people comprising five architects, contractors, quantity surveyors, project managers and engineers currently practising in the construction industry. The sample was obtained randomly from the list compiled for the major survey.

The aims of the pilot study were to:

- check the effectiveness of the research design,
- test whether the questions concerned were clear and free from ambiguities, and
- estimate the cost and duration of the main study.

Three responses were received from each group making a total of 15 completed questionnaires, representing a 60 percent response rate. The feedback from the pilot study was analysed and some comments and criticisms were incorporated, leading to substantial changes to the original draft.

The questionnaire was changed in the following ways:

- the overall layout of the questionnaire to suit the nature of the questions making it clearer and easier to follow,
- the number of questions, reducing them from 35 to 28,
- rewriting some questions that were highlighted as being unclear,
- rewriting Part Three of the questionnaire which helps to lay down the foundation for case studies in the later part of this research project, and
- including a pairwise comparison matrix to rank the economic and environmental criteria identified as being important for project selection, since the traditional ranking technique caused confusion.

The purpose of these changes was to maximise the opportunity of obtaining quality information from the survey such as understanding the scope of environmental projects that have been undertaken by building professionals.

As a result, the revised questionnaire is divided into three parts. The first part is intended to obtain information about the respondents and details of their organisations. The second part is based on 11 previously identified economic and environmental factors considered important in selecting a project for development. Respondents were requested to rate the significance of each factor on a five-point scale ranging from one to five where one represents the least important factor and five indicates the most important factor. A pairwise comparison matrix is used to rank these 11 attributes and the result from this evaluation matrix will form an important part in developing a sustainability index as a decision-making tool at a later stage.

Finally, the third part contains eight questions designed to identify the respondents' level of expertise and their training in relation to administering environmentally sensitive projects.

5.2.4 Extensive questionnaire

Following the pilot study, an extensive questionnaire was undertaken. The questionnaire was sent to 600 consultants, environmentalists, contractors, developers, project managers and planners in New South Wales by post in October 1999 in two groups to permit easy management. The first group was sent to environmentalists, building developers, project managers, contractors and planners; the second group to engineers, architects and quantity surveyors. Follow-up reminders were also sent to survey participants toward the end of November 1999, which led to the return of 152 completed questionnaires, representing a 25.33 percent response rate. This response rate is acceptable for research of this type. The aim was to obtain a general view of building professionals, therefore a small response rate is inevitable.

The samples were compiled using a random sampling method from membership lists from the following professional organisations:

- Royal Australian Institute of Architects,
- Australian Institute of Quantity Surveyors,
- Australian Institute of Builders,
- Master Builders Association,
- Australian Institute of Engineers of Australia,
- Institute of Project Managers,
- Property Council,
- Australian Property Institute,

Local councils and Department of Public Works and Services and Department of Housing were also contacted for undertaking the survey.

The sample was compiled with no considerations of the participants' work experience, age or educational background as there is no published source of this information. Table 5.1 shows the distribution of survey participants.

Table 5.1 Distribution of survey participants

Results	Arch	Cont	Eng	Env	Plan	PM	Bldg Dev	QS	Others	Total
Sent	100	100	100	20	70	50	50	100	10	600
Returned	20	18	33	16	10	18	7	27	3	152
% of total	13.16	11.84	21.71	10.53	6.58	11.84	4.61	17.76	1.97	100

Note:
Arch - Architects
Cont - Contractors
Eng - Engineers
Env - Environmentalists
Plan - Planners
PM - Project Managers
Bldg Dev - Building Developers
QS - Quantity Surveyors
Others - included Building Surveyors and Land Surveyors

The main objectives of this survey are to:

- explore and assess environmental awareness amongst building professionals currently practising in construction,
- determine the critical environmental criteria that are important in assessing building sustainability, and
- investigate the current techniques of assessing sustainability in construction.

Full details of the results are contained in Appendix B.

5.2.5 Rationale for data analysis

The choice of statistical test to use is one of the most important tasks any researcher has to address. The selected option must reflect the problem being investigated and the answers the researcher is looking for in the study. There are many statistical methods that can be used to analyse data.

The aim of this research was to examine the subject of environmental awareness and the building professionals' approach to environmental protection. The results obtained from the survey were undoubtedly based on experience and opinions of building professionals in construction. However, opinions on the controversial topics of environmental values were likely, in some respects, to be subjective. At the same time, definitive assumptions about population parameters could fundamentally flaw the research conclusions. Consequently, it was decided to use non-parametric statistics such as the Kendall coefficient of concordance W, which is distribution free, and can deal directly with scores while remaining valid, even when normality assumptions are violated (Kumaraswamy & Chan, 1998; Keller & Warrack, 2000).

5.2.6 Observation and analysis

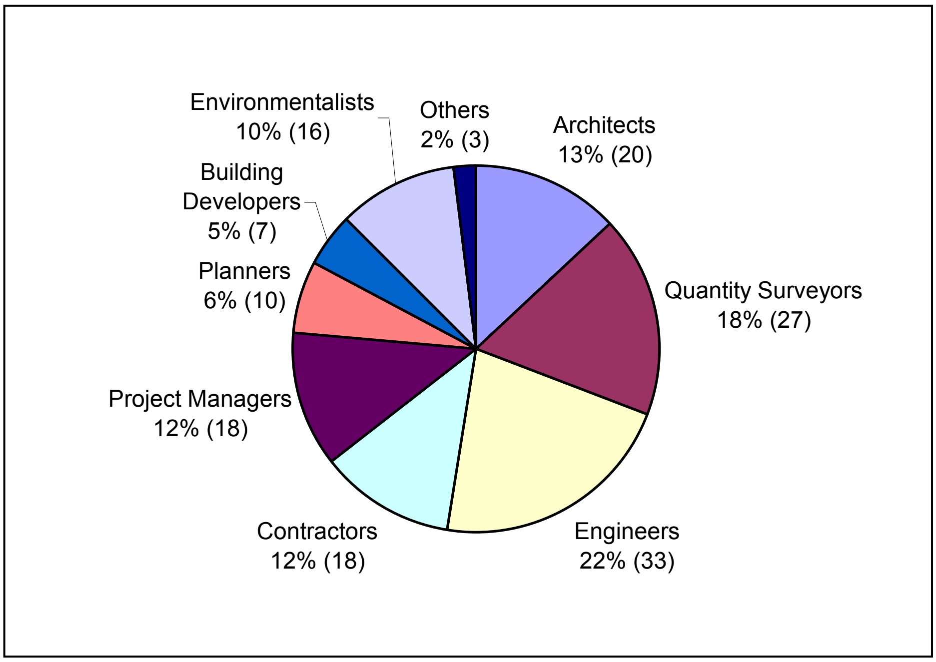
General background

Analysis of the returned questionnaires showed that 78 percent of the respondents work in the private sector whilst 22 percent work for the government. Response from the private sector predominated since more people are employed in the private sector than in the public sector. Therefore, the opinions obtained through this survey tend to be more representative of the private sector. The lack of public sector participants could be improved by undertaking personal interviews with building professionals working in the public sector.

Figure 5.1 shows the distribution of respondents by professions. The response rate of engineers, quantity surveyors and architects made up 51 percent whilst the remaining 49 percent were distributed among contractors, project managers, building developers, environmentalists, planners and others.

Gender distribution shows that 93 percent of the respondents were male. Female respondents were architects, environmentalists, planners and quantity surveyors. There were no responses from female engineers, contractors or project managers. Although female participants in this survey are seriously under-represented, this is not an astonishing result as construction has always been a male dominated field and female building professionals tend to confine themselves to architectural and quantity surveying companies. Therefore, the analysis of the survey results may predominantly represent opinions from the male building professionals but will not have a significant impact on the outcomes.

Figure 5.1 Distribution of respondents by professions (total = 152)



The majority of the participants, approximately 66 percent, were aged between 36 and 55 years (see Figure 5.2). About 80 percent of this group have more than 10 years experience in construction. A minority were aged over 55 and below 25. The survey participants, therefore, are a group of relatively young and experienced professionals in construction.

Figure 5.2 Distribution of respondents by age (total = 152)

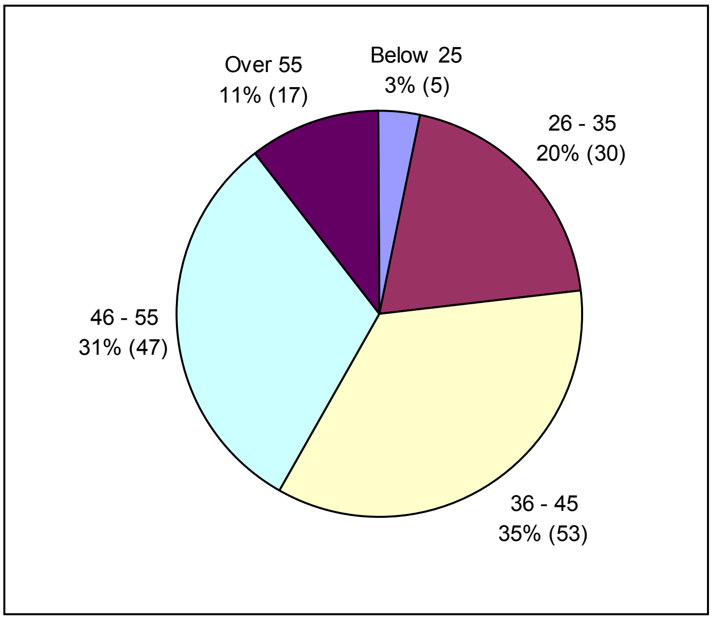
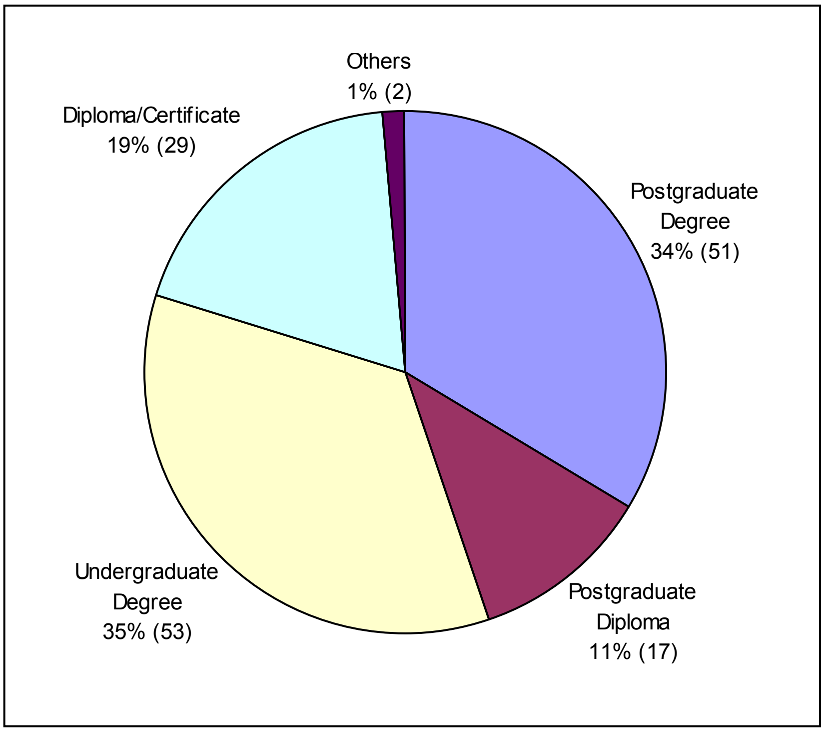


Figure 5.3 shows that 80 percent of the survey participants have completed at least undergraduate degrees and 45 percent have additional postgraduate qualifications. The survey also shows that about 45 percent of the participants have experience in environmental design or environmental assessment of projects with 25 percent having more than 6 years experience working on environmentally sensitive projects. This means that the outcomes obtained from the survey represents the opinion of a group of building professionals with a good educational background and sufficient knowledge of environmentally sensitive projects to provide a significant contribution in identifying environmental criteria to be included in the decision-making model of a sustainability index.

Figure 5.3 Distribution of respondents by education (total = 152)



Environmental awareness analysis

One of the purposes of this survey is to investigate the environmental awareness and attitudes of building professionals to the environment. Part Two of the questionnaire forms the core of this study. The majority of the participants, approximately 98 percent (149 participants), considered environmental assessment an important issue for building development while approximately 99 percent (150 participants) agree that the impact of environmental effects needs to be incorporated into the project selection process.

Most respondents (112 or 74 percent) indicated that the best stage at which to consider incorporating environmental issues is the feasibility study, followed by the design development stage. These results indicate without doubt that environmental issues are important, they should be part of the project selection process, and they have to be introduced at an early stage.

Respondents were asked to rate 14 environmental issues (Question 2.3) that relate to construction on a scale of one to five where a score of one represents the least importance and a score of five represents the most importance. The total weight for each factor is calculated and a relative importance index (RII) is constructed reflecting the level of importance of these factors using the formula (Olomolaiye et al., 1987; Bubshait & Ai-Musaid, 1992, Shash, 1993; Chinyio et al., 1998; Kumaraswamy and Chan, 1998; Tam et al., 2002):

$$\mathrm{RII_s} = \frac{\sum_{i=1}^{n} W_i}{\mathrm{AN}} \qquad (5.1)$$

where: $\mathrm{RII_s}$ = relative importance index, W = weighting as assigned by each respondent on a scale of one to five with one implying ‘least important’ and five ‘most important’, A = the highest weight (5), N = the total frequency in the sample. The relative rankings of the factors within each group are assigned on the basis of the factor $\mathrm{RII_s}$. The weighted average of the $\mathrm{RII_s}$ for each of the previously identified 14 factors from each group is computed by combining all the $\mathrm{RII_s}$. The combination of these $\mathrm{RII_s}$ to find the weighted average for each factor is achieved by summing the products of the $\mathrm{RII_s}$ for each group with the proportion of respondents from the corresponding group.

The rankings of these environmental impacts are summarised in Table 5.2. Respondents rated water, air and noise pollution as having the most impact in construction. These three issues received the highest ranking for consideration during the construction stage of a development. There is no doubt that building construction is the main polluter of air and water quality (Uher, 1999). The water run-off from building sites is one of the main pollutants of underground water and rivers, and dust generation associated with building work degrades the air quality (Uher, 1999). Building sites also generate noise during construction, which seriously affects people living in the vicinity. More effort needs to be undertaken to minimise these effects.

Table 5.2 Summary of relative importance ranking of environmental impacts in construction

	Relative importance index (RII)	**Weighted**	

Environmental impacts	Arch	Cont	Eng	Env	Plan	PM	Bldg Dev	QS	Others	average RII (%)	
Water pollution	0.95	0.92	0.88	0.94	0.84	0.88	0.94	0.91	0.93	90.7	1
Air pollution	0.91	0.90	0.86	0.86	0.82	0.84	0.86	0.90	0.87	87.4	2
Noise pollution	0.83	0.88	0.84	0.84	0.86	0.77	0.80	0.83	0.93	83.5	3
Depletion of non-renewable resources	0.88	0.82	0.75	0.84	0.72	0.78	0.91	0.84	0.93	81.3	4
Deforestation	0.87	0.74	0.76	0.79	0.72	0.74	0.77	0.83	0.80	78.4	5
Ozone depletion	0.87	0.79	0.74	0.73	0.68	0.78	0.83	0.81	0.87	78.2	6
Destruction of historic buildings	0.78	0.77	0.80	0.80	0.72	0.73	0.80	0.75	0.93	77.4	7
Global warming	0.84	0.77	0.73	0.78	0.72	0.74	0.74	0.77	0.80	76.4	8
Population growth	0.81	0.69	0.65	0.71	0.80	0.77	0.77	0.76	0.93	73.7	9
Acid rain	0.87	0.71	0.70	0.68	0.64	0.74	0.80	0.76	0.60	73.6	10
Salination	0.82	0.62	0.73	0.74	0.70	0.73	0.77	0.76	0.73	73.5	11
Depletion of renewable resources	0.70	0.71	0.65	0.74	0.70	0.70	0.71	0.75	0.80	70.6	12
Biodiversity	0.75	0.67	0.63	0.89	0.76	0.66	0.54	0.70	0.60	69.8	13
Desertification	0.77	0.50	0.66	0.63	0.64	0.60	0.63	0.71	0.60	65.0	14

Note:

1. RII for each profession is calculated as total score divided by the total number in the sample multiplied by the highest weight (5). For example the RII of water pollution for architect was calculated as 95/(20 x 5) = 0.95. Survey details refer to Appendix B.
2. The weighted average RII was calculated as:
   0.95 x 20/152 + 0.92 x 18/152 + 0.88 x 33/152 + 0.94 x 16/152 + 0.84 x 10/152 + 0.88 x 18/152 + 0.94 x 7/152 + 0.91 x 27/152 + 0.93 x 3/152 = 0.907

As also indicated in the study, other areas such as depletion of renewable and non-renewable resources, deforestation and ozone depletion are also considered significant impacts in construction. Special attention is also required to minimise such effects in project development.

Project appraisal selection criteria

With regard to project development, survey respondents agreed that environmental factors should be considered during the decision-making process. Incorporating these factors may take place at the feasibility study stage. Current environmental building assessment methods (refer to Chapter Four, Section 4.2) are more suitable for use at the design stage to provide guidelines or boundaries, but may not be of practical assistance in the selecting the best option among the available alternatives (Crawley & Aho, 1999; Cole, 1999a).

Developing a sustainability index as a decision-making model for project appraisal is at the heart of this research. It is intended to fill the gap left by current environmental building assessment methods. The usefulness of such a model relies heavily on identifying and incorporating essential and sufficient criteria to encapsulate the principal objective of a project, while simultaneously satisfying sustainability goals.

Deciding which types of criteria to include is a significant step before a model can be developed. From the literature reviews, 11 economic and environmental criteria were identified as being important when selecting a project for development (see Chapters Two to Four):

- aesthetics/visual impact—project image,
- energy consumption/conservation—embodied and operational energy.
- environmental impact—negative externalities e.g. pollution,
- functional layout—planning efficiency and flexibility,
- heritage preservation—preservation of existing requirements,
- maintenance/durability—low ongoing maintenance requirements,
- overall financial return—return on investments,
- project life span—projects that are long lasting,
- recycling/refurbishment potential—reuse of building materials,
- social benefits—positive externalities e.g. entertainment, tourism, and
- user productivity gains—efficiency of project users.

Assessing these criteria is an enormous task making the model too complex to be useful in project appraisal. Also, as stated in van Pelt (1993b), the number of criteria should be limited as research has shown that people can only assess a small number of criteria when making meaningful decisions. In addition given that developments are time-critical, if too many criteria are to be assessed before a decision to go ahead with a development, its profitability may be seriously jeopardised (Bennett, 2003). Therefore, expert opinion is required in the survey and is used to rank these 11 criteria and only the top few will be incorporated into the model of the sustainability index.

A pairwise comparison matrix is used to rank these criteria where each criterion is compared with all the other criteria in order to denote whether they are equally significant, or whether one of them is somewhat more significant than the other (see Question 2.6 of the survey).

Each criterion is assigned a letter starting from ‘a’ through to ‘k’ and respondents are asked to compare two criteria at a time then place the letter of the more important criterion in the corresponding cell, or both letters for equal importance. A point system is used to arrive at the total score to reflect the final ranking. The more important of the two compared criteria is allotted one point, and if the criteria are considered to be of equal ranking, then a half point is allotted to each. The total score of each criterion was computed for each participant. This was then repeated by combining the total scores for all the participants for each building professional. The criterion with the highest total score will be in the top ranking position. The final ranking of environmental criteria by profession is shown in Table 5.3.

The Kendall coefficient of concordance *W* is used to consider the relationship amongst the rankings expressed by building professionals in the survey. The coefficient of concordance *W* is an index of the divergence of actual agreement shown in the data from the maximum possible or perfect agreement (Kendall, 1970; Siegel & Castellan, 1988).

Table 5.3 Ranking of economic and environmental criteria by professions

Hypothesised environments criteria	**Arch**	**Cont**	**Eng**	**Env**	**Plan**	**PM**	**Bldg Dev**	**QS**	**Others**	$\mathbf{R}_i$	$\overline{\mathbf{R}}_i$
Aesthetics/ visual impact	5	7	11	9	6	11	2	7	6	64	7.11
Energy consumption/ conservation	8	3	7	8	7	9	3	4	4	53	5.89
Environmental impact	6	2	2	1	1	2	5	2	2	23	2.56
Functional layout	3	6	3	7	4	4	4	3	7	41	4.56
Heritage preservation	2	8	4	3	3	5	6	11	8	50	5.56
Maintenance/durability	11	4	6	5	9	3	7	10	9	64	7.11
Overall financial return	1	1	1	4	2	1	1	1	1	13	1.44
Project life span	7	5	10	10	8	7	10	6	10	73	8.11
Recycling/ refurbishment potential	10	9	8	6	10	10	11	8	3	75	8.33
Social benefits	4	10	5	2	5	6	8	9	5	54	6.00
User productivity gains	9	11	9	11	11	8	9	5	11	84	9.33
W = 0.5304											

In Table 5.3, the sums of the rank for each profession is denoted by R_i and R_i, represents the average rank of environmental criteria. If all the participants had been in perfect agreement about the ranking of the economic and environmental criteria, then the criterion would have received a scale of 1 from each professional group and R_i would equal to 9.

The Kendall coefficient of concordance *W* is computed by the following formula:

$$W = \frac{\sum_{i=1}^{N} (\overline{R}_i - \overline{R})^2}{N(N^2 - 1)/12} \qquad (5.2)$$

where $\overline{R}_i$ = average assigned to the *i*th object, $\overline{R}$ = the average of the ranks assigned across all objects, and N = the number of objects being ranked. After calculation *W*, which must be between 0 and +1, = 0.5304, indicating some consensus among the respondents and that they are applying essentially the same standard in ranking the eleven factors under study. The *W* was tested at a 5 percent level of significance. The result with χ^2 ($\chi^2 \geq 806.21$) equals, or exceeds, the critical value from the chi-square distribution and with 10 degrees of freedom, it is concluded that there is a high probability of agreement among respondents in their rankings of the criteria for project appraisal.

The final ranking (Table 5.4), of these economic and environmental criteria is in accordance with the order of the various sums of ranks (i.e. $\overline{R}_i$) as suggested by Kendall (1970).

Table 5.4 Final ranking of economic and environmental criteria

Appraisal criteria	Final ranking
Overall financial return	1
Environmental impact	2
Function layout	3
Heritage preservation	4
Energy consumption/conservation	5
Social benefits	6
Aesthetics/visual impact	7
Maintenance/durability	8
Project life span	9
Recycling/refurbishment potential	10
User productivity gains	11

Given the earlier calculations and the resulting final ranking, the building professionals are in some degree of agreement about the importance of these economic and environmental factors in project appraisal. The financial return is in the top position indicating that financial gain is the principal aim for a development. This is followed by environmental impact, then functional layout, heritage preservation, energy consumption and social benefits. These areas emphasise the environmental aspects of a project and are also the performance-based criteria of a development. These are the areas that can be incorporated into the model of the sustainability index. Detailed discussion of these criteria is included in Section 5.3 of this chapter.

Part Two of the survey also included a question to explore the techniques that building professionals use when selecting projects for development (see Question 2.9). Table 5.5 records the results when participants were asked to state how often they use the techniques from the list.

Table 5.5 Project selection techniques used by building professionals

Project selection techniques	R_i	$\bar{R}_i$	Ranking
Simple payback or accounting rate of return	39.0	4.88	5
Discounted cash flow method (including CBA)	31.5	3.94	4
Feasibility studies (non-discounted)	20.0	2.50	1
Multiple criteria analysis (MCA)	51.0	6.38	7
Risk analysis	20.0	2.50	1
Energy analysis	41.5	5.19	6
Environmental impact assessment (EIA)	21.0	2.63	3
$W = 0.5084$			

The results indicate that building professionals most frequently use feasibility studies and risk analysis as a decision-making tool, followed by environmental impact assessment. Feasibility studies and risk analysis are techniques that have been widely used in project selection for a long time and they are largely used to examine profitability as an aid for decision-making (Powell, 1996; Postle, 1998; Burke, 1999). However, feasibility studies and risk analysis are not so useful when attempting to evaluate environmental goods and services (Kohler, 2002). Only environmental impact assessment (EIS) has any capacity to assess environmental issues and the results are, as a consequence, included as part of the decision-making process. However, EIS may be mandatory to get planning approval but not a matter of choice.

The survey responses show that there are only a few participants who have heard about multiple criteria analysis (MCA), as this method is mainly used for urban planning, infrastructure and environmental assessments but is seldom used to help decision-making in construction (Voogd, 1983; Nijkamp et al., 1990; Janssen, 1992). Most project appraisal techniques focus on a single criterion, such as financial return or energy usage, but MCA allows multiple criteria to be considered and combined to aid decision-making. This powerful method is widely used in other areas for decision-making e.g. environmental management and urban planning (Voogd, 1983; Nijkamp et al., 1990; van Pelt, 1993b; Triantaphyllou, 2000). This approach provides the methodological framework for the development of the sustainability index.

5.2.7 Summary

Most survey respondents were aware of the environmental problems caused by construction and accept that the sector needs to take remedial action against further destruction of the natural environment. Project developers and owners also realise that their development should be less detrimental to the environment and ecosystems (there is no doubt that their decisions may be caused by the compulsory requirements of planning or market pitch). Many building professionals, such as architects and engineers, have already incorporated green strategies such as energy efficiency and recycling into the scope of their design work. Others, such as contractors and project managers, are involved in collecting recycling building materials on site (Ofori, 1992; Spence & Mulligan, 1995; Lawson, 1996b; Bourdeau, 1999; Uher, 1999).

Based on the discussion in this chapter, there is no doubt that some building professionals are working together to protect the natural environment and their contributions have been obvious in construction (Cole, 1999a; Uher, 1999). Nevertheless, to only consider environmental issues during the design and construction stages is inadequate. Environmental issues need to be considered as early as possible during the feasibility study where development options are selected. In order to protect the environment, it is necessary for environmental matters to be included as part of the decision-making process. However, current project selection techniques tend to focus on a single criterion, that is profitability. But it is clear that decision-making models need to embrace sustainability as well as profitability (Nijkamp et al., 1990; van Pelt, 1993b).

Survey respondents identified and ranked economic and environmental criteria according to their importance in project selection. The findings in the study will provide a foundation and a decision-making model will be developed as the main purpose of the research to incorporate environmental issues.

5.3 DEVELOPING A SUSTAINABILITY INDEX FOR PROJECT APPRAISAL

5.3.1 Introduction

As discussed in the previous chapters, in order to protect the environment, sustainable development is essential for project development. The principal determinants in project appraisal of sustainable development have been identified using a questionnaire to elicit the opinions of professionals in construction (details refer to Section 5.2).

With reference to the survey analysis (see Section 5.2.6), the participants' opinions are significant as they represent the views of a group of practising professionals with academic qualifications in building development, practical experience in construction work, and specialist knowledge in designing and constructing environmental projects. The survey results indicated that 45 percent of the participants have experience in the environmental design or assessment of projects and about a quarter have over six years work experience in constructing environmentally sensitive projects. Therefore, their opinions have provided a broad spectrum of knowledge, experience and expertise in terms of economic, social and environmental issues and will be valuable in developing a multiple criteria decision-making model for project appraisal. This will challenge the predominantly conventional economic view currently used in project appraisal.

The opinions obtained from the questionnaire allow the criteria requiring consideration in the sustainability index to be ranked. This section examines, in detail, the criteria to be incorporated in developing the sustainability index as a decision-making tool for project appraisal. The assessment approach and the benefits of using an index system in project appraisal will also be discussed. Finally, the conceptual framework of the sustainability index is presented and discussed. The framework of the sustainability index developed in this chapter lays down the foundation work for the data collection in Chapter Six.

5.3.2 The derivation of project appraisal criteria

Following the results of the survey in Section 5.2, the 11 criteria identified as being important components of project appraisal are analysed and ranked according to building professionals' opinions as shown in Section 5.2.6. The ranking process showed that financial return, environmental impact and energy consumption are in the top positions and are, therefore, the key areas to be assessed in the model.

The remaining criteria are also important and deserve consideration in appraising projects, but it will be inappropriate and too complex to assess all the criteria in the decision-making model. Therefore, these criteria are integrated and evaluated as sub-criteria of a criterion termed 'external benefits'. Accordingly, external benefits consist of both performance-based criteria and intangibles. The performance-based criteria include functional layout, heritage preservation, maintenance/durability, project lifespan, recycling potential, and productivity. The intangibles include aesthetic impact and social benefits.

Consequently, the sustainability index includes the following criteria:
- financial return,
- energy consumption,
- external benefits, and
- environmental impact.

These four criteria reflect the key criteria as judged by the survey participants and are brought together in developing an index system to aid decision-making. The four criteria in the derived sustainability index are measured by different methodologies and in different units that are best suited to their quantitative assessment. Since these criteria are derived from the survey through expert opinion, they symbolise the sustainable determinants that promote joint economic and environmental consideration of a development. Consideration of these four criteria in project appraisal will ensure ecologically sustainable development in construction that emphasises the using environmentally friendly building materials, sustainable construction methods and efficient allocation of resources including the construction site to protect the environment and encourage economic development in a community.

5.3.3 Rationale of project appraisal criteria

Since the essential components of project appraisal have been identified, it is important to ensure that the decision-making model is not confined to evaluating a project's cost implications and environmental impact, but is used to aid decision-making in selecting the best option from the alternatives. This section is devoted to discussing the nature and boundary of these criteria in order to establish the methodological framework for their assessment and the sustainability index.

Financial return

It is necessary to determine whether a particular course of action is of net cost or net benefit to society. The most popular technique used to ascertain this is cost benefit analysis (CBA) (Tisdell, 1993; Perkins, 1994). It is a powerful tool which assists decision-makers in project selection, taking into account the efficient allocation of resources, maximising return and maintaining sufficient protection of the environment. The ultimate aim is to maintain economic development without giving up further environmental quality. However it is not without its problems or critics (van Pelt, 1993b).

Efficient allocation of scarce resources involves choosing between alternative projects; such choice requires evaluating the options. The evaluation process is so pervasive in economics that project appraisal has become synonymous with cost benefit analysis (van Pelt, 1993b). Gilpin (1995, p.169) defines CBA as "the identification and evaluation of all costs and all benefits attributable to a policy, plan, program, or project". Faced with conflicting objectives and limited resources, it is essential that governments have a basic mechanism for determining whether a given use of resources will maximise community welfare, and where alternatives compete for resource allocation, which alternative will provide the greatest improvement. For private developments, financial return is the important criterion, however the decision support techniques are similar. The option with the highest net benefit will normally be selected, whereas other options will be lower ranked, and those showing negative benefit will be abandoned altogether.

Costs and benefits (excluding externalities) are quantified in monetary terms wherever possible and are discounted to determine net present value (NPV). The accuracy of their quantification depends on the significance of the project, data availability, cost of obtaining missing data and the clarity of project objectives. At this stage, all calculations are performed with varying levels of uncertainty. Therefore, it may be possible to attach probabilities to impact, understand uncertain events and to calculate an expected value (Hanley & Spash, 1993; Abelson, 1996).

Project costs comprise the total opportunity costs of resources consumed by a project over its expected life. Life of a construction project can easily extend for many years making most of the forecasting or estimations uncertain. The literature gives some idea about the optimal length of a building's life, and the economic life is often calculated by maximising the capital value (Wübbenhorst, 1986). However, correctly identifying a building's economic life is critical to calculating life cost.

Apart from direct costs that may occur for a development, indirect costs, such as theoretical environmental damage, may also be generated. Indirect costs comprise the evaluation of environmental damage which includes the negative impact of a project during its construction and over its operational life, such as air/noise pollution, stormwater runoff, deforestation and the like. These costs will not be included in measuring project cost in the sustainability index. They are subjective issues and will be dealt with using a multiple criteria approach as a separate criterion in the sustainability index named environmental impact (see later part of this section).

Project benefits comprise the total benefits related to the positive impacts associated with project implementation. Direct benefits may be revenue produced from the project (as distinct from income earned by selling goods and/or services produced by the project), or in the form of periodic revenue received by leasing the property to a tenant. The indirect benefits generated by project implementation such as increased productivity, employment opportunities, better living environment, improved leisure facilities or better traffic arrangements, will be treated in the same manner as indirect cost and included as a separate criterion in the sustainability index named external benefits.

Measuring indirect costs and benefits in monetary terms is rarely complete, and so may be undervalued in the final decision or completely ignored (Nijkamp et al., 1990; Tisdell, 1993; van Pelt, 1993b). The complex nature of the environment and the non-market characteristics of environmental goods and services are the major hindrance in this respect. As highlighted in the survey, the unpriced impacts (or intangibles) are still an important component of the final decision, and should be included separately so that they are part of the decision framework.

Quantifying project costs and benefits may be relevant to private developments as a decision to proceed with a project depends on project benefits outweighing the project costs. However, this may not be applied to public projects. The decision to proceed with public projects does not depend on project benefits outweighing the project costs, but fundamentally on the needs of the general public.

The data needed to make the necessary forecasts of project costs and benefits often involves uncertainty or is incomplete, because some elements are difficult to predict or suitable data may be unavailable at certain stages. Even though the data may be available or uncertainty reduced using historical data and statistical methods, the uncertainty still exists of how to project those figures into the future (Woodward, 1997). Technological advances can exacerbated these uncertainties and they may change a building's economic life. Future prices are also difficult to predict and can affect potential alteration and maintenance costs. The uncertainty may also be caused by the errors in estimates such as the price rates, the frequency of the maintenance factor, variation of the asset's utilisation or operation time, and variation of corrective maintenance hours per operating hour (Woodward, 1997).

The sensitivity of particular key variables affects the relative desirability of the alternatives. The outcome may change the accept or reject decision, or the ranking of alternatives. For instance, it is difficult to forecast when major repairs will be required for building projects. Therefore, the existence of this uncertainty often jeopardises the reliability of an outcome.

Sensitivity analysis is often used to test the robustness of results with different scenarios. It helps to analyse the economic structure of a project in such a way as to identify those variables that have more or less influence upon economic desirability. This sort of test gauges the effect of changes in assumptions on the ranking and comparison of alternatives. It helps to derive a range of values within which an alternative is economically desirable and the certainty levels that can be expected, and requires considerable judgement and experience. Key variables typically include discount rate, project life span, physical quantities and quality of inputs and outputs, and investment and operation costs (OECD, 1994). Initially, alternatives are ranked on the basis of the original NPV. If the recalculated NPV does not alter the accept or reject decision, or the ranking of alternatives, then the original alternative is insensitive to the changes and therefore has a low risk level. On the other hand, if project viability or the ranking of alternatives is affected, then the risk attached to the project selection is much higher.

There are more sophisticated methods of risk analysis that can be applied to NPV calculations, but the ultimate purpose is to assess the likelihood of choosing a project that might have problems. High returns are often associated with risky projects, but this situation is often accepted by risk-seeking investors. In the case of social projects however, governments are often risk-neutral or risk-averse and so would be looking for projects that reflect stability and a reasonable level of confidence that they are in the public interest.

Energy consumption

As discussed in Chapter Three, Section 3.3, energy consumption has a significant impact on the built environment. Energy is the challenge in the search for sustainable development because of the complex relationship between energy usage and environmental degradation (Cole, 1998b). Energy is used in the form of fuel to support all the activities and processes associated with building and construction creating a wide range of quantifiable environmental effects including depletion of energy resources and greenhouse gas emissions. However, in project appraisals total energy consumption does not currently form part of the decision-making process and particularly not the energy embodied in the building materials and components (Treloar et al., 1999; Tiwari, 2001).

The 1970s oil embargo brought energy to the economic centre stage, and many environmental analysts and researchers have treated energy use as an important indicator of environmental impact (Baird et al., 1994; Brown & Herendeen, 1996). In the 1990s, the greenhouse implication of fossil fuel burning has again promoted energy's use as an environmental indicator, particularly in the context of global warming, ozone depletion, and local and regional pollution (Cole & Rousseau, 1992; Brown & Herendeen, 1996).

A variety of climatic conditions and system efficiency make the relationship between energy use and a building system extremely complex and creates a problem estimating building energy. Considerable attention has been focused on the problem of predicting energy use in buildings (Baird et al., 1984; Howard & Roberts, 1995; Lawson, 1996b; Adalberth, 1997a; Hui, 2001). In a building, various types of energy are used to operate its engineering services such as heating, ventilation and air-conditioning, lighting, vertical transportation and hot water supply. The purpose is to maintain a suitable indoor built environment in order to sustain activities that may be carried out in a building. However, even though energy is closely linked to the economic activities of a building, its price rarely reflects the environmental costs associated with its use (Pullen, 1999).

Total energy consumption requires a comprehensive energy analysis to cover the full spectrum of energy consumption throughout the building's economic lifespan (Cole & Kernan, 1996; Adalberth, 1997a; Fay & Treloar, 1998). As discussed in Chapter Three, Section 3.3, a comprehensive energy analysis involves a life cycle approach of energy use, which includes all the energy inputs from the start of a project through to its final demolition. Indeed, energy consumption may start with the energy initially required to extract materials from the ground through to the end of the building's life (Adalberth, 1997a). In the sustainability index the lower total energy consumption the better.

Of the various energy inputs, the operational energy is often the most significant and is traditionally measured as one of the financial costs of running a facility (Howard & Roberts, 1995; Pullen, 1999; Stern, 1999). However, research has revealed that the energy consumed in the extraction, manufacture and supply of the materials and components of the building can also be significant (details refer to Chapter Three, Section 3.3). When full life cycle energy analysis is undertaken, embodied energy may also be extended to include the energy associated with maintaining, repairing and replacing materials and components over the lifetime of a building (Treloar, 1994; Pullen & Perkins, 1995).

In order to calculate the total energy of a building, embodied energy and operational energy need to be dealt with separately. The operational energy is obtained via two approaches. The first approach is based on a computer package, which simulates a real building to estimate the energy use during its operational stage. A large variety of software packages are available that can be used in different situations (Fay & Treloar, 1998; Department of the Environment and Heritage, 2001; Matthews & Treloar, 2001). The second approach involves the collecting energy records for the building (Cole & Kernan, 1996; Fay & Treloar, 1998; Pullen, 2000b). Energy records can be obtained through the energy bills received quarterly and can also be categorised by engineering services system using sub-meter readings. Records may be required over a period of time in order to derive average energy consumption and to detect any variants due to seasonal and climatic conditions.

Calculating embodied energy is considerably more involved as the type and quantities of materials for the entire building are required. The embodied energy calculation can be carried out in two stages. The first stage is to calculate initial embodied energy, which includes all the energy incurred in extracting raw materials through to the final completion of the building on site.

Calculating initial embodied energy involves using a measured bill of quantities, which breaks down the building into different parts, or trades. However, a copy of the bill of quantities may not be sufficient as some of these items are measured in bulk quantities. It is necessary to break down these items into basic materials, so that embodied energy intensity may be applied. In the future, the bill of quantities may be modified in such a way as to accommodate the calculation of embodied energy. The process of embodied energy calculation may be expressed a just data input. However, a bill of quantities of such a format may be too time-consuming and too complicated to prepare.

Once the quantities of the materials have been derived, the initial embodied energy is estimated by applying energy intensity coefficients multiplied by each type of material. An energy intensity coefficient is the energy used to produce a building material or component. It represents the indirect energy in unit items either expressed as energy/mass (MJ/kg) or volume (MJ/m^3) or energy/standard unit (MJ/sheet or block), etc. Research on the energy intensity of building materials has produced reasonable agreement on acceptable values for some of the materials (Cole & Rousseau, 1992). The total initial embodied energy is obtained by totalling the embodied energy associated with individual elements of the building.

The second stage of the embodied energy calculation is estimating embodied energy consumption during the post-occupancy period of a building. The recurrent embodied energy covers the energy used for routine maintenance, scheduled repair and renovation, and replacing materials or components over the effective life of the building. This stage involves estimating the building’s life span and the replacement rates of materials or components. Recurrent embodied energy intensity will probably be reduced if manufacturing technologies for materials are improved.

Building construction is a great consumer of energy and project development is considered a major contributor to the depletion of fossil fuels, speeding climate change and the depletion of the ozone layer (Spence & Mulligan, 1995; Uher, 1999). Identifying total energy consumption of projects can help decision-makers to choose amongst alternatives in an environmental context. Projects with high total energy consumption may be ignored or redesigned to reduce non-renewable fossil fuel consumption and overcome other related environmental problems.

Energy consumption, as similar to financial return, will be affected by time. However, the literature offers no guidance on discounting of total energy consumption of buildings. The requirement of discounting would be more important for the operational energy of a building (energy used during its life span) than the embodied energy (that used during the construction and manufacturing processes). In addition, discounted energy consumption yields highly uncertain results as it relies heavily on the expectations of improved technology, fuel types, building life span and new construction methods. In addition, it is estimated that the community's current energy consumption will remain constant and there is no reason to suggest that its value will increase. Therefore, the assumptions of discounting of energy become less crucial.

External benefits and environmental impact

With reference to the literature review, a decision-making framework is critical to the success or failure of a project. In construction, making a decision on a project often focuses on whether it will generate a return on investment. However, there is a growing concern that there is too much emphasis on the investment return making these decisions (Abelson, 1996; Joubert et al., 1997; Prato, 1999). A decision based on such an approach may seriously harm the environment even though the investment may make a return. Thus environmental issues may have a place in the decision-making framework in project development.

As discussed earlier, the reason for environmental issues not being considered in the decision-making process is that they are public goods and services that cannot be traded in the market (Tisdell, 1993). Therefore, placing a monetary value on environmental issues hinders project appraisal, as the current methodology is insufficient to monetarise these effects (Nijkamp et al., 1990; Hanley, 1992; Joubert et al., 1997). The relative absence of adequate models for environmental systems in the market means that no probabilities are available in relation to uncertain information. The differences in measurement scales and certainty of the effects pose difficulties in comparing effects that may easily result in excluding uncertain or qualitative information from the decision.

In Section 5.2, it was demonstrated that the construction industry professionals surveyed considered external benefits and environmental impact important criteria to be incorporated into the decision-making framework. However, external benefits and environmental impact cannot be adequately priced using a traditional market approach. External benefits refer to the positive contribution of a project towards the natural and man-made environment and consists of both performance-based criteria and intangibles. They encompass issues which are largely subjective and community-centred. In essence, they deal with value enhancement as measured by non-monetary indicators such as efficiency, productivity, image and social welfare. These non-market goods may be valued beyond an economic framework and a weighted criteria approach may be used to assess social issues across alternatives (Nijkamp et al., 1990; van Pelt, 1993b; RICS, 2001). High scores of external benefits in the evaluation process indicate that a project contributes significantly in the sustainability index.

Environmental impact focuses on the judgement of long-term impact on the environment. Often, during the project evaluation stage, the information available to make the necessary forecasts of project costs and benefits involves uncertainty and is incomplete because some elements are difficult to predict at the outset. In addition, the complexity of both ecosystems and projects often extends well into the future, enhancing the degree of uncertainty. In the sustainability index the lower the level of impact the better.

Due to limited knowledge and the complexity of environmental systems, non-monetary evaluation techniques will be used to evaluate external benefits and environmental impact. Non-monetary evaluation techniques originated in operational research and developed in response to criticism of monetary methods (Nijkamp et al., 1990; Janssen, 1992; van Pelt, 1993b). Since the 1970s, a collection of evaluation techniques has been developed under the area of multi-criteria analysis (Voogd, 1983; Nijkamp et al., 1990; Janssen, 1992; Hobbs & Meier, 2000). These techniques aim to provide a method to systematically evaluate different options for a project involving a series of criteria. Multi-criteria analysis provides a powerful framework for evaluating environmental effects (Abelson, 1996; Joubert et al., 1997; Munda et al., 1998).

In a project, decision-making processes using multi-criteria evaluation methods can yield some extra insights into the ranking of a series of criteria such as resource allocation, environmental consideration in addition to the financial aspect (Nijkamp et al., 1990; Roy, 1996).

A non-monetary evaluation technique can generate different outcomes. It may result in a complete ranking of alternatives (i.e. A>B>C>D) or the best alternative (i.e. A>B, C, D), may be defined from a series of alternatives. The evaluation may also generate a set of acceptable alternatives (i.e. A, B, C>D), or may end up with an incomplete ranking of alternatives (i.e. A>B, C, D or A, B>C, D) (Janssen, 1992). No matter what results are generated, the multi-criteria decision-making framework provides a broad and flexible methodology for evaluating environmental effects.

Evaluating external benefits and environmental impact will follow a multi-criteria approach, which is not a simple linear process but rather exhibits a cyclic nature. Each stage can yield additional information and form part of the feedback loop to provide a more precise consideration for the forthcoming stage or stages (Nijkamp et al., 1990; Janssen, 1992; Bentivegna et al., 2002; Ding, 2002b). Once the development alternatives are compiled, the sub-criteria of external benefits and environmental impact are defined. The sub-criteria have a measurable quantity whose value reflects the degree to which a particular objective is achieved. These sub-criteria will reflect the degree of external benefits and the level of impact associated with a development.

The type of criteria will vary in accordance with the type of construction. Some construction may have more detrimental effects on the environment than others. The list of sub-criteria for external benefits and environmental impact is generated through a brainstorming workshop. Participants include members from the design team, representatives of the developer and environmentalists, in consultation with the local council and the general public. The list of criteria must be precise and sufficiently comprehensive to cover the full spectrum of environmental effects should the project go ahead and adequately indicate the degree to which the objective of the development is met.

Detailed analysis of each sub-criterion is an important step in determining its score in relation to its impact on a development. The analysis involves expressing impacts in numeric terms. Each sub-criterion is scored to reflect its relative importance against all the others. A criteria score may be determined by the personnel directly associated with the project development. The representative from the local council and participation by the general public may also be included in this process. Public participation is important as the environmental effects of a development concern them more than they concern the developer. Incorporating the public's opinions into the decision-making process will ensure that a development will not have detrimental effects on their well-being (Seabrooke et al., 1997, Price, 2000).

Weights are assigned to each sub-criterion of external benefits and environmental impact to reflect its relative priority. Details of how weightings are developed can be found in Section 4.3.3 of Chapter Four. An appraisal score is calculated for each sub-criterion by first multiplying each value by its appropriate weighting, followed by summing the weighted scores for all sub-criteria and for all alternatives.

5.3.4 <u>The conceptual framework of the sustainability index</u>

Background

The economic approach to decision-making has dominated project development in the construction industry. In many cases, little or no allowance was made for current or future associated externalities (Powell, 1996). Socially, the overall objective of a project may be the development at the least cost to the developer with due regard to environmental protection and minimal use of natural resources. It may no longer be acceptable to make decisions about a project by only considering financial costs and benefits. A range of social and environmental effects must also be considered and encompassed within the appraisal process.

It may be difficult, or even impossible, to improve social welfare in a society if the natural environment continues to be abused and depleted. Indeed, within the economic evaluation framework, environmental assets are ignored or under-estimated as there are often considerable difficulties in measuring all relevant impacts of a project in money units (Abelson, 1996).

Furthermore, since the media and general public constantly focus on ecologically sustainable development, intangibles and externalities have become major issues in project developments (Joubert et al., 1997; Bentivegna et al., 2002). There is concern about the potential impact of a project on the man-made and natural environments. The externalities, risks and spill-overs generated by project development preclude a meaningful and adequate use of market approach methodology (Krotscheck & Narodoslawsky, 1996). When the analysis turns to such effects as environmental quality, or loss of biodiversity due to development, it is rarely possible to find a single variable whose direct measurement will provide a valid indicator (Mitchell et al., 1995). Although many efforts have been undertaken to arrive at values for intangibles and externalities it is, in practice, almost impossible to place anything more sophisticated than subjective numerical values on such effects. The requirement for incorporating environmental issues into project appraisal process becomes wider and wider; the imputation of market prices more and more questionable.

Alternatives have been researched and suggested to completely replace the traditional market approach with techniques that not only identify environmental effects, they do not require valuation since they are difficult, or even impossible to assess (see Chapter Two, Section 2.4). Cost effectiveness analysis (CEA) and environmental impact assessment (EIA), are leading in this respect (Abelson, 1996; Postle, 1998). Other researchers have suggested supplementing CBA with a technique to measure environmental costs in other than monetary terms (Nijkamp et al., 1990; Hanley, 1992; van Pelt, 1993b; Abelson, 1996). Multiple criteria analysis (MCA) is also a widely accepted tool to aid decision-making for environmentally sensitive projects (van Pelt, 1993b & 1994). Projects are better assessed by non-monetary techniques, which means we can contemplate environmental costs in a more relevant manner. However, from the methodological and practical perspectives, the debate on conventional versus modern evaluation analysis has settled on CBA and MCA as complementary, rather than competitive, tools (Watson 1981; Jones, 1989; Nijkamp et al., 1990; Gregory et al., 1993; van Pelt, 1993b; Powell, 1996; Joubert et al., 1997; Mirasgedis & Diakoulaki, 1997; RICS, 2001).

The model of a sustainability index for project appraisal

Any alternative methods to a market-based approach are still problematic and do not fully consider environmental effects (Curwell et al., 1999). It is necessary to consider different components of a project and their long-term impact on the environment and the people in the community. Simply using a non-monetary approach to replace or to complement the monetary approach in project appraisals is inadequate. A new approach is required to incorporate the strengths of both market-based and non-monetary approaches that embrace the key elements of sustainable development in order to choose the best option from competing alternatives (Munda et al., 1998).

A number of different approaches have been developed to measure sustainability. Developing indicators has becomes one of the instruments to consider environmental effects and to move toward more sustainable practices (Mitchell et al., 1995; Sands & Podmore, 2000; Dale & Beyeler, 2001). It became an emerging research area in project appraisal because developers prefer minimum information to tell a complex technical story to a non-technical audience (Bell & Morse, 1999). The obvious use and success of economic indicators has led to a call for environmental and sustainability indicators.

The Organisation for Economic Co-operation and Development (OECD 1994) proposed the following important environmental indicators for:

- climate change,
- ozone layer depletion,
- acidification,
- toxic contamination,
- urban environmental quality, and
- biodiversity.

These sustainable indicators help to protect the environment and provide direction for future development. As Meadows (1990) states a set of sustainable indicators give the decision-makers signals to identify whether the development is sustainable and whether the environment is better or worse should the project go ahead. However, using sustainable indicators may run into difficulty in deciding as to what and how to measure them. Krotscheck and Narodoslawsky (1996) go on to suggest that indicators only describe a certain appearance like desertification, but cannot be used as a strategic measure.

Another way to protect the environment is to set standards for activities in society which help to define and fix the strategic goals. However, it cannot also be used as a strategic measure (Krotscheck & Narodoslawsky, 1996). Eco-labelling schemes are also being used to provide information and evaluation of products' and services' environmental performance. However, as Ball (2002) states, one weakness of eco-labelling is that it is over-represented by product manufacturers who may have influenced the criteria set for achieving a required level. Further, the consumers infrequently have any representation in the process. Finally, eco-labelling often over emphasises politically driven value judgements, rather than scientific data.

So it can be seen that using a single indicator, standard or eco-labelling to assess an environmental issue is insufficient. Curwell et al. (1999, p. 292) state that "it is necessary to use composite indicators, that is, a small number of factors that are used to indicate the performance over a whole basket of issues". Indeed, the ultimate objective for developing a decision-making tool is to provide a single tool that can demonstrate the environmental performance of a development by looking at its sustainability while not undermining the developers' economic objectives. These criteria may be combined together into a single decision model.

As discussed in Section 4.3.2, the single criterion methods such as the building energy rating and economic evaluation methods are insufficient. Developing a more comprehensive and holistic methodology will ensure that sustainability is taken into account when evaluating all development activities and facilities that may affect current and future generations (Woolley et al., 1999). Achieving sustainable development requires the project appraisal methodology to take into account the full range of economic, environmental and social issues raised.

Various types of environmental indices have been developed as tools to aggregate and simplify diverse information into a useful and more advantageous form. The gross domestic product (GDP) indicator of economic welfare has been frequently used as a proxy measure of quality of life since the 1940s (Lawn & Sanders, 1999; Chambers et al., 2000). GDP is an aggregate statistical measure that adds up different goods and services so that they are expressed as a monetary unit. Since the 1970s, there has been growing criticism as to the usefulness of GDP as an indicator for economic growth (Stockhammer et al., 1997). It was argued that GDP does not reveal anything about human welfare or unpaid services such as housework, community service and volunteer work. Social activities and recreation are also excluded from GDP calculations (Chambers et al., 2000). In addition, GDP does not take into account the depreciation to the economy affected by the consumption of natural resources (Castaneda, 1999; Chambers et al., 2000). High GDP growth is necessarily to have higher welfare when unpaid services and the contribution of the natural capital are taken into consideration. However, even though GDP fails to be used as a measure of sustainable economic welfare, it is still widely used as the key indicator for economic policy (Stockhammer et al., 1997).

Since the late 1960s, many discussions have taken place about the links between economic growth, social welfare and the environment as economic growth is restricted by the availability of natural resources and the level of pollution in the environment (Castaneda, 1999). Attempts, therefore, have been made to account for depletion of both natural and man-made capital, and defensive expenditures. Daly and Cobb developed the Index of Sustainable Welfare (ISEW) in 1989 as a better means of measuring welfare changes in an economy (Lintott, 1996; Hanley et al., 1999; Chambers et al., 2000). ISEW takes into account GDP and includes adjustments to value housework, social costs, environmental damages, resource depletion and income distribution. In addition, it also adjusts for defensive and non-defensive expenditure that does not necessarily contribute to economic welfare (Herendeen, 1998). Nevertheless, Castenada (1999) states that ISEW cannot be used for international comparisons due to the methodological insufficiency. Calculating defensive expenditure is very limited to local effect only, which lacks the proper approach to extrapolate for the rest of the country or world.

In 1994, the ISEW was further developed into the Genuine Progress Indicator (GPI) to document benefits and to distinguish between economic transactions that contribute to, or diminish, well-being (Hanley et al., 1999; Chambers et al., 2000). It adds up the value of products and services consumed in the economy, and subtracts those which dos not improve well-being, such as defence expenditure and depreciation of the natural world (Hanley et al., 1999). GPI aggregates everything into a single indicator that facilitates international comparison. However, it fails because GPI attempts to translate everything into a monetary unit, which ignores the complexities of assigning monetary value to many social and ecological services (Chambers et al., 2000).

Rees and Wackernagel promulgated the ecological footprint in early 1994 by as a new way to measure and communicate sustainability using an area-based indicator (Hanley et al., 1999; Chambers et al., 2000; Roth et al., 2000). It deals with measuring human demands in comparison with the demand on the land and everything is expressed as a land area. Therefore, a footprint indicates an impact on the natural capital. A computer-based footprinting tool, EcoCal, was developed to help household explore their impact on the environment. However, as Hanley et al. (1999) describe, footprint measure fails to provide detailed advice to policy makers and does not provide any predictive ability to indicate improvement in sustainable development based on the current ecological footprint. In regards to using an ecological footprint to assess buildings, Curwell and Cooper (1998) argue that the system boundaries make the developing a practical assessment tool based on the footprint principle very difficult. On this basis, a sustainable building can only be achieved when using the minimum of resources, obtaining local resources, and minimising the generation of pollution and waste and disposing of them safely within the confines of the site or the community.

In 1990, the United Nations Development Programme (UNDP) launched the Human Development Index (HDI) which aims towards a more comprehensive measure of human development. It brings the indexes for income, longevity and education into a simple arithmetic average to measure human development. This system is appropriate for comparing developed and developing countries, but it fails to investigate the affect on the natural system by activities that potentially contribute to national income (Herendeen, 1998; Neumayer, 2001).

In Malaysia, an index has been developed for the cabbage farming industry. The farmer sustainability index (FSI) was developed to accumulate a series of scores assigned to specific responses to questions from a survey in accordance with their intrinsic sustainability, by looking at the organisational affiliation, self-identification, or key practice such as use, or non-use of synthetic agricultural chemicals (Taylor et.al, 1993). The FSI combines 33 different practices used to control insects, diseases, weeds and soil erosion, and to maintain and enhance soil fertility, into a composite index to measure sustainability. The higher the FSI, the greater the sustainability of the practice. It has been proved to be successful, reflecting the degree of sustainable practice among individual farmers (Taylor et al., 1993). The FSI as developed by Taylor et al. (1993) has been extended to evaluate cabbage and potato farming in Indonesia (Norvell & Hammig, 1999).

An index has also been developed to rank the sustainability of European cities. This index involves 12 European cities, the goal being to develop a system of indicators that can be used in cities throughout Europe. The European sustainability index describes the situation in view of the development of the city by means of a number of representative elements and compares this with the situation in previous years. It offers a compact index that is flexible, adjustable and intended for general application at the local level, and for comparisons at the international level (Deelstra, 1995). A similar type of index, based on the quality of life indices derived from investigating the weighted mean of a set of amenities to rank cities in Canada, has also been developed and used (Giannias, 1998).

Other similar index systems have been developed, such as the Sustainable Process Index for measuring the areas needed to provide the raw materials and energy demands and to accommodate by-product flows from a process (Krotscheck & Narodoslawsky, 1996). Other indicators or indexes used to indicate the performance of the economy in everyday life include the bank interest rate, rainfall, temperature, unemployment figures and the FT100 share index (Mitchell et al., 1995).

A sustainability index can also be developed to model the most significant criteria in a construction-related decision. The sustainability index captures the complexities of the ecosystem, yet remains simple enough to be used. A sustainability index can provide direction to strategic planning and can make a process more understandable and help to make the choice among alternatives more amenable to rational discussion in society (Krotscheck & Narodoslawsky, 1996). The development of a sustainability index combines objective factors, that is costs (financial return) and energy usage, together with subjective issues such as external benefits and environmental impact.

Developing a sustainability index is a reflection of the integral concept of sustainable construction that involves evaluating competing investment opportunities, investigating their environmental impact and assessment of sustainability. The comparative assessment of sustainability indicates which of the acceptable alternatives may be selected by screening out the worst options. The sustainability index framework also provides a means to aggregate information into a single indicator of relative performance. The purpose of the sustainability index is to ensure that the important aspects of the ecosystem, the economy and society are included, and that everyone can find a measure that applies.

These criteria comprise financial return, energy consumption, external benefits and environmental impact. Both financial return and energy consumption are relevant to the resource input in project development. This is very important today, as the supply of natural resources is under serious threat (Winpenny, 1991b; Gregory et al., 1993; Barbier, 2003). Financial return reflects the effective allocation of scarce resources by measuring total project costs and benefits, discounted over time. This is the ratio of the discounted value of benefits to the discounted value of costs. The greater the ratio the more efficient the proposal. Energy consumption includes both embodied energy and operational energy consumption over the project life span. When viewed simplistically, resource usage needs to be minimised. Energy consumption can be measured as annualised Gigajoules per square metre of floor area in the same way the building cost is expressed.

The other two criteria (external benefits and environmental impact) focus on the effects building development has on the natural and man-made environments. Due to the complex nature of the environment and its non-market characteristics, there is no problem-free technique to value the environment (Woolley et al., 1999; RICS, 2001). External benefits refer to the positive contribution of a project in terms of improving living standards, such as time saving and accident reduction arising over the operational life of a project. These non-market goods may be valued beyond an economic framework and a multi-criteria weighting approach can be used to assess social issues across alternatives. High scores indicate significant external benefits.

Environmental impact measures long-term negative impact of a development on the environment. Environmental impact is assessed using the same approach as described previously for external benefits to reflect the level of environmental uncertainty. Lower scores indicate that environmental impact is less significant and that therefore it is a preferable development option.

The model of the sustainability index can be used not only to compare options for a given problem, but also to benchmark projects. The model applies to both new designs and refurbishment, and can be used to measure facility performance.

Figure 5.4 shows the sustainability concept of a development. The sustainability index, as based on this concept, has four main criteria:

- Maximise wealth: Profitability is considered part of the sustainability equation. The objective is to maximise financial return. Financial return is measured as benefit-cost ratio (BCR) and therefore includes all aspects of maintenance and durability.
- Maximise utility: External benefits, including social benefit and other performance-based criteria, are another clear imperative. Designers, constructors and users all want to maximise utility which can relate to wider community goals. A weighted score can be used to measure utility.

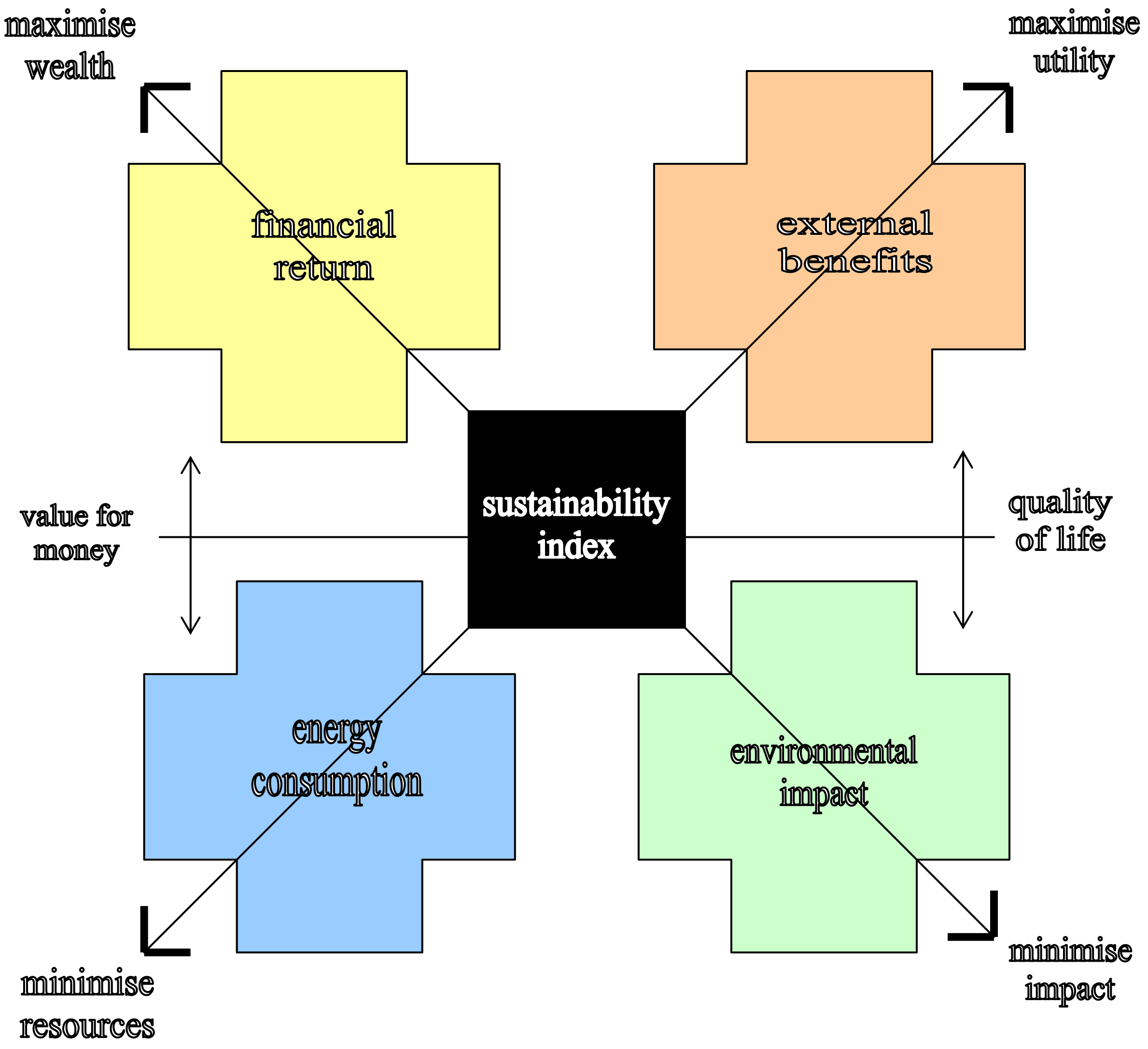
- Minimise resources: Resources include all inputs over the full life cycle, and can be expressed in terms of energy (embodied and operational). When viewed simplistically, resource usage needs to be minimised as much as possible. Energy usage can be measured as annualised Gj/m^2 of floor area.
- Minimise impact: Environmental impact encompasses all pollution and damages associated with the design and construction of a project. The aim is to minimise impact. A weighted score can also be used to measure impact.

These criteria can be assembled to illustrate the performance of new projects and changes to existing facilities using a multi-criteria approach. This investigation is a design tool to predict the extent to which sustainability ideals are realised, and is also an aid in ongoing facility management. Criteria can be individually weighted to reflect particular client motives.

Value for money is defined as the ratio of wealth output to resource input and is investor-centred. The higher the ratio the more attractive is the proposal. Quality of life is more community-centred. It can be measured as the ratio of external benefits to environmental impact. High ratios are preferred.

When all four criteria are combined, an indexing algorithm is created to rank options of projects and facilities on their contribution to sustainability. The algorithm is termed the ‘sustainability index’ Each criterion is measured in different units reflecting an appropriately matched methodology. Criteria can be weighted either individually, or in groups, to give preference to investor-centred or community-centred attitudes. Each criterion is measured and combined to give an index score. The higher the index, the more sustainable is the outcome.

Figure 5.4 The proposed sustainability index model



$$\text{Investor-centred performance (value for money)} = \frac{\text{maximise wealth}}{\text{minimise resources}}$$

$$= \frac{\text{financial return}}{\text{energy consumption}}$$

$$\text{Community-centred performance (quality of life)} = \frac{\text{maximise utility}}{\text{minimise impact}}$$

$$= \frac{\text{external benefits}}{\text{environmental impact}}$$

Model implementation

The project appraisal model, as discussed in Section 4.3.3, provides a framework to develop a sustainability index. The sustainability index utilises the multi-criteria evaluation methods based on discrete problems to investigate a number of choice possibilities in the light of conflicting priorities (Voogd, 1983; Nijkamp et al., 1990). These choice possibilities can be plans or strategies, regions or areas and so forth. The evaluation approach consists of a two-dimensional matrix (Voogd, 1983; Nijkamp et al., 1990; Janikowski et al., 2000) as indicated in Figure 5.5, where columns express the various alternatives and rows indicate the criteria by which the alternatives must be evaluated. Weights are inserted in the last column of the matrix. In the evaluation matrix alternatives *i* compares against decision criteria *j* with weights (*W*) attached to each criterion to reflect the level of importance in the assessment.

Figure 5.5 Two-dimensional evaluation matrix

		Alternatives I_1 I_2 … I_i	**Weights**
Criteria	J_1		W_1
	J_2		W_2
	J_3	Criterion scores	W_3
	.		.
	.		.
	.		.
	.		.
	J_j		W_j

The evaluation matrix as described previously may be denoted by the symbol E. This can be expressed as:

$$E = \begin{bmatrix} e_{11} & . \; . \; . \; . & e_{1i} \\ . & & . \\ . & & . \\ . & & . \\ e_{J1} & . \; . \; . \; . & e_{Ji} \end{bmatrix} \tag{5.3}$$

This matrix has elements e_{ji}, which represents a measure for the quality of alternative *i* (*i*=1, …….. I) for criterion *j* (*j*=1, …….. J).

Public opinion can now be used to identify the relevant criteria of, and alternatives to, a development. The design team, together with the developer, may outline the essential criteria and possible alternatives in accordance with the objectives and goals of a development. Individuals in the community in which a proposed project is going to be constructed may be invited to provide opinions or modification to the list in order to reflect the level of impact that may be caused by the decision.

Once the alternatives and criteria have been developed, the criteria weights have to be derived. The weights reflect the relative importance of criteria and criterion scores to one another. In multi-criteria techniques, the weights can have a major effect in the resulting ranks of alternatives (Voogd, 1983; Nijkamp et al., 1990; van Pelt, 1993b; Hobbs & Meier, 2000). A slight variation of weights can yield another ranking of the alternatives under consideration. Applying weights to criteria requires great attention and should be approached with care because as the literature described, it can be a source of bias or distort preferences (Hobbs & Meier, 2000).

There are numerous techniques developed in the literature to weight criteria. They are used under different circumstances such as paired comparison, ranking, rating and so on (Nijkamp et al., 1990; Janssen, 1992; Saaty, 1994; Hobbs & Meier, 2000) and public participation can be included here too. This is particularly important as the weights for criteria will reflect the level of impact of a development on individuals. Such a process provides the public with an opportunity to participate in decisions that affect them. It is almost impossible to arrive at a set of quantitative weights, as knowledge and the willingness to express their opinions are usually rare (Nijkamp et al., 1990; Hobbs & Meier, 2000). Therefore, the exercise may be regarded as approximations of weights, which provide evidence as to the likelihood of a set of weights to criteria, and as a representation of the relative importance of the criteria.

Weights (W) can be expressed as:

$$\sum_{j=1}^{J} W_j = 1 \text{ and } \qquad W_j = (j=1, \ldots\ldots, J) \tag{5.4}$$

where W_j denotes the weights assigned to the criteria j. From a decision theory point of view, criterion weights must reflect the trade-offs among marginal shifts in the criterion scores. It is just the same role as prices in the economic evaluation methods. It serves to maximise wealth and utility while minimising resource use and impact.

Here the four criteria are measured in different units and are mutually incompatible. In order to make these scores comparable it is necessary to transform them into a common dimension or a common dimensionless unit. Scores can be transformed into standardised scores using one of the available standardisation procedures for each criterion. They transform the raw scores into an additive constraint, ratio-scale or interval-scale property (Voogd, 1983; Nijkamp et al., 1990).

Once the criteria are standardised, they can be incorporated into a decision-making model. The sustainability index (SI) model can be expressed as follows:

$$SI_i = \sum_{j=1}^{J} e_{ji} W_j \qquad (i=1, \ldots\ldots\ldots\ldots I) \tag{5.5}$$

$$e_{ji} = f\{\text{ BCR, EC, EB, EI }\} \tag{5.6}$$

The symbol SI_i denotes the sustainability index for an alternative I; W_j represents the weight of criterion j; and e_{ji} indicates value of alternative i for criterion j. The result will indicate that higher values for e_{ji} and W_j imply a better score, and that alternative i will be judged as better than alternative i' if the score of SI_i is greater than the score of SI_i'. The BCR is benefit-cost ratio where EC denotes energy consumption, EB external benefits, and EI environmental impact.

They are obtained from the following formulae:

$$\mathrm{BCR} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \tag{5.7}$$

where:
BCR = benefit-cost ratio
r = selected discount rate
t = period ($t = 0,\ldots\ldots n$)
B = benefit
C = cost

$$\begin{aligned} \mathrm{EC} &= E_e + E_o \\ E_e &= E_m + E_t + E_p \end{aligned} \tag{5.8}$$

where:
EC = energy consumption
E_e = embodied energy (include initial & recurrent)
E_o = operational energy
E_m = manufacturing energy of building materials and components
E_t = energy for transportation
E_p = energy used in various processes

$$\mathrm{EB} = \sum_{j=1}^{I} B_{ji} W_j \tag{5.9}$$

where:
EB = external benefits
i = alternatives
j = sub-criteria
B = benefit

$$\mathrm{EI} = \sum_{j=1}^{I} R_{ji} W_j \tag{5.10}$$

where:
EI = environmental impact
i = alternatives
j = sub-criteria
R = impact

The sustainability index is calculated for each alternative by first multiplying each value by its appropriate weight followed by totalling the weighted scores for all criteria. The best alternative is the one with the highest sustainability index score. The amalgamation method yields a single index of alternative worth, which allows the options to be ranked. The higher the sustainability index, the better the chosen alternative.

The benefits of using a sustainability index to appraise projects

The development of a sustainability index framework provides a tool to enable the decision-maker to integrate issues of sustainable development into the project evaluation process. It uses a mixture of resources including economic, environmental and social issues within a unified approach in a full life-cycle estimate for each option. The broad range of topic areas covered in the model of the sustainability index still permits the use of a composite index containing all the diverse criteria, allowing the selection of the best option from the alternatives.

The sustainability index is a comprehensive methodology that includes the quantification of both objective and subjective measures that gives a full life-cycle analysis of buildings. The framework respects the importance and usefulness of conventional methods of economic CBA. It recognises the need to use monetary values as a unit of measuring resource efficiencies that it is readily understood by the decision-makers and stakeholders. In addition, the energy consumption is quantified for both embodied and operational energy. The calculations of absolute quantities of mass and energy flow will allow the impacts created by the buildings during their life cycle to be compared (Uher, 1999). The subjective criteria of environmental and social issues are quantified using a multiple criteria approach. Uher (1999) argues that an environmental assessment can be achieved by using absolute rather than marginal performance indicators for life cycle assessment of physical facilities. The advantage of obtaining absolute data is that the ecological footprint of buildings can be calculated, and that large internal differences in impacts for comparable functional units will appear.

With regards to the environmental building assessment methods, BREEAM, BEPAC, LEED and GBC use similar frameworks with a credit-weighting scale to assess buildings. ENER-RATE is principally set up to assess multiple criteria in design. BEQUEST is predominantly used for sustainable urban planning (details refer to Chapter Four, Section 4.2). The sustainability index can assist in decision-making for a project from as early as the feasibility stage. The survey revealed that professionals in the building industry are of the opinion that buildings should already be assessed at the feasibility stage in order to choose the best option that maximises financial return and minimises detrimental effects to the environment. The concept of a sustainability index is enhanced by the development of the comprehensive project evaluation (CPA) by the RICS, which indicates that building performance assessment methods should move away from relative scales into absolute measures (RICS, 2001).

Soebarto and Williamson (2001), when comparing environmental building assessment methods, say that most methods exclude cost and in some schemes, only part of the total cost is included. Curwell (1996) states that since they are not a life-cycle analysis method for buildings these methods would not give a balanced assessment between a development and the environment. Cooper (1999) further states that the methods provide only a relative, not absolute, assessment of a building's performance. Such relative assessments conceal the specific impact of a development on the environment and there is no guarantee that the buildings which score highly against the framework, are making a substantive contribution to increase environmental sustainability on a global scale. Rees (1999) continues, commenting that such relative assessments do not reveal the global carrying capacity appropriated by the development, and therefore cannot be used to measure progress for sustainability.

Due to the weakness of environmental building assessment methods of assessing buildings using relative terms, Cooper (1999) states that the direction for assessing building performance needs to be capable of providing absolute measures. Such absolute assessment can reveal the global carrying capacity appropriated by the development and be capable of measuring progress toward sustainability.

The sustainability index is used at the outset to appraise projects in selecting the best option from the alternatives. The index helps to distinguish buildings with reduced environmental impacts, and to induce design teams to incorporate holistic environmental performance requirements, significantly reducing the potential environmental impact of a new project at an early stage. It can facilitate the designer's iterative approach, where initial understanding of the problems and means of addressing it are allowed to evolve even before the project arrives at the design stage. However, environmental building assessment methods are rarely used during the design stage.

Soebarto and Williamson (2001) state that environmental building assessment methods endorse the concept of a complete design rather than assisting the designer during the design process. The environmental building assessment methods are apparently providing guidelines in design development and offer some insight into the issue of the comparability of design solutions. Nevertheless, they are, in general, inadequate as assessment tools to be used in the design process. The time and effort that need to be spent on verifying the compliance of building designs with the magnitude of current energy and environmental regulations are enormous, both in the process of verification and in terms of producing necessary documentation (Crawley & Aho, 1999).

According to Cooper (1999), Cole (1999a) and Todd et al. (2001), environmental building assessment methods are predominantly concerned with environmental protection and resource efficiency, with only limited ability to assess socio-economic sustainability. The environmental assessment of buildings using methods such as BREEAM and BEPAC are inadequate for addressing wider sustainability issues (Curwell & Cooper, 1998; Lee et al., 2002). Curwell and Cooper (1998) go on to state that these methods deal with environment and futurity only. The sustainability index, in principle, embraces economic and social concerns as well as environmental aspects of sustainability. It has provided a theoretical framework to consider potential contributions in furthering environmentally responsible building selection and practices. The evaluation of the four criteria over the life span of a building further enhances the principle of futurity and equity in project appraisal.

The environmental building assessment methods based the assessment on the opinion of a trained assessor to validate the achievement of building performance. Not only may the outcome be subjective but also it is only larger projects that can afford external expertise (Crawley & Aho, 1999). In addition, the assessment results are derived from just adding up all the points to get a total score. Even if a building rates poorly on a few key factors such as energy consumption, it can still achieve a high score from meeting other, more marginal criteria (Curwell, 1996).

The inherent weakness of subjectivity and point systems in assessment methods will not be a problem in the model of sustainability index. The composite index is obtained from a methodology that involves the participation of not just the design teams, but also the local council and people in the community that participate in assessing the social and environmental issues of a proposed development. The methodology allows information from heterogeneous qualitative sources, such as community questionnaires and surveys, to form part of the appraisal. Besides, the sustainability index does not derive a result from a point scoring system. Instead the resource usage and energy consumption are quantified to provide an absolute assessment of building performance as opposed to the relative assessment of most environmental assessment methods.

The sustainability index ranks projects using a composite index, but it is derived from absolute measures of criteria using the most suitable methodology. Therefore the outcome, whilst providing a ranking of developments with competing alternatives, also reveals the resources consumption and the extent of environment effects in the evaluation process.

5.3.5 Summary

Building developments involve complex decisions and the increased significance of external effects has further complicated the situation. Society is not just concerned with economic growth and development, but also the long-term affects on living standards for both present and future generations. Certainly sustainable development is an important issue in project decisions. Using a conventional single-dimension evaluation technique such as CBA to aid decision-making is no longer adequate. A much more sophisticated model needs to be developed to handle multi-dimensional arrays of data. The development of a sustainability index is a way to address multiple criteria in relation to project decision-making. Using a sustainability index will greatly enhance the assessment of external effects generated by construction activity, realise sustainable development goals and thereby make a positive contribution to the identification of optimum design solutions.

The model of a sustainability index has been established and discussed in this chapter. The next two chapters concentrate on evaluating the four criteria of the sustainability index based on a sample of 20 government high schools. Data on each criterion are collected and their relationships analysed and presented.

5.4 CONCLUSION

Following the development of a multiple dimensional model of project appraisals in Chapter Four, this chapter presented the process of identifying essential criteria to be incorporated into the decision-making model. It is based on an industry questionnaire to ascertain how building professionals rank a list of economic and environmental criteria identified in the literature review. This chapter also presented the methodological framework of a sustainability index for project appraisal.

The model of the sustainability index is based on a multiple dimensional concept that encompasses economic, environmental and social factors as well as energy consumption in the evaluation process. The combination of these criteria into a single decision tool is fundamental to decision-making. It provides a flexible and easy-to-use evaluation instrument that represents a systematic and holistic approach to decision-making.

The sustainability index will be examined by studying the four criteria over a sample of 20 government high school projects in NSW. Data of the four criteria as discussed in this chapter will be collected and analysed. Chapter Six will present the detailed research methodology, research design, hypotheses and data collection. Data analysis will be included in Chapters Seven and Eight.

CHAPTER
SIX

RESEARCH METHODOLOGY AND DATA COLLECTION

6.1 INTRODUCTION

This chapter’s objectives are to firstly present the research methodology used in the study; to expand the research hypothesis introduced in Chapter One into seven working hypotheses, and to present the research design. It also provides a background to the selected case studies and data collection procedures for the variables. Finally, this chapter includes descriptive statistics to highlight features of the data and provide a general understanding of the data collected. Detailed statistical analysis of data is included in Chapters Seven and Eight.

This is a significant introduction to the case studies as the work involves using various methods of data collection and different measurement methods for the four previously identified variables.

Case studies were chosen as the best means to explore sustainability relationships and dependencies of criteria in the sustainability index, and to show how the sustainability index works to rank projects. Data on the four criteria included in the model were collected and the relationships between variables were analysed to test the model’s robustness.

The task of data collection included the following:

- financial return—quantifying construction and building life cost,
- energy consumption—undertaking building life-cycle energy analysis,
- external benefits—quantifying external benefits of projects, and
- environmental impact—quantifying environmental risk and damage from projects.

To achieve the stated objectives of the research, 20 government high school projects in New South Wales were selected as a sample for the case studies. Many high school projects were completed in the past few years in New South Wales, which provided a potential database for analysis. This research project received assistance from the Department of Public Works and Services (DPWS) (now the Department of Commerce) and information was obtained from their Sydney office.

Government high schools were chosen for the case studies because the DPWS Sydney office keeps records of high school projects either in the form of a bill of quantities or a cost plan. In addition, the database had abundant information and could be accessed immediately which reduced the time required for data collection, thus removing a substantial obstacle given the amount of data required. A further benefit is that government high school construction is based on the same set of pre-designed criteria, providing an ideal platform for analysis and comparison. Given that building projects are in many ways unique, these 20 similar school projects facilitated easier data analysis and comparison and provided a good opportunity to test the sustainability index.

6.2 RESEARCH METHODOLOGY

This research involves developing a sustainability index for project appraisals. The research questions posed in Chapter One include identifying the fundamental criteria to be considered in project appraisal in order to ensure that a development conforms with sustainable practice. Identifying the essential criteria for project appraisal, using an extensive survey of construction professionals, was covered in detail in Chapter Five. Therefore, the next research question will be to investigate how these criteria interrelate with each other if they are to be combined into a single decision tool. There is currently no such aggregation described in the literature and it has not been possible to locate any previous research in this area. Hence, studying the interactions between various criteria is new and exploratory research. In view of the complex nature of the research, case studies were deemed to be the preferable method to generate the essential data for analysis.

Case studies have previously been adopted as a relevant and adequate research methodology in planning, economic and political science (Gillham, 2000; Yin, 2003). They allow an empirical inquiry into the real-life context of research work. They are particularly useful when the research context is too complex for surveys or experimental strategies (Gillham, 2000).

Using case studies of a single unit is often suspect, because there may be many elements that are specific to that particular unit but may not be relied on to draw conclusions about the population (Yin, 2003). Because building projects are principally unique, it is highly unlikely that conclusions can be drawn based on the findings from a single unit. It was, therefore, necessary to use multiple case studies to investigate the research questions and to generate more reliable data for inferences and to minimise misrepresentation. The results generated through these case studies are considered more compelling and more robust (Yin, 2003) and hence will be more useful in developing a sustainability index for project appraisal.

The desired outcome from using these case studies is to develop pertinent hypotheses and propositions for further inquiry. High school projects were chosen as the multiple case designs using an embedded approach. The theoretical framework derived for data collection is based on a multi-method approach and data were accumulated by different methods, but bearing on the same issue (Gillham, 2000). Different methods of data collection have been used for the four criteria of the sustainability index, and were selected as the most suitable methods for the complex nature of these criteria.

The number of projects to be included in the case studies is restricted by various constraints. The case studies involve quantifying the four criteria identified in Chapter

Five as fundamental for enhancing ecologically sustainable development in the construction industry. The data collection to quantify each criterion required comprehensive resources and the sample size needed to be a realistic and manageable size. The type of project and comprehensive nature of the information also affected the sample size.

The number of projects that are available for the study was also limited. Eighty-five projects were received from DPWS, but after a screening process only 20 were found to satisfy the stated requirements for the study as detailed in Section 6.5. Even though the sample size may seen small, it will not significantly effect the analysis as almost all relevant statistical techniques are applicable for samples of that size (Yin, 2003). A bigger sample would have been expected to narrow the confidence limits, but would not have changed the analysis.

6.3 RESEARCH HYPOTHESES

The working hypothesis presented in Chapter One has been refined and expanded into seven working hypotheses in order to provide a clear framework and guidelines for collecting, analysing and interpreting the data. The set of working hypotheses also serves as a testing tool of the relationships between variables for the sustainability index. Detailed analysis will be discussed in Chapters Seven and Eight, however the working hypotheses with corresponding null hypotheses are as follows:

Hypothesis one (H1) is set up to explore the relationship between building cost and total energy consumption. The purpose is to examine whether the increases in the total building cost will affect the total energy consumption.

Null Hypothesis H_0 (1)

The building cost will exhibit no relationship with energy consumption.

Alternate Hypothesis H_a (1)

The building cost will exhibit a relationship with energy consumption.

Hypothesis two (H2) is set up to explore the relationship between building costs and external benefits. The purpose is to examine whether increased total building cost will increase environmental benefits.

Null Hypothesis H_0 *(2)*

The building cost will exhibit no relationship with external benefits.

Alternate Hypothesis H_a *(2)*

The building cost will exhibit a relationship with external benefit.

Hypothesis three (H3) is set up to explore the relationship between building cost and environmental impact. The purpose is to examine whether or not increased total building cost will increase environmental impact.

Null Hypothesis H_0 *(3)*

The building cost will exhibit no relationship with environmental impact.

Alternate Hypothesis H_a *(3)*

The building cost will exhibit a relationship with environmental impact.

Hypothesis four (H4) is set up to explore the relationship between total energy consumption and external benefits. The purpose is to examine whether increased energy use will increase external benefits.

Null Hypothesis H_0 *(4)*

The energy consumption will exhibit no relationship with external benefits.

Alternate Hypothesis H_a *(4)*

The energy consumption will exhibit a relationship with external benefits.

Hypothesis five (H5) is set up to explore the relationship between total energy consumption and environmental impact. The purpose is to examine whether increased energy use has an impact on the environment.

Null Hypothesis H_0 *(5)*

The energy consumption will exhibit no relationship with environmental impact.

Alternate Hypothesis H_a *(5)*

The energy consumption will exhibit a relationship with environmental impact.

Hypothesis six (H6) is set up to explore the relationship between external benefits and environmental impact. The purpose is to examine if increased environmental benefits will affect environmental impact.

Null Hypothesis H_0 (6)

The external benefits will exhibit no relationship with environmental impact.

Alternate Hypothesis H_a (6)

The external benefit will exhibit a relationship with environmental impact.

Hypothesis seven (H7) is set up to explore the complex relationship between energy consumption and the rest of the criteria. The purpose is to examine whether energy consumption is the function of building cost, external benefits and environmental impact.

Null Hypothesis H_0 (7)

The energy consumption will exhibit no relationship with building cost, external benefits and environmental impact.

Alternate Hypothesis H_a (7)

The energy consumption will exhibit a relationship with building cost, external benefits and environmental impact.

Data on each criterion were collected, analysed and interpreted in this chapter. Chapter Seven further explores data properties and characteristics. The hypotheses developed in this section will be tested, discussed and presented in Chapter Eight.

6.4 RESEARCH DESIGN

The multiple case studies have been carried out in three stages. The first stage is transferring the information from the bill of quantities or cost plans to an electronic format using a spreadsheet. The spreadsheet was used to calculate construction, initial and recurrent embodied energy. The building life cost was calculated using the LIFECOST computer program.

The second stage involved obtaining data to calculate operational energy for the case studies. To obtain this data a questionnaire was designed and distributed to public high schools to obtain records of energy bills for 2001. A copy of the questionnaire is included in Appendix C.

The third stage involved evaluating each school's environmental performance using a multi-criteria analysis. As discussed in Chapter Two, multi-criteria analysis is a widely used methodology for appraising environmental effects using a weighted scoring method. A comprehensive list of environmental criteria pertinent to school projects was compiled based on the school's environmental reports and the literature review. Given the highly specialised nature of the work and the potential for subjectivity, experts from the construction industry were invited to participate.

Ten professionals were selected from the industry survey participants based on the information completed in Part Three of the questionnaire (see Chapter Five). The group included project managers, site managers, construction managers, registered architects and engineers who have experience either designing or constructing environmental projects. Each specialist was given from one to three schools to assess its environmental performance. The specialists visited the school, completed an evaluation form and prepared a brief description of the environmental performance. A copy of the evaluation form has been included in Appendix D of the thesis. Further, detailed discussion can be found later in this chapter in Section 6.6.

Finally, all the data collected for the case studies have been categorised, analysed and presented in Chapters Seven and Eight.

6.5 OVERVIEW OF CASE STUDY PROJECTS

DPWS builds many high schools every year in New South Wales but there is no information about the total number of school completed. However, in 2001, information on 85 school projects completed within the past 20 years was obtained from the DPWS Sydney office. The documents received were either in the form of sketch design cost plans or bills of quantities. In addition, some projects also came with contract drawings, specifications and environmental reports. The case study research required detailed examination of construction cost, building life cost, environmental analysis and energy usage. Therefore sufficient details of the projects were required for the study.

Since not all projects gave sufficient detail for the study, a screening process was employed to examine all the projects in detail to select suitable projects. The selection criteria included looking for projects that had comprehensive data for the analysis and which represented different locations, sizes, completion years, specifications and construction methods in an attempt to provide an adequate coverage for data analysis.

The screening process eliminated all but 20 projects that satisfied all the requirements. Table 6.1 summarises these projects which varied in completion years from fairly recently constructed to 18 years old, were located throughout New South Wales, sized between 1,295 and 15,631m^2, and ranged from a small school of 165 to a large school with 1,076 students.

These projects were scattered around New South Wales. As shown in Figure 6.1 (see next page) eight projects were located in the Sydney region and 12 projects were scattered in country regions, the farthest located approximately 275km away from the Sydney CBD.

Table 6.1 Summary of information for the 20 public high schools in New South Wales

Project No.	Student No.	Year of completion	GFA (m^2)	Location
1	975	1989	9,800	Shellharbour
2	960	1986	13,519	Campbelltown
3	920	1985	8,092	Central Coast
4	1,009	2000	12,565	Campbelltown
5	1,076	1997	11,398	Liverpool
6	704	2000	15,344	Dubbo
7	846	2002	5,268	Dubbo
8	808	1990	8,610	Mt Druitt
9	851	1997	12,265	Penrith
10	956	2000	10,747	Lake Macquarie
11	1,000	2002	13,213	Campbelltown
12	900	1995	3,040	Bathurst
13	828	1994	9,220	Central Coast
14	184	1994	1,295	Dubbo
15	850	1990	8,864	Bondi
16	787	1997	8,500	Central Coast
17	979	2001	15,631	Central Coast
18	946	1997	4,066	Wagga Wagga
19	870	1986	7,516	Penrith
20	165	1999	3,524	Dubbo

Figure 6.1 Locations of the 20 public high school projects

For the 20 projects, five bills of quantities and 15 sketch design cost plans were received. Floor plans, construction details and specification were available for some projects only. No data were received in electronic format. The initial step, therefore, was to convert the documents into electronic format using a spreadsheet. The spreadsheet was designed with rows for details about construction which were directly transferred either from the bills of quantities or cost plans. The spreadsheet also contained columns to calculate construction cost, initial embodied energy and recurrent embodied energy. A copy of the spreadsheet is included in this report as Appendix E.

All projects were prepared in the elemental format in accordance with the Australian Cost Management Manual (ACMM) prepared by the Australian Institute of Quantity Surveyors, July 2000 (Australian Institute of Quantity Surveyors, 2001). The format contained a list of standard elements and sub-elements then individual materials. The gross floor areas (GFA) were also measured in accordance with the definition and methods of ACMM.

A bill of quantities has advantages and disadvantages for use in the case studies. It provides a comprehensive record of all the materials and workmanship for the project. However, it does not always give quantities of the constituent materials used in each item at the level of detail needed for this analysis. In addition, a bill of quantities is arranged by trades (e.g. concrete and structural steel), not by elements (e.g. upper floors and columns). Some trades are used across many elements and have to be manually re-classified. To classify difficult items, the architectural and structural drawings were consulted to determine where items were located in accordance with the ACMM standard list of elements.

The 15 projects obtained in the form of sketch design cost plans were already arranged by elements. Consequently, the effort of transferring the cost plans to an electronic format using the pre-designed layout became easier and more efficient. The disadvantage, however, was that most of the items were measured in ‘bulk quantities’, which lumped several items into one. Further work was required to break the elements down into basic materials.

6.6 DATA COLLECTION

6.6.1 Financial return

Financial return comprises measuring construction and building life costs. Construction cost covers expenditure on labour, plant and materials used to construct facilities such as the foundation, structure and finishes. It also usually includes development costs, such as professional fees, land cost and agent fees. However, these costs were excluded from the study as they do not apply to government projects. In addition, there is no consistent way to measure them so to include them would introduce bias. As the projects were completed at different times they were converted into current prices at 2002 using the Building Price Index of the Sydney region to facilitate comparison (Rawlinsons, 2003).

The second part of the financial return involved undertaking a building life cost study of each project. This cost is an economic assessment of a building over its economic life expressed in terms of equivalent dollars. It includes expenses incurred during the normal building operations such as labour, materials, utilities and related costs. It typically accounts for at least 50 percent, and sometimes up to 80 percent of the total project cost and usually is accounted for during the building's in-service life (Griffin, 1993).

In physical terms, with the right kind of materials a building can last for a very long time and is likely to become technologically and financially obsolete long before it falls down. For simplicity, an arbitrary life cycle of 60 years was chosen for all 20 projects as most research on life cycle costing has based the calculations on such a period (Ashworth, 1993).

Estimating building life cost is a process of identifying the building elements or components that may require regular maintenance, repair and scheduled renovation. Building structure does not require too much work over the life span once it is completed. However, other parts of the building such as building fabric, internal finishes and furniture may require more frequent maintenance, repair and refurbishment. Building life cost studies for the case studies was carried out using the LIFECOST Version 2.1 software. This is spreadsheet-based software that helps to calculate life cost over the designated life expectancy of building materials and components. A detailed study and investigation were carried out to the cost plan or bill of quantities of each project to identify building components requiring regular or scheduled maintenance and repair. The items were then entered into the spreadsheet together with specification and quantities to calculate the building life cost.

Another equally important step of building life cost studies is to distinguish the life expectancy of components or materials in order to work out the number of times an item is replaced, maintained or repaired over the life cycle. If the item is never replaced, such as the structure, the replacement rate is zero. If the item is replaced once in the building's life, the replacement rate is calculated by dividing the building life cycle (60) by the life expectancy (50) of the item, that is, once (1), in this example.

According to Langston (1994), Kirk and Dell'Isola (1995) and Australian Institute of Quantity Surveyors (2002), the life expectancy of items varies in accordance with types of building. Calculating building life cost relies on appropriate, relevant and historical information and data. Most life cost studies have been focused on commercial buildings; studies on high schools are rare. Therefore, the building life cycle data for the case studies is based on Langston (1994), Kirk and Dell'Isola (1995) and Australian Institute of Quantity Surveyors (2002). These sources of information provide the required information on life cycle data for maintenance, operational demands and replacement needs for selected building elements or components.

Discounting is important in order for project costs and benefits to be compared and considered at today's prices (Price, 1993; Harding, 1998). However, Langston (1994) states that discounting is recognised as being applicable when comparing two or more alternatives, but is irrelevant to specific measurements of a given design. Therefore, all costs have been priced at 2002 and projected into the designated life cycle based on a discount rate equal to zero. Table 6.2 summarised the life cost data used in the study.

Table 6.2 Summary of life cycle data used in the case studies

Element	Life expectancy
Staircases	
Balustrade	30
Handrail	30
Granolithic topping	20
Repaint balustrade	6
Repaint handrail	6
Repaint soffit	10
Roof	
Roof cladding	30
Roof plumbing	30
Roof accessories	30
External Walls	
Cladding	30
Accessories	30
Windows	
Aluminium	40
Metal louvre	40
Metal sunscreen	30
Blinds	10
External Doors	
Solid core	40
Aluminium	40
Roller shutter	30
Repaint	10
Internal Walls	
Glazed partitions	30
Stud partitions	25
Internal Doors	
Solid core	80
Hollow core	30
Folding	25
Repaint	10
Wall Finishes	
Cladding	30
Wall tiles	25
Timber lining	40
Repaint timber	7
Other repaint	10
Floor Finishes	
Carpet & underlay	12
Vinyl	20
Parquetry	35
Granolithic topping	20
Floor tiles	25

Element	Life expectancy
Ceiling Finishes	
Suspended ceiling	15
Repaint	20
Fitments	
Furniture	30
Fittings	30
Special Equipment	
Special equipment	30
Sanitary Fixture	
Toilet suite	35
Basin	35
Sink	40
Wash trough	40
Urinal	35
Sanitary disposal unit	35
Shower curtain/track	5
Sanitary Plumbing	
Traps	30
Water Supply	
Tap	30
Hot water unit	20
Fire Protection	
Fire hose reel	30
Fire blanket	30
Refill fire extinguisher	5
Space Heating	
Heaters	20
Roads, paths, etc.	
Resurface road	40
Granolithic topping	20
Boundary wall, etc.	
Fence & gates	40
Outbuildings, etc.	
Roof cladding	30
Roof plumbing	30
Roof accessories	30
Wall cladding	30
Landscaping	
Plant replacement	1% p.a.
Aluminium seating	50
Flagpole	50
Tree surgery	10

Source: Langston, 1994; Kirk and Dell'Isola, 1995 and Australian Institute of Quantity Surveyors, 2002

The manufacturing techniques, nature of use and many other factors will no doubt affect the life expectancy of materials and components. Therefore, the life expectancy of materials and components included in Table 6.2 represents an average of a probability distribution for the sources relevant to high school projects.

It is hard to accurately forecast costs 60 years ahead. It is not generally accepted that the life cycle time horizon should be increasingly related to current use expectation associated with the cyclical effect of population movements in the society. Therefore, the forecasting can only be carried out in the light of present knowledge. The future can only be predicted within the limits of present day expectations and knowledge.

It is also difficult to forecast with any degree of accuracy the possible changes in technology, materials and construction methods that may occur in the future (Ashworth, 1993). Therefore, no consideration of technological changes is taken into account in building life cost for the case studies.

Return on investments is not considered in the case studies. Financially, the return on high school projects consists of funding received from the government and fees obtained from students plus other fund-raising activities. Since government projects are generally non-profit making, the benefits received will at least partially be political and social rather than economic. Therefore it is intended to compare costs with the other three criteria in the model without taking into consideration the revenue generated through the project.

Table 6.3 summarises construction and building life costs of the 20 public school projects calculated over a 60-year life cycle. The table shows that the building life cost exceeded the construction cost by approximately one to three times over an economic life of 60 years, highlighting the importance of building life cost studies in a life cycle analysis of a project. One anomaly is project 20 which indicated that building life cost was 3.89 times more than the construction cost. However this was because it included both new construction and refurbishment of existing buildings and was therefore not directly comparable.

Table 6.3 Summary of construction and building life costs over a 60-year life cycle

Project No.	Construction cost ($)	Building life cost ($)	Total cost ($)
1	14,156,026.94	16,440,940.00	30,596,966.94
2	17,874,912.87	18,108,224.26	35,983,137.13
3	11,666,223.82	12,218,112.73	23,884,336.55
4	17,089,957.74	23,030,654.99	40,120,612.73
5	13,806,320.77	17,004,757.72	30,811,078.49
6	17,758,856.86	25,282,202.37	43,041,059.23
7	6,988,223.60	13,320,357.55	20,308,581.15
8	13,625,022.38	13,590,692.16	27,215,714.54
9	16,104,053.77	19,832,480.91	35,936,534.68
10	15,423,724.32	19,654,007.73	35,077,732.05
11	16,186,966.98	23,628,872.86	39,815,839.84
12	3,640,851.85	8,176,231.05	11,817,082.90
13	10,962,293.01	17,512,979.94	28,475,272.95
14	1,941,553.73	4,096,456.71	6,038,010.44
15	16,071,139.45	13,789,919.34	29,861,058.79
16	13,869,918.03	13,847,538.15	27,717,456.18
17	19,748,015.33	25,209,697.91	44,957,713.24
18	7,334,737.78	13,363,054.70	20,697,792.48
19	9,864,048.50	12,319,172.25	22,183,220.75
20	2,350,323.43	9,151,978.53	11,502,301.96
Mean	12,323,158.57	15,978,916.60	28,302,075.15
Standard Deviation	5,355,987.46	5,720,161.23	10,696,737.19

6.6.2 Energy consumption

Energy consumption includes initial and recurring embodied energy plus the operational energy and any energy required for decommissioning (Treloar et al., 1999). It must be noted that the energy requirement, or energy gain arising from reuse, recycling or combustion is not considered here, because it depends on the quality and the extent to which it is processed. The available data from recent publications are still incomplete and too vague to be used with confidence (Adelberth, 1997b).

Initial embodied energy

Initial embodied energy was calculated using the same spreadsheet as for financial return (see Appendix E). The main dimensions were converted to units in accordance with the embodied energy intensity. Previously, these coefficients were based on unit mass of materials, requiring considerable conversion. Now, most coefficients are based on units used either in the bill of quantities or in the more user-friendly cost plans.

The basic embodied energy calculation is simply a process of identifying the relevant embodied energy coefficients and data input. The quantity of a material is then multiplied by its embodied energy coefficient to obtain the energy used to produce that material. The total embodied energy for all the materials can then be found by totalling the individual values. The relevant embodied energy coefficients for major materials are obtained from different sources in the literature as summarised in. Table 6.4.

Table 6.4 Summary of embodied energy coefficient from different sources for the major materials used in the case studies

Material	Unit	Embodied energy coefficient (GJ per unit)			
		[1] Treloar	[2] Lawson	[3] Pullen	[4] Alcorn
Aluminium	t	231.530	170.000	420.000	191.000
Brick	t	4.730	2.500	3.300	2.500
Concrete	t	5.090	4.080	4.320	2.400
Roof tile	m^2	0.301	0.090	-	-
Glass	m^2	0.635	0.318	-	-
Stainless Steel	t	229.311	-	141.280	-
Reinforcement	t	95.650	34.000	-	12.500
F82	m^2	0.173	0.137	-	-
F72	m^2	0.135	0.106	-	-
F62	m^2	0.108	0.085	-	-
Structural Steel	t	95.650	38.000	26.100	34.000
6mm Fibre cement	m^2	0.238	0.014	-	-
7.5mm Fibre cement	m^2	0.297	0.019	-	-
Copper sheet	t	135.390	100.000	-	-
Copper pipe	t	135.390	-	425.960	70.600
Copper wire	t	135.390	-	117.260	-
10mm Plasterboard	m^2	0.044	0.031	0.055	0.043
Steel tray decking	m^2	0.374	0.139	-	-
9mm Plywood	t	-	10.400	-	10.400
Carpet	t	0.413 (m^2)	-	270.700	72.400
Polyethylene	t	-	0.090	0.066	0.103
100mm dia. PVC pipe	t	-	-	0.132	0.070
Hardboard	t	-	0.024	-	0.024
MDF	t	-	0.011	-	0.012
Particleboard	m^3	16.003	5.040	-	5.040

Source:
1 Unpublished data from Treloar, G. (2002)
2 Lawson, B. (1996)
3 Unpublished data from Pullen, S. (2001)
4 Alcorn, A (1998)

The table shows that the differences of embodied energy coefficient among different sources varied greatly from material to material. As discussed in Chapter Three, the variations in embodied energy coefficient may be as a result of different methodologies used for calculation and the system boundaries set for the analysis. The energy required to produce most material also varies depending upon economies of scale, quality of input, efficiency of fuel use and waste conservation practices. However, given that the buildings are not similar, but the type of materials used are similar for each project in the case study, it is unlikely that typical variations will affect the overall results if the energy calculations are based on the same source of information.

Due to the material breakdowns of building services, data on furniture and fittings are unavailable together with the incomplete or unavailable information on the embodied energy coefficients in these areas. Therefore, these elements were estimated based on a percentage added to the total embodied energy as derived from the literature. As detailed in Chapter Three, the following percentages were allowed when calculating initial embodied energy:

- building services—19% and a replacement rate of every 30 years (refers to Table 3.4)
- furniture and fittings—0.7GJ/m^2 and a replacement rate of every 10 years (Treloar et al., 1999)
- on-site process—10% (refers to Table 3.2)
- incompleteness—20% (Treloar et al., 1999)

On-site process energy is required for the work carried out on-site during the construction period. This covers material delivery, component assembly, operation of plant and equipment, and demolition of existing structures (details refer to Chapter Three, Section 3.3.5). Incompleteness is the percentage allowance allowing for the energy used in other forms such as insurance, financial sources and technical errors are, at best, incomplete (Treloar et al., 2001a).

As discussed in Chapter Five, Section 5.3.3, discounting energy was not taken into consideration in the study because there is a lack of evidence that the energy consumption of today's community will be better or worse than that of the community of tomorrow. Therefore, the assumption of discounting energy consumption becomes less crucial and so a discount rate equal to zero was used in the study.

Recurrent embodied energy

As discussed previously, there is little documented information concerning the mortality of high school buildings in Australia. Relevant data on the replacement cycles of building components is equally as difficult to obtain as any existing information is historical, referring to schools built in the past when building techniques and durability of materials may have been different.

The recurrent embodied energy of the building materials and components was estimated alongside the initial embodied energy on the same spreadsheet (see Appendix E). The recurrent embodied energy comprises additional requirements for building products used in maintenance and miscellaneous repairs and was estimated by assigning replacement rates to items in the initial embodied energy during the lifetime of the building. The replacement rate used in the calculation of recurrent embodied energy was obtained from Table 6.2 in Section 6.6.1. The total recurrent embodied energy was obtained by totalling the individual values for each project.

Operational energy

The operational energy data were obtained through a survey of public high schools in New South Wales. Respondents from the schools were asked to retrieve information from the energy bills of 2001 and complete the questionnaire as provided (see Appendix C). The energy consumption pattern for high schools is assumed to be very similar from year to year with the school terms covering a period of 40 weeks per year at approximately eight hours per weekday. Therefore, one year's energy consumption would provide sufficient insight into the energy usage for the effective life cycle of school buildings. The operational energy consumption of the projects was based on the actual energy use for a given period of time. This method has been used in other research works of operational energy consumption (Pullen & Perkins, 1995; Howard & Roberts, 1995; Adalberth, 1997a; Treloar & Fay, 1998; Pullen, 2000b) as discussed in detail in Chapter Three, Section 3.3.

In May 2002, a questionnaire (Appendix C) was sent to 28 NSW high schools. Eighteen responses were received representing a response rate of 64 percent. The operational energy includes energy used for heating, cooling, lighting, water heating and appliances. The data received were for electricity and gas consumption only with quantities expressed in terms of delivered energy measured at the place of consumption. The total quantities of delivered energy were then converted to primary energy using factors of 3.12 and 1.22 for electricity and gas respectively (Pullen, 2000a).

Three schools did not return the survey and a further three new schools were completed in 2001 and 2002 so energy data was not available at the time of research. Therefore, the operational energy consumption for these six projects was estimated using regression analysis. The relationship between energy consumption and the number of students was established and was hypothesised as directly related to the number of students attending the school. The straight line formulae as derived from regression analysis were as follows:

Electricity consumption: $$y = 304{,}851.11 + 816.20x \quad (t = 4.01) \tag{6.1}$$

Gas consumption: $$y = 208{,}643.22 + 863.66x \quad (t = 2.94) \tag{6.2}$$

where x represents the number of students. Correlation analysis was used to measure the strength of association between energy consumption and the number of students. The coefficient of correlation (r) for electricity and gas were 0.77 and 0.72 respectively indicating a strong positive correlation between the two variables. The number of students was strongly associated with a high consumption of energy. The coefficient of determination (r^2) implies that 60 percent and 54 percent of the variations in the energy consumption can be explained by the variations in the number of students in the school and is the source of the remaining variations. Both coefficients are significant at the 5 percent level. Based on the formulae (6.1) and (6.2), the operational energy consumption was estimated for the six projects in the case studies.

Table 6.5 presents the results of initial and recurrent embodied energy and operational energy for the 20 projects in the study. The table shows that both initial and recurrent embodied energy played important roles in the total energy analysis of a building. Further analysis and discussions are included in Chapter Seven.

Table 6.5 Summary of embodied and operational energy

Project No.	Energy consumption (GJ)			
	Initial	Recurrent	Operational	Total
1	84,998.11	79,497.89	252,407.68	416,903.68
2	113,623.34	109,975.72	233,661.52	457,260.58
3	82,137.20	70,597.64	214,619.77	367,354.61
4	109,947.52	110,012.39	250,076.73	470,036.64
5	81,056.76	97,774.72	198,987.05	377,818.53
6	94,865.80	122,518.39	300,889.61	518,273.80
7	25,597.36	37,163.73	184,648.82	247,409.91
8	77,188.74	75,216.66	204,325.21	356,730.61
9	89,882.33	104,969.72	225,622.13	420,474.18
10	101,805.15	97,370.76	330,293.74	529,469.65
11	88,482.53	103,914.59	257,808.00	450,205.12
12	24,279.01	24,383.46	293,092.42	341,754.89
13	51,265.71	69,709.54	220,653.84	341,629.09
14	7,954.98	10,433.52	96,534.42	114,922.92
15	71,630.45	67,820.21	225,406.11	364,856.77
16	81,318.63	75,121.86	224,489.12	380,929.61
17	125,984.76	130,433.53	393,193.54	649,611.83
18	52,684.17	38,639.08	343,892.44	435,215.69
19	65,348.86	62,754.48	229,726.36	357,829.70
20	10,352.83	20,704.25	61,721.07	92,778.15
Mean	72,020.21	75,450.61	237,102.48	384,573.30
Standard Deviation	33,823.87	34,966.99	75,934.39	127,601.75

6.6.3 External benefits and environmental impact

This section sets out to quantify external benefits and the environmental impact associated with each project on the locale. As discussed in Chapters Two and Three, environmental matters are difficult to quantify in physical units. The methodology used to quantify external benefits and environmental impact, therefore, followed a multi-criteria analysis (MCA) approach as discussed in Chapter Two. This methodology is particularly useful when evaluating environmental issues (Voogd, 1983; Nijkamp et al 1990; van Pelt, 1994; Powell, 1996).

The high schools used in the case studies are scattered across NSW, therefore, the boundary of analysis for environmental issues will be confined to the suburb where the project is located, excluding environmental impacts occurring outside the local boundary. The analysis, however, includes discharge of pollutants to air, watercourses and land. It should also be noted that the examination of national and international environmental issues was outside the scope of the studies.

Each project was examined in detail to identify the likelihood of positive and negative environmental issues as related to the development of a school. For projects completed since 1997, the government required an environmental study to be carried out during the feasibility stage. The environmental study provided a detailed investigation and discussion of the site and the project's potential impacts on the environment. These reports provided significant information when compiling attributes to evaluate environmental issues applicable to high school projects in Australia.

The environmental analysis of each project was divided into two sections, external benefits and environmental impact. External benefits dealt with the contribution of positive effects of a school project to the environment. Seven criteria were identified from the survey (see Chapter Five) and each criterion was broken down into sub-criteria (refer to Figure 6.2). A group of specialists assessed each sub-criterion using a weighted scoring approach. Environmental impact dealt with the negative effects a school project might generate. In this section, five criteria were identified from the literature and the school environmental reports. Each criterion was broken down into sub-criteria. The analysis of environmental impact followed a life cycle of a project, which started from the initial manufacture of building materials or components, through to the completion of work on site. Figure 6.3 outlines the criteria and sub-criteria of environmental impact in the analysis. An MCA weighted scoring approach was also used to assess each criterion in the same manner as the external benefit.

Figure 6.2 Criteria and sub-criteria of external benefits

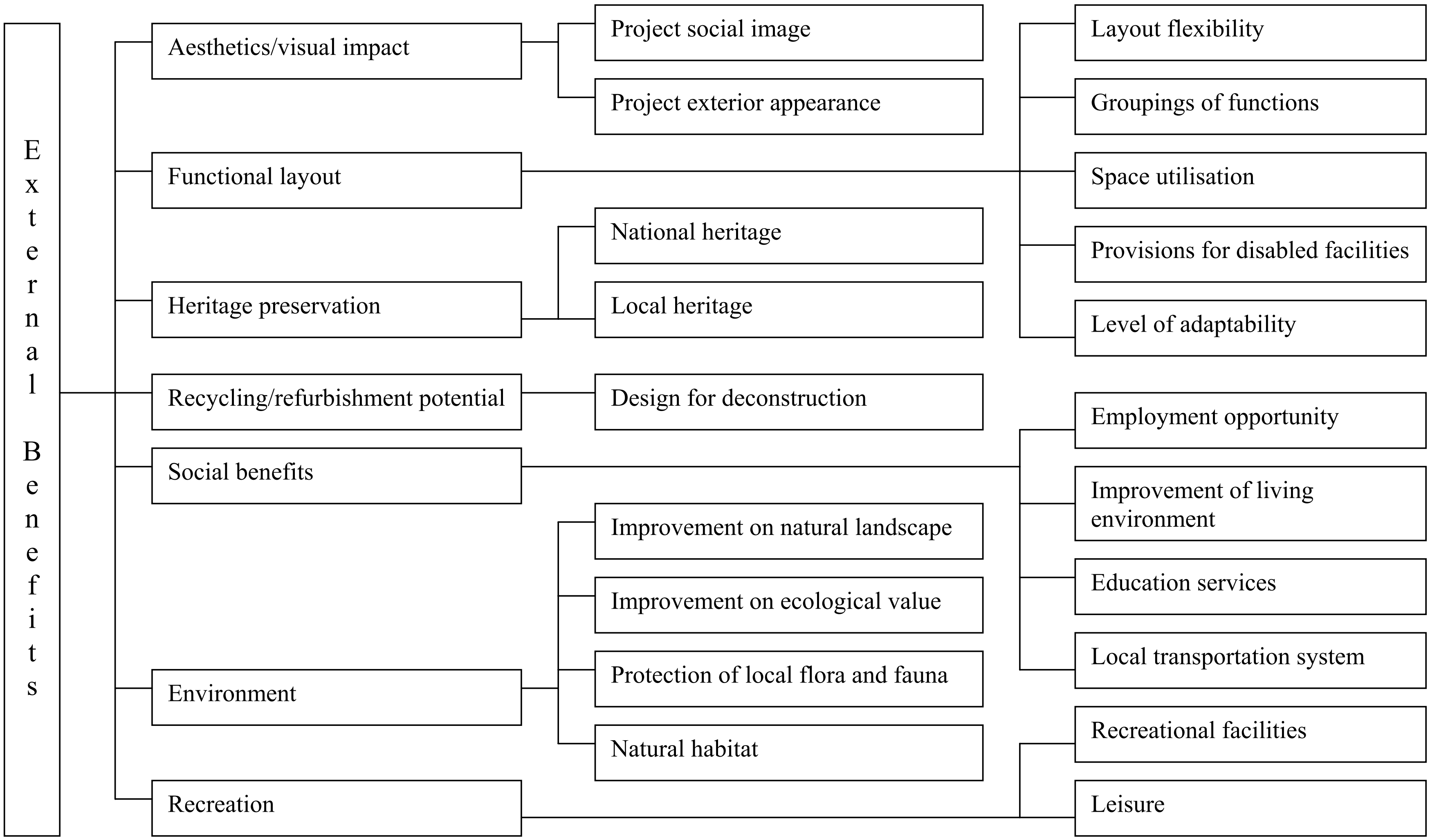
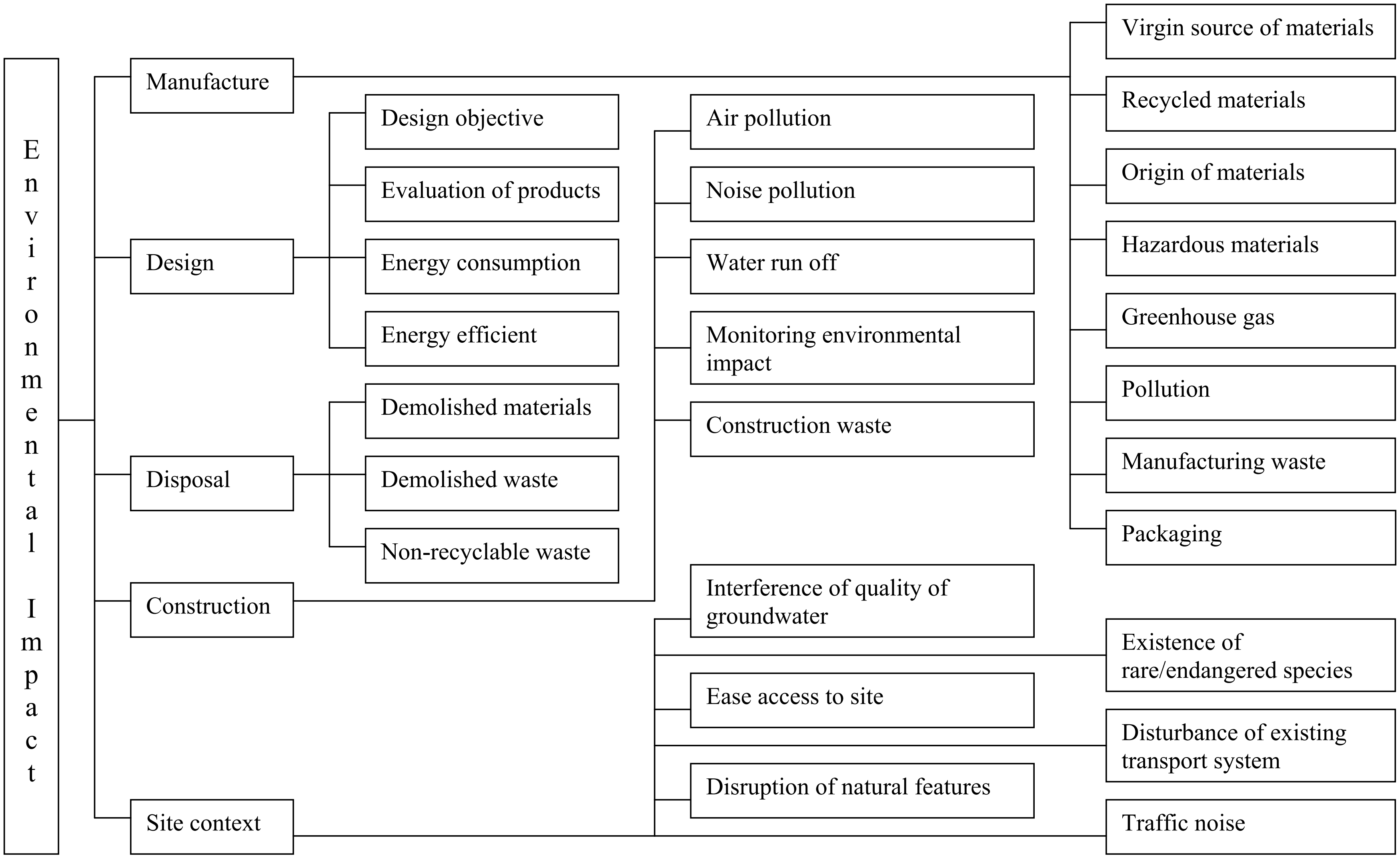


Figure 6.3 Criteria and sub-criteria of environmental impact



A multi-criteria analysis approach was used to quantify external benefits and environmental impact (see Appendix D). The criteria and sub-criteria were put together into a questionnaire format and expert opinions on the degree of benefits and level of impact were sought. Parts A and B were used to evaluate the criteria and sub-criteria of external benefits and environmental impact. They were rated on each project in accordance with their level of benefit or impact on a scale of one to five with scale one indicating the lowest level.

One of the main features of the MCA approach is weighting the criteria. Each criterion is assigned a weight to reflect its level of importance. The criteria weighting process for the 12 external benefit and environmental impact criteria was carried out in two stages included as Part C of the questionnaire. The first stage used a pairwise comparison matrix to weight the 12 external benefits and environmental impact criteria to reflect their relative importance (Saaty, 1994). On the criteria scoring matrix, all criteria have been listed and compared, one against another. One pair of attributes is compared at a time. Letters of both attributes were indicated on each cell. If the two attributes are judged to be equally important, respondents are asked to insert both letters. On the other hand, if one attribute is judged to be more important than the other, only the letter of that attribute will be inserted.

This method has been widely used to evaluate non-monetary benefits such as aesthetics and environmental sustainability (Voogd, 1983; Njikamp et al, 1990; Saaty, 1994; Kirk & Dell'Isola, 1995). This process is designed to isolate important criteria, establishing their weights of relative importance. Each criterion is first scored relative to every other criterion. The results of this paired scoring are used to assign weights to each criterion. Through this process of comparison, all criteria received equal consideration in determining the final weight of importance.

The second stage of weight estimation was to use a ranking method to arrange the attributes in the order of importance. After all possible criteria pairs had been compared and scored, raw scores were developed by adding the scores for the individual criterion. Each criterion is counted and recorded. When one letter is inserted the criterion is awarded one point but if both letters are inserted, each is awarded half a point. The total scores for each criterion will be calculated and listed in descending order. The seven criteria of external benefits are ranked from one to seven with one being the least important. The five environmental impact criteria are ranked from one to five with one being the least important.

A team of 10 experts from the construction industry evaluated external benefits and environmental impact. The team consisted of project managers, site managers, construction managers, registered architects and engineers. A workshop was organised to discuss the criteria and sub-criteria in the questionnaire before the field exercises. Each member was responsible for assessing from one to three projects in accordance with their proximity to the projects. They were required to visit the site and evaluate each project in accordance with the questionnaire. In addition, they were required to take photographs and prepare a brief report on the projects that they were assessing.

Once the weights had been established, the criterion score and weights were amalgamated. The weights and value functions were combined into a single overall value using a weighted summation technique (Voogd, 1983; Nijkamp et al, 1990). The weighted summation technique used here is a utility-based multi-criteria method and the weights are interpreted in the context of a linear utility function. The numerical weights obtained from Part C of the survey were applied to the criteria in Parts A and B for each project. For each criterion, the scores were multiplied by the weight and then added to give a total score for each project. Table 6.6 (see next page) shows the scores for external benefits and environmental impact.

Table 6.6 Summary of the weighted value scores of external benefits and environmental impact of 20 high schools in NSW

Project No.	External benefits (value score)	Environmental impact (value score)
1	275.50	185.50
2	231.50	222.00
3	254.00	250.00
4	350.90	172.50
5	298.50	240.00
6	360.30	222.58
7	321.50	245.50
8	236.50	202.00
9	268.50	205.50
10	310.50	193.00
11	276.00	228.00
12	184.00	244.00
13	259.50	213.00
14	328.00	149.00
15	246.00	213.00
16	305.00	196.00
17	275.00	168.95
18	159.00	207.50
19	315.00	232.00
20	265.00	218.00
Mean	276.01	210.40
Standard Deviation	50.82	27.24

The weighted value scores, as presented above, provide an assessment of the environmental performance of each project using a multi-criteria analysis approach. For external benefits, the higher the score the better the project, whilst for environmental impact the lower the score the better the project. Further analysis and discussion are included in Chapter Seven.

6.7 CONCLUSION

The literature review in Chapters Two to Four has provided a comprehensive evaluation of the current thinking on environmental problems, their relationship to construction, and the ways that the construction industry has used to minimise detrimental effects. It was also suggested, in the literature review, that it is inadequate to consider environmental effects only during the design stage; they also need to be considered at an early stage of a development as part of the decision-making process. Following the industry questionnaire survey discussed in Chapter Five that aimed at identifying sustainable development determinants in project appraisal, this chapter summarised the case study and data collection processes for the four criteria to be assessed in the sustainability index. The processes and methods included using a traditional approach to measure construction cost, building life cost and energy consumption. A questionnaire was also used to compile data to assess each project's environmental performance. The details of data collection were discussed and the results also presented in this chapter.

In Chapter Seven, descriptive statistics and regression analysis are used to examine the properties and characteristics of the data, followed by a detailed discussion.

CHAPTER SEVEN

DATA ANALYSIS AND DISCUSSIONS

7.1 INTRODUCTION

Chapter Five presented the conceptual model of the sustainability index to appraise built projects and facilities. The literature review and the industry survey identified the main determinants for inclusion in the index. In order to establish the index structure and to understand the specific relationships between building cost, energy consumption, external benefits and environmental impact in the index, data were derived in Chapter Six using a variety of approaches.

This chapter presents the results of the data analysis for the data collected in Chapter Six for each criterion. The main objective of this chapter is to examine properties and characteristics of the data for the four criteria in the sustainability index. Data analysis also includes comparing projects by age and by geographical location. In this chapter tables, graphs and charts are used to present the data. Further analyses are also carried out to examine the relationships between building cost and energy consumption and the size of projects. Regression analysis and a two-sample ‘t’ test are used to explore the results. The results obtained in this chapter will provide information for the development of new decision-making models in Chapter Eight.

7.2 BUILDING COST

7.2.1 Construction and building life costs

Building cost is the sum of construction and building life costs, but excludes land and other development such as infrastructure, demolition and recycling costs. The building life cost was measured over an economic life of 60 years. The detailed methods used to collect data and calculate building cost were discussed in Chapter Six. The results of that data analysis are presented and discussed in this section. Table 7.1 shows the summary of construction costs and building life cost per square metre of gross floor area for the 20 projects.

Table 7.1 Summary of construction and building life costs

Project No.	Construction cost		Building life cost (60 years)	
	Total	$\$/m^2$	Total	$\$/m^2$
1	14,156,026.94	1,444.49	16,440,940.00	1,677.65
2	17,874,912.87	1,322.21	18,108,224.26	1,339.46
3	11,666,223.82	1,441.70	12,218,112.73	1,509.90
4	17,089,957.74	1,360.12	23,030,654.99	1,832.92
5	13,806,320.77	1,211.29	17,004,757.72	1,491.91
6	17,758,856.86	1,157.38	25,282,202.37	1,647.69
7	6,988,223.60	1,326.54	13,320,357.55	2,528.54
8	13,625,022.38	1,582.46	13,590,692.16	1,578.48
9	16,104,053.77	1,313.01	19,832,480.91	1,617.00
10	15,423,724.32	1,435.17	19,654,007.73	1,828.79
11	16,186,966.98	1,225.08	23,628,872.86	1,788.30
12	3,640,851.85	1,197.65	8,176,231.05	2,689.55
13	10,962,293.01	1,188.97	17,512,979.94	1,899.46
14	1,941,553.73	1,499.27	4,096,456.71	3,163.29
15	16,071,139.45	1,813.08	13,789,919.34	1,555.72
16	13,869,918.03	1,631.76	13,847,538.15	1,629.12
17	19,748,015.33	1,263.39	25,209,697.91	1,612.80
18	7,334,737.78	1,803.92	13,363,054.70	3,286.54
19	9,864,048.50	1,312.41	12,319,172.25	1,639.06
20	2,350,323.43	666.95	9,151,978.53	2,597.04
Mean	12,323,158.56	1,359.84	15,978,916.59	1,945.66
Standard Deviation	5,355,987.46	251.12	5,720,161.23	574.69

From the table, it can be seen that construction cost ranged from $\$666.95/m^2$ to $\$1,813.08/m^2$ with an average of $\$1,359.84/m^2$. In accordance with Rawlinsons Edition 21, the estimated building costs per square metre of secondary schools with a maximum of three storeys, including covered ways, are in the range of $1,485 to $1,615 per square metre (Rawlinsons, 2003, p. 39). The average construction cost per square metre is approximately 12 percent lower than the average price in Rawlinson Edition 21.

The building life cost ranges from $4,096,456.71 to $25,282,202.37 with an average of $15,978,916.59 over a 60-year life span. The $1,945.66/m^2 average building life cost is about 43 percent more than the construction cost per square metre of gross floor area.

Table 7.2 shows the summary of construction and building life cost per annum and per square metre of gross floor area. For the 20 projects the average annual building life cost is approximately 30 percent more than the construction cost. Alternatively, it shows that 46 years of the average building life cost is equivalent to the average construction cost, which is usually spent during the first two years of a development. The importance of building life cost is obvious in comparison with construction cost.

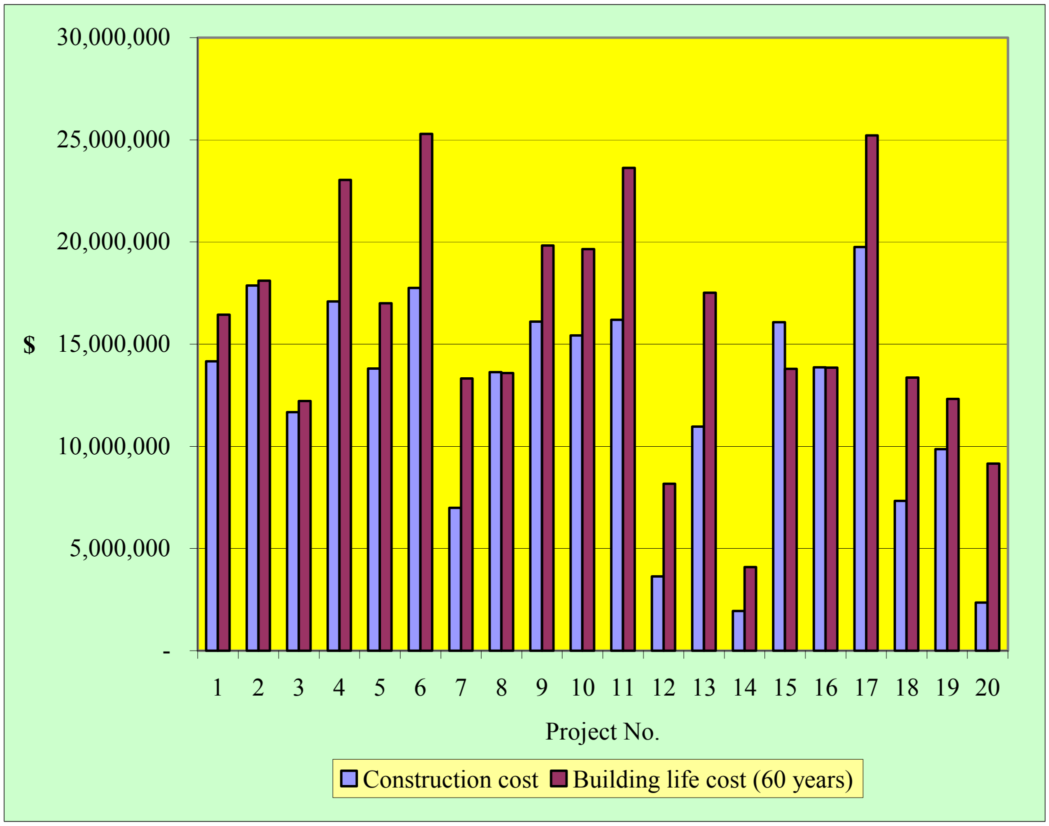
Table 7.2 Summary of construction and building life cost per annum and per square metre of gross floor area

Project No.	Construction cost			Building life cost		
	Annual (60 years)	$/m^2	Proportion of total (%)	Annual (60 years)	$/m^2	Proportion of total(%)
1	235,933.78	24.07	46.27	274,015.67	27.96	53.73
2	297,915.21	22.04	49.68	301,803.74	22.32	50.32
3	194,437.06	24.03	48.84	203,635.21	25.17	51.16
4	284,832.63	22.67	43.60	383,844.25	30.55	57.40
5	230,105.35	20.19	44.81	283,412.63	24.87	55.19
6	295,980.95	19.29	41.26	421,370.04	27.46	58.74
7	116,470.39	22.11	34.41	222,005.96	42.14	65.59
8	227,083.71	26.37	50.06	226,511.54	26.31	49.94
9	268,400.90	21.88	44.81	330,541.35	26.95	55.19
10	257,062.07	23.92	43.97	327,566.80	30.48	56.03
11	269,782.78	20.42	40.65	393,814.55	29.81	59.35
12	60,680.86	19.96	30.81	136,270.52	44.83	69.19
13	182,704.88	19.82	38.50	291,883.00	31.66	61.50
14	32,359.23	24.99	32.16	68,274.28	52.72	67.84
15	267,852.32	30.22	53.82	229,831.99	25.93	46.18
16	231,165.30	27.20	50.04	230,792.30	27.15	49.96
17	329,133.59	21.06	43.93	420,161.63	26.88	56.07
18	122,245.63	30.07	35.44	222,717.58	54.78	64.56
19	164,400.81	21.87	44.47	205,319.54	27.32	55.53
20	39,172.06	11.12	20.43	152,532.98	43.28	79.57
Mean	205,385.98	22.66	41.85	266,315.28	32.43	58.15
Standard Deviation	89,266.46	4.19	8.03	95,336.02	9.58	8.03

The relative proportion of construction and building life cost also indicates that about 58 percent of the building cost is used for running and maintaining the building whilst only 42 percent is used for its initial construction. On the other hand, the analysis indicates that building life cost offers a potential area for cost reduction in the activities carried out during the operational period. If they can be properly managed by facilities managers to optimise the efficiency of the building, cost can be minimised.

Figure 7.1 presents the comparison between construction cost and building life cost using a column chart. Almost all the projects have higher building life cost than construction cost. There are only three projects (Nos. 8, 15, 16) that have a construction cost approximately equivalent or slightly higher than the building life cost.

Figure 7.1 Comparison of construction cost and building life costs (60-year life span)



7.2.2 Comparing construction and building life costs by elements

Table 7.3 (see next page) illustrates the construction and building life costs by elements and by proportion of the total. The construction and building life costs are compared in an elemental standard format in accordance with the Australian Cost Management Manual (Australian Institute of Quantity Surveyors, 2001). From the table, the roof is identified as the most important element in construction cost, costing 10.29 percent of the total, followed by substructure (8.02 percent), external wall (6.97 percent), electrical and lighting (5.38 percent). In building life cost, electrical and lighting are the most important elements accounting for 23.27 percent of the total building life cost, followed by floor finishes (13.45 percent), roof (7.85 percent) and windows (4.93 percent).

The table also indicates that the cost of the structure (from substructure to external walls) accounts for approximately 31 percent of the construction cost whilst structure consumes only about 11 percent in the building life cost. The majority of the building life cost is replacing floor finishes, roof covering and building services. The internal finishes consume about 22 percent of the total building life cost, but their construction cost is only about 11 percent.

Of building services, electrical and lighting accounts for 5.38 percent of the construction cost but requires 23.27 percent of the building life cost to run and maintain the system. This is mainly affected by the efficiency of equipment and the weather conditions. Building services also offer a great potential for cost saving during the operational stage of a building.

Table 7.3 Summary of average construction cost and building life cost by elements and by proportion

Elements	Construction cost		Building life cost	
	Average ($)	Proportion of total (%)	Average ($)	Proportion of total (%)
Preliminaries	1,139,942.86	9.25	1,536,158.42	9.61
Substructure	988,612.31	8.02	16,013.70	0.10
Columns	194,190.01	1.58	12,132.20	0.08
Upper floors	401,693.78	3.26	3,514.90	0.02
Staircases	88,159.74	0.72	138,117.95	0.86
Roof	1,268,178.51	10.29	1,254,871.64	7.85
External walls	859,232.86	6.97	318,013.00	1.99
Windows	538,866.81	4.37	787,591.73	4.93
External doors	149,504.88	1.21	156,138.41	0.98
Internal walls	340,574.42	2.76	203,004.59	1.27
Internal screens	177,011.20	1.44	261,683.35	1.64
Internal doors	169,602.71	1.38	119,661.09	0.75
Wall finishes	343,646.35	2.79	774,992.45	4.85
Floor finishes	488,543.31	3.96	2,149,733.10	13.45
Ceiling finishes	510,992.30	4.15	512,135.39	3.21
Fixtures and fittings	450,448.00	3.66	688,872.43	4.31
Special equipment	69,484.35	0.56	126,919.72	0.79
Sanitary fixtures	251,679.95	2.04	467,653.30	2.93
Sanitary plumbing	144,430.63	1.17	275,177.50	1.72
Water supply	47,695.71	0.39	388,139.45	2.43
Gas services	46,598.35	0.38	408,208.98	2.55
Space heating	58,750.45	0.48	73,305.75	0.46
Ventilation	176,287.00	1.43	75,382.73	0.47
Evaporative cooling	81,741.22	0.66	50,249.00	0.31
Air conditioning	8,139.41	0.07	8,900.00	0.06
Fire protection	18,475.81	0.15	27,321.60	0.17
Electrical & lighting	663,387.90	5.38	3,718,362.32	23.27
Communication	41,298.22	0.34	18,689.30	0.12
Transportation	61,617.72	0.50	30,000.00	0.19
Special services	22,623.06	0.18	10,834.16	0.07
Site preparation	432,283.71	3.51	11,161.75	0.07
Roads, footpaths	589,857.10	4.79	435,721.51	2.73
Fence	120,201.63	0.98	120,876.60	0.76
Outbuildings	284,965.24	2.31	222,476.20	1.39
Landscaping	320,466.43	2.60	307,876.07	1.93
External stormwater	223,324.52	1.81	34,500.00	0.22
External sewer	79,291.75	0.64	13,852.50	0.09
External water supply	78,387.51	0.64	31,585.00	0.20
External gas	39,931.42	0.32	3,190.00	0.02
External fire protection	46,381.95	0.38	15,613.00	0.10
External electrical & lighting	190,506.67	1.55	119,431.47	0.75
External communication	11,227.14	0.09	35,732.37	0.22
Special provision	104,923.67	0.84	15,121.97	0.08

Figures 7.2 to 7.5 show the proportion of elements by category using percentage component bar charts. Figure 7.2 shows the composition of superstructure for construction and building life costs. In comparison, the roof is the most important element; this particularly evident in building life cost. It accounts for a majority of the expenditure in the building life cost.

Figure 7.2 Composition of superstructure for construction and building life costs

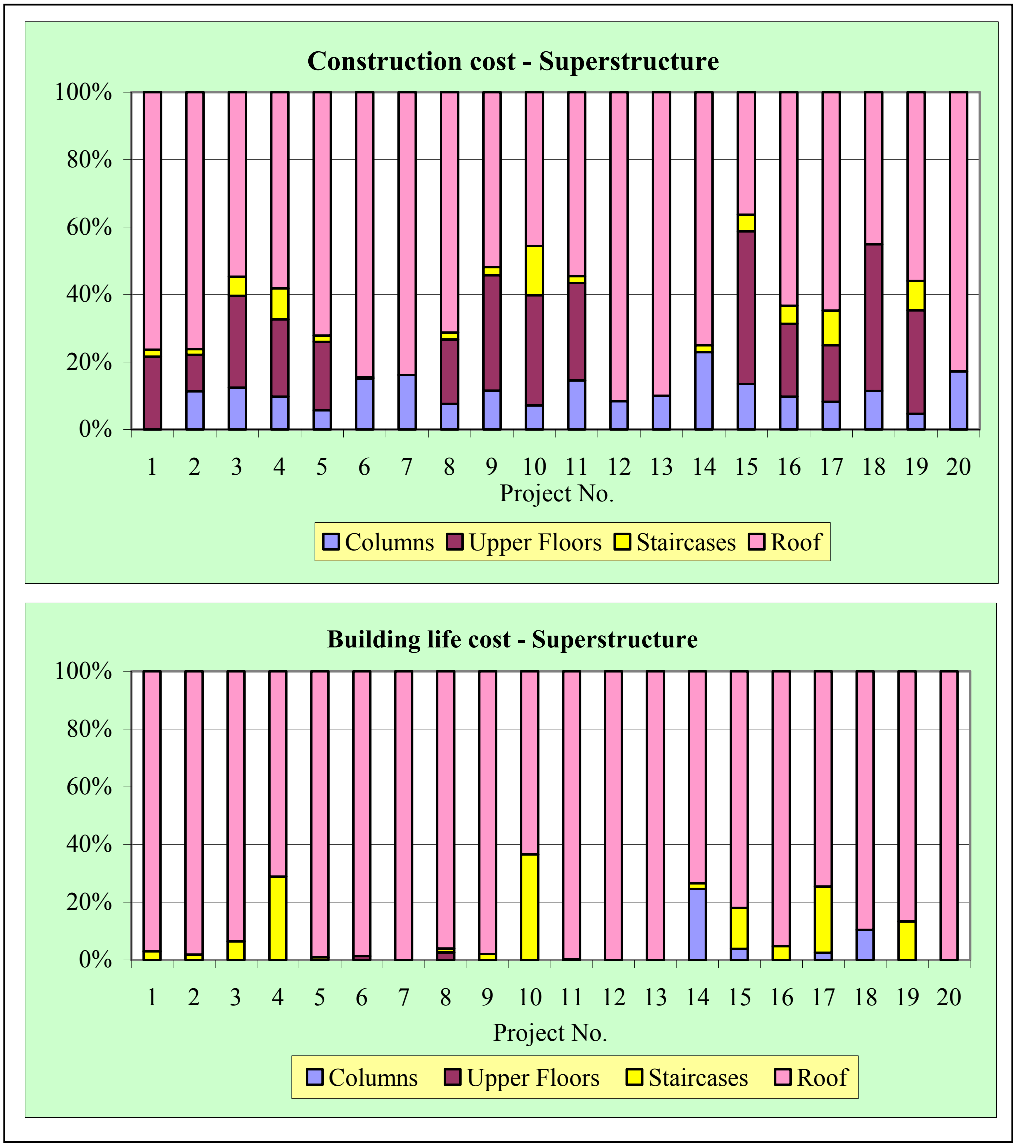


Figure 7.3 compares the composition of the external fabric of construction with building life costs. In construction cost the proportion of external wall is more important than the other elements but during operational period the window element takes the lead. This may be because windows require more regular cleaning, repair and replacement than the other elements in the same group.

Figure 7.3 Composition of external fabric for construction and building life costs

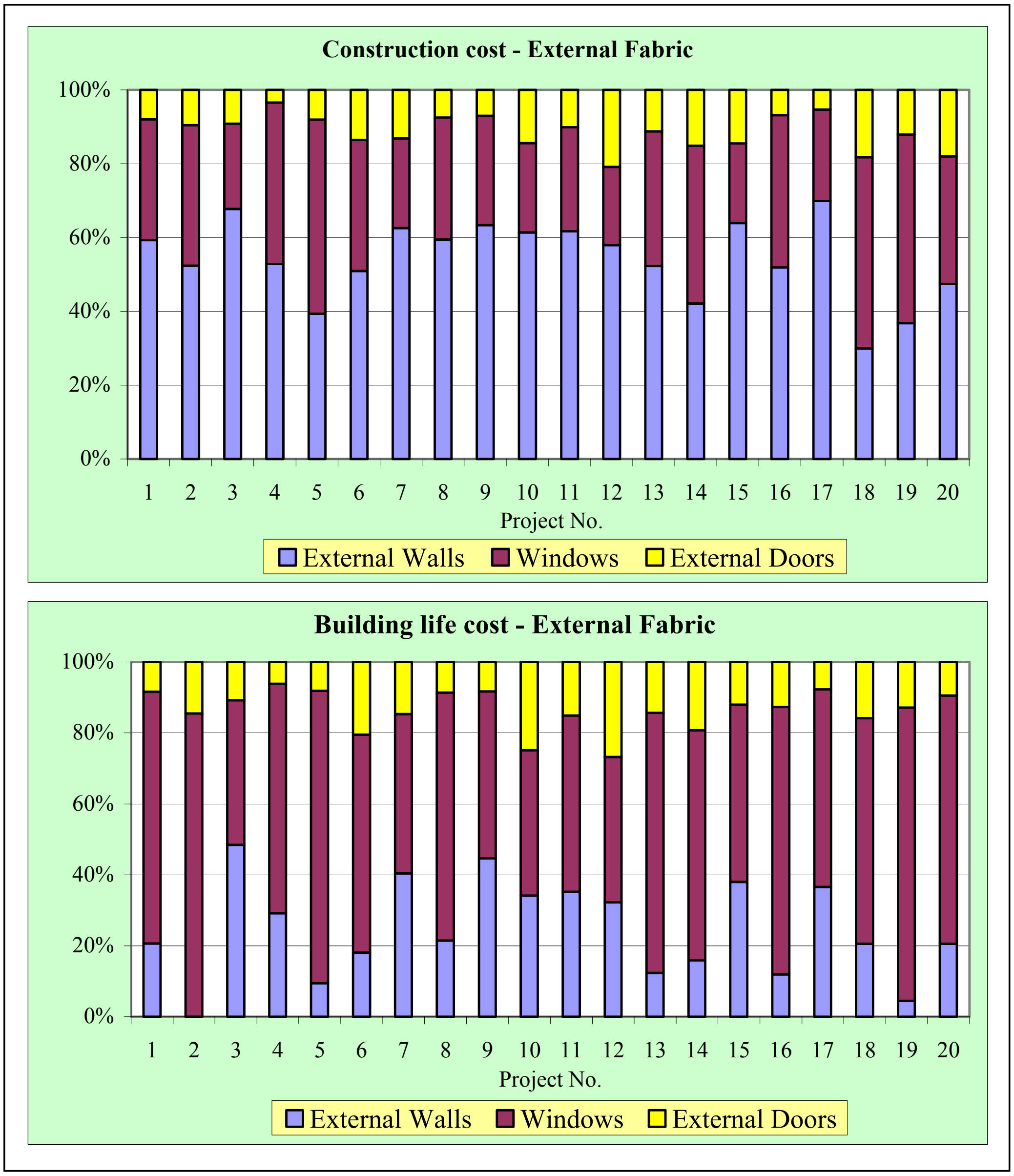


Figure 7.4 demonstrates the composition of internal finishes. It is evident that floor and ceiling finishes contribute equally to construction cost, whilst during the operational period the floor finishes are predominately more important than the rest of the elements. Floor coverings in high schools are mainly vinyl and carpet which require regular vacuum cleaning, repair and replacement. Carpets in particular are expensive and require more frequent maintenance and replacement.

Figure 7.4 **Composition of internal finishes for construction and building life costs**

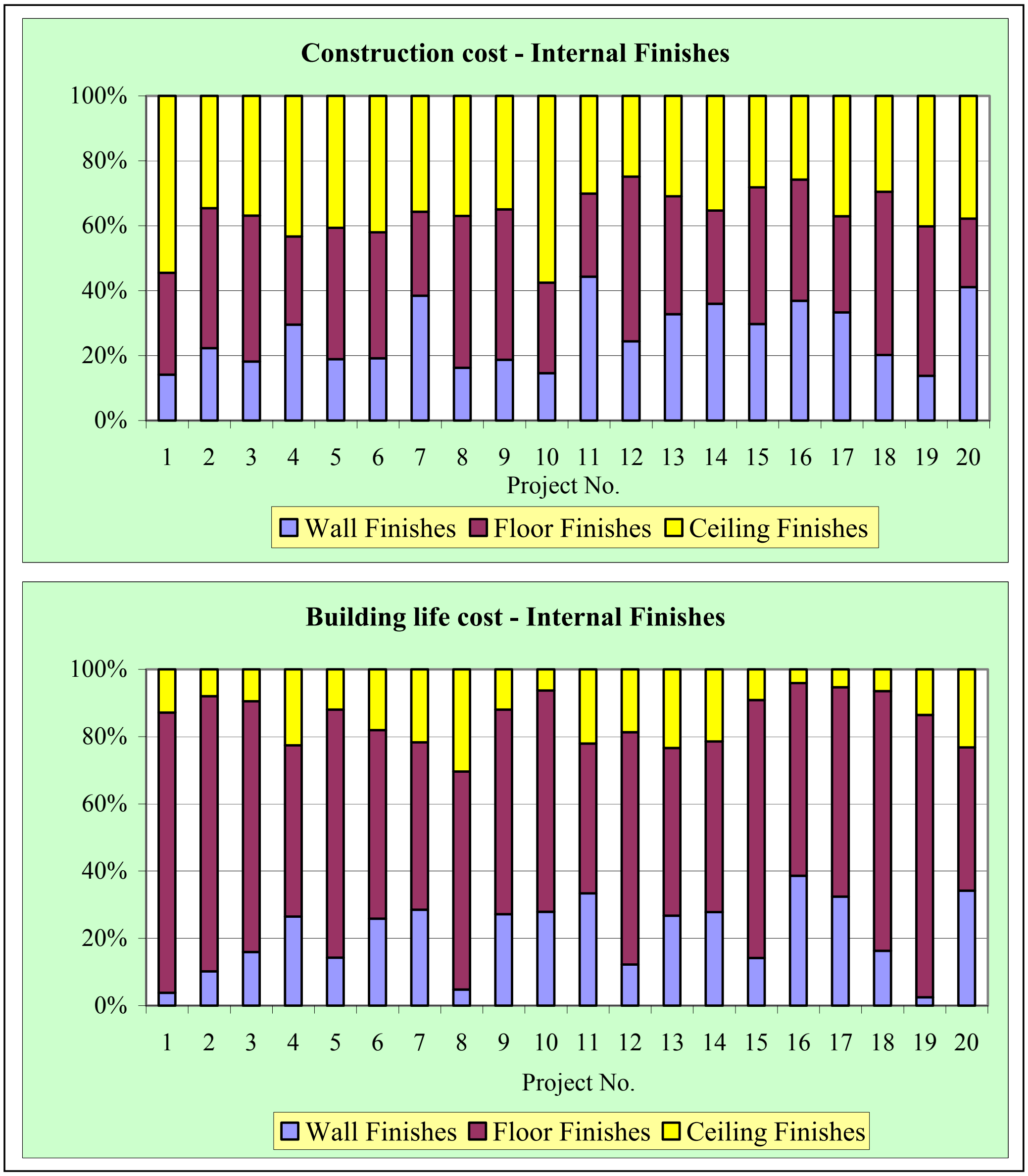
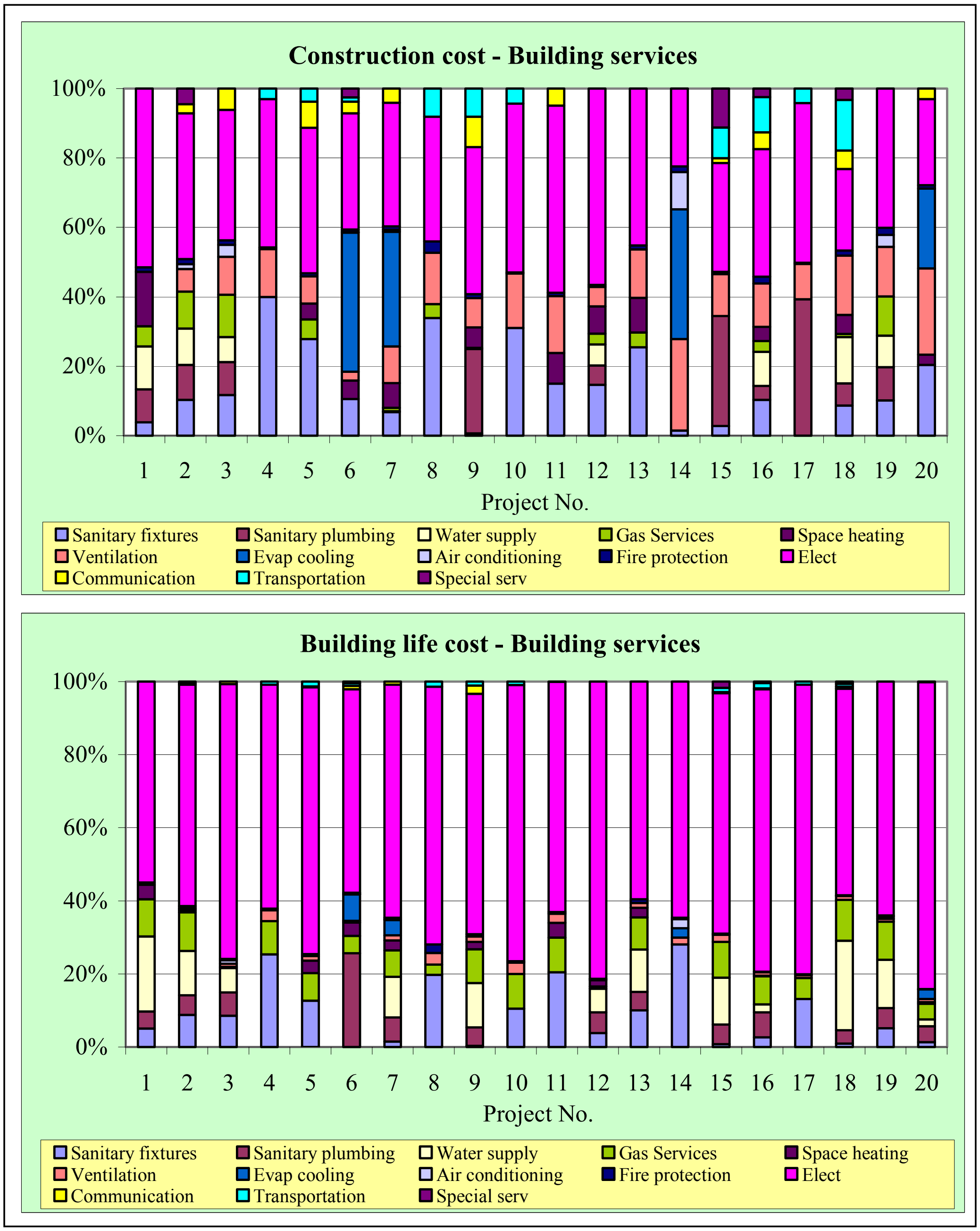


Figure 7.5 (see next page) shows the breakdown of building services. In construction cost the percentage of electrical, lighting and sanitary fixtures are most significant. However, during the operational period, electrical and lighting prevails over the other elements as the major cost with the rest accounting only for a small fraction.

Figure 7.5 **Composition of building services for construction and building life costs**



Construction cost - Building services

Building life cost - Building services

7.3 ENERGY CONSUMPTION

7.3.1 Initial and recurrent embodied energy

Total energy comprises the initial and recurrent embodied energy of building materials and components plus the operational energy, measured over the building's economic life. Chapter Six detailed the data collection methods and total energy consumption calculation. This section presents and discusses the results from analysing the energy consumption of the projects' data. Discussing life cycle energy for the sample of case studies requires an estimate of building age at the time of demolition (Yohanis & Norton, 2002). As there is no way to accurately predict this event, this energy has been omitted from the study. Detailed discussions are included in Chapter Three.

The embodied energy of building services was not estimated in this study as detailed designs were not available. In addition, the material energy intensity information was inadequate, failing to provide enough information for energy analysis. The estimate was adopted from the literature and a proportion of 19 percent of the total initial embodied energy (before the energy allowance for on-site processes, fixtures and fittings, and incompleteness) has been added, which was the lowest allowance found in the literature (Cole & Kernan, 1996; Treloar, 1996a; Pullen, 2000b; Yohanis & Norton, 2002) (details see Table 3.4 of Chapter Three).

Fixtures and fittings including furniture are required to fit out rooms in a school building such as classrooms, offices, libraries and laboratories. For similar reasons as above, these elements were not estimated but a measure of 0.70 GJ/m^2 was adopted from the literature (McCoubrie & Treloar, 1996; Treloar et al., 1999).

The literature recommends adding a further 10 to 20 percent to the initial embodied energy calculation to cover the direct energy consumption of the construction process. This also allows for the incomplete embodied energy coefficient (Lawson, 1996b; Pullen & Perkins, 1995; Stewart et al., 1995; Treloar & Fay, 1998; Treloar et al., 1999; Pullen, 2000a & b). Detailed discussion of these allowances appears in Chapter Three.

The embodied energy calculation includes initial embodied energy and recurrent embodied energy. Initial embodied energy measures the energy used to produce building materials and components. The recurrent energy occurs as a result of materials used in routine maintenance, repair and refurbishment during the operational period. A maintenance cycle of materials and components, as shown in Table 6.3 of Chapter Six, was used in calculating recurrent embodied energy for a 60-years life span.

Table 7.4 summarises the initial and recurrent embodied energy for the 20 school projects. The initial embodied energy consumption for the 20 high schools was in the range of 7,954.98 GJ to 125,984.76 GJ with an average of 72,020.21 GJ. The average initial embodied energy per square metre of floor area was 7.83 GJ/m^2. Additionally, an average 75,450.61 GJ of recurrent embodied energy was required over a 60-year life cycle to operate and maintain the projects. The recurrent embodied energy represented an additional of 8.19 GJ/m^2 was required for the 60-year life span.

Table 7.4 Summary of initial and recurrent embodied energy

Project No.	Initial embodied energy		Recurrent embodied energy	
	Total (GJ)	GJ/m^2	Total (60 years) (GJ)	GJ/m^2
1	84,998.11	8.67	79,497.89	8.11
2	113,623.34	8.40	109,975.72	8.13
3	82,137.20	10.15	70,597.64	8.72
4	109,947.52	8.75	110,012.39	8.76
5	81,056.76	7.11	97,774.72	8.58
6	94,865.80	6.18	122,418.39	7.98
7	25,597.36	4.86	37,163.73	7.05
8	77,188.74	8.97	75,216.66	8.74
9	89,882.33	7.33	104,969.72	8.56
10	101,805.15	9.47	97,370.76	9.06
11	88,482.53	6.70	103,914.59	7.86
12	24,279.01	7.99	24,383.46	8.02
13	51,265.71	5.56	69,709.54	7.56
14	7,954.98	6.14	10,433.52	8.06
15	71,630.45	8.08	67,820.21	7.65
16	81,318.63	9.57	75,121.86	8.84
17	125,984.76	8.06	130,433.53	8.34
18	52,684.17	12.96	38,639.08	9.50
19	65,348.86	8.69	62,754.48	8.35
20	10,352.83	2.94	20,704.25	5.88
Mean	72,020.21	7.83	75,450.61	8.19
Standard deviation	33,823.87	2.14	34,966.99	0.78

Because data is unavailable for high school projects, the initial embodied energy per square metre of gross floor area found in this study can be compared with the study of embodied energy for other types of buildings (see Table 3.1 of Chapter Three). For residential development, the initial embodied energy ranged between3.60 to 8.76 GJ/m^2 (Edwards et al., 1994; Pullen, 1995; Treloar, 1996b; Treloar, 1998; Pullen, 2000b). A bigger range was found in commercial developments where the initial embodied energy ranged from 3.40 to 19.00 GJ/m^2 (Oppenheim &Treloar, 1995; Cole & Kernan, 1996; Treloar, 1996b; Pullen, 2000c; Yohanis & Norton, 2002). The initial embodied energy for a university building was 11 GJ/m^2 (Pullen, 2000c).

The initial embodied energy intensity of 7.83 GJ/m^2 as found in this study was within the range of these research results and was reasonably consistent with the outcomes found in the literature. The divergence of initial embodied energy was well documented in the literature, as there are many variables that may affect the outcomes (Cole & Kernan, 1996; Fay & Treloar, 1998; Pullen, 2000b). The potential errors associated with embodied energy estimates have been discussed in detail in Chapter Three. It is also possible that the divergence may be due to the energy terms used in the research. The results reported in this study were presented in primary energy terms, whilst the energy terms for most research work found in the literature were not stated (Fay & Treloar, 1998; Pullen, 2000b). This study also has wider boundaries than most previous studies by including such items as furniture, appliances, landscaping and services which have often been neglected in previous studies.

The recurrent embodied energy per square metre of gross floor area found in the study was 8.19 GJ/m^2 over a 60-year life span, representing approximately 5 percent more than the initial embodied energy. From the literature, the recurrent embodied energy for residential development was 9.90 GJ/m^2 (Pullen, 2000b) while commercial development ranged from 6.32 to 20.40 GJ/m^2 (Cole & Kernan, 1996; Yohanis & Norton, 2002) (see Table 3.3 of Chapter Three). The figure found in this study was lower than the residential development and at the lower end of commercial development ranges. This may partially be due to the different life expectancy of school buildings, and difference in the nature and frequency of maintenance and refurbishment during the operational period. The information from the literature may perhaps only be used as a reference point as it is difficult for any comparison to be carried out with the lack of sufficient details on the studies. As with initial embodied energy, fixtures and fittings were included although, in most studies, they have not. A percentage allowance was made given the lack of detailed information.

Table 7.5 and Figure 7.6 (see next pages) present the average initial and recurrent embodied energy by element. Apart from building services, fixtures and fittings, and incompleteness, the substructure of a building was the most significant building element in the initial embodied energy analysis accounting for 10.39 percent, followed by external walls (9.82 percent) and roof (9.16 percent). These main structures of a building are usually high in initial embodied energy content due to the type of materials used in the construction such as concrete, reinforcement, structural steel and bricks in high school projects.

Internal finishes, screens and doors, and external doors were the least important elements, each accounting for less than 2 percent. Even though these elements were less important for initial embodied energy calculation, they played a significant role in the recurrent embodied energy analysis due to the need for regular repair, refurbishment, maintenance and replacement.

The recurrent embodied energy associated with maintenance, repair, refurbishment and replacement can be predicted, to some extent, as far as general upgrading is concerned. However, it is more difficult to anticipate future alterations to building use as a result of changes in teaching techniques and community needs. In the recurrent embodied energy calculation, building services were to be upgraded or replaced at every 30 years and fixtures and fittings (including loose furniture and fixed fittings) were to be replaced at every 10 years.

Table 7.5 shows that the building services, and fixtures and fittings account for 72.34 percent of the total recurrent embodied energy representing approximately 373 percent of the initial embodied energy of 19.38 percent. Also shown in Table 7.5, the other significant elements of recurrent embodied energy were the roof (8.39 percent), floor finishes (7.09 percent) and windows (3.39 percent). The building structure became less significant in the recurrent embodied energy analysis, using a total of less than 1 percent.

Table 7.5 Average initial embodied energy by element

Elements	Initial embodied energy		Recurrent embodied energy	
	Average (GJ)	Proportion of total (%)	Average (GJ)	Proportion of total (%)
Substructure	7,907.49	10.39	27.19	0.04
Columns	1,683.60	2.21	108.08	0.14
Upper Floors	4,622.26	6.07	86.14	0.11
Staircases	581.90	0.76	487.27	0.64
Roof	6,970.83	9.16	6,387.61	8.39
External Walls	7,478.31	9.82	1,281.84	1.68
Windows	2,219.92	2.92	2,576.33	3.39
External Doors	219.22	0.29	244.69	0.32
Internal Walls	2,943.65	3.87	763.77	1.00
Internal Screens	380.13	0.50	552.22	0.73
Internal Doors	250.90	0.33	123.05	0.16
Wall Finishes	539.32	0.71	641.95	0.84
Floor Finishes	1,251.48	1.64	5,396.55	7.09
Ceiling Finishes	1,289.23	1.69	948.66	1.25
Fixtures and fittings	6,386.82	8.39	38,320.94	50.35
Building Services	8,369.36	10.99	16,738.72	21.99
Site Preparation	1,420.00	1.87	101.05	0.13
Roads & Footpaths	4,451.76	5.85	365.21	0.48
Fence	1,720.00	2.26	245.51	0.32
Outbuildings	1,720.00	2.26	625.12	0.82
Landscaping	513.06	0.67	80.53	0.11
On-Site Process	4,404.94	5.79	N/A	N/A
Incompleteness	8,809.88	11.57	N/A	N/A

Figure 7.6 Average initial and recurrent embodied energy by elements

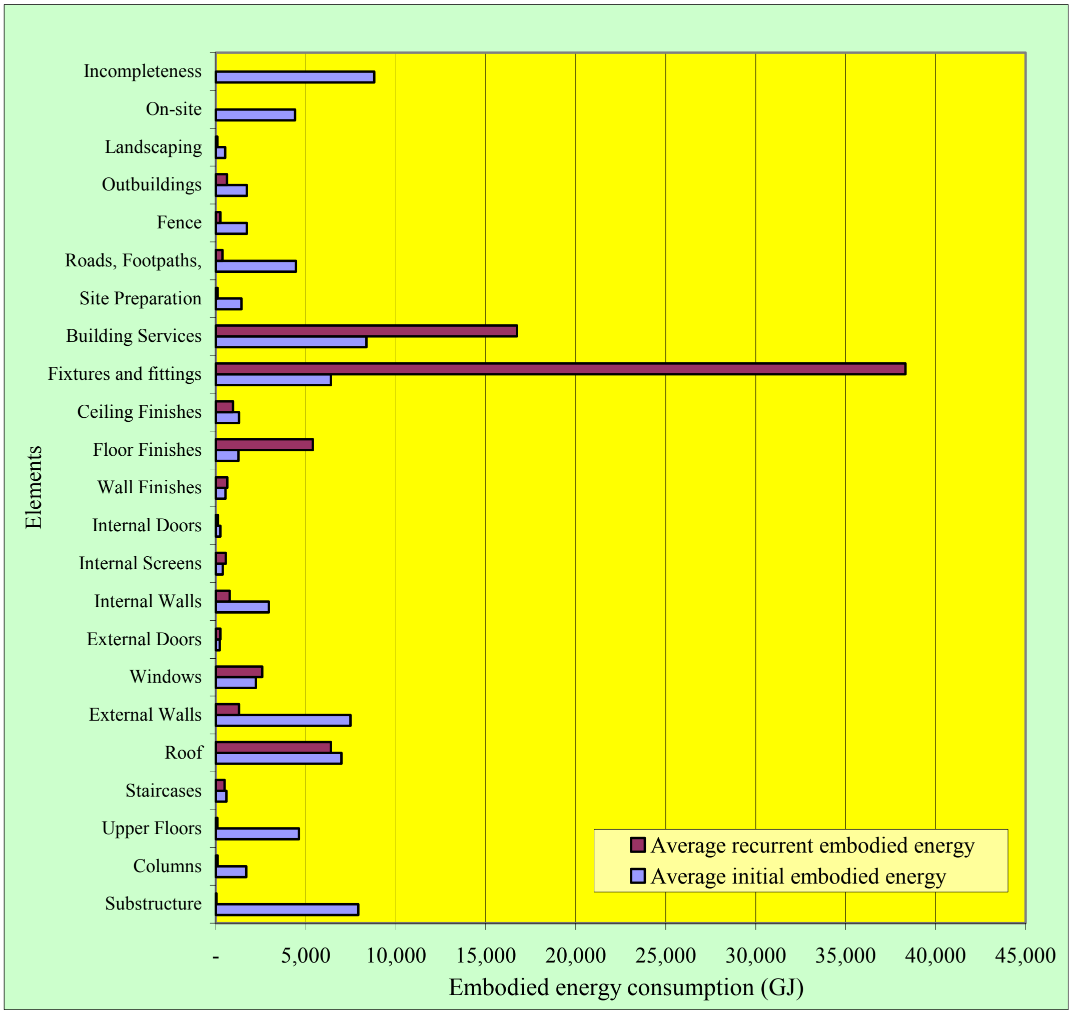


Figure 7.7 compares initial and recurrent embodied energy by major elements. It was shown that initial embodied energy was evenly distributed amongst the major elements, whilst in recurrent embodied energy, building services, and fixtures and fittings were the prime energy consumers for repair, maintenance and refurbishment.

Figure 7.7 Comparison of initial and recurrent embodied energy by major elements

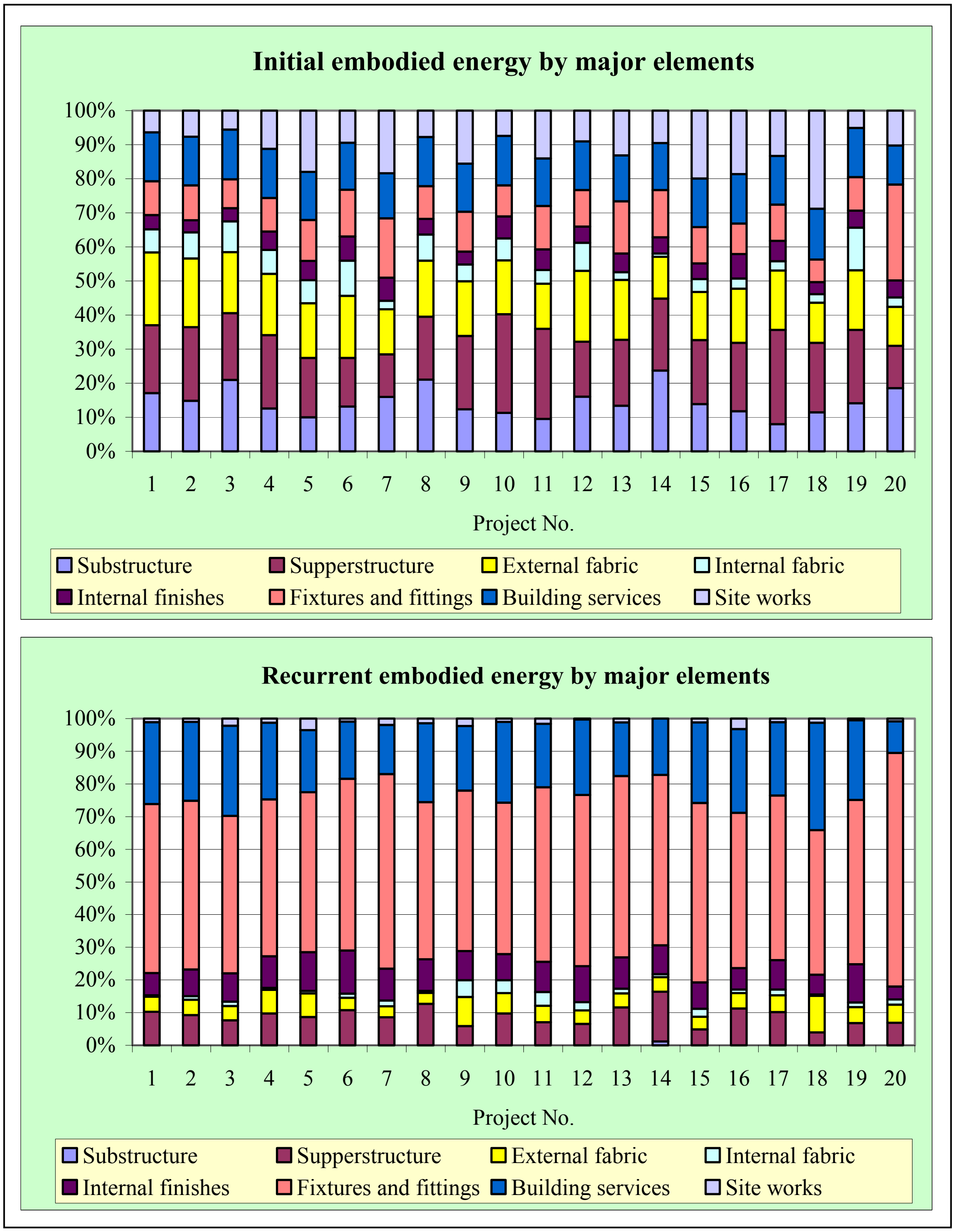


Table 7.6 compares annual consumption of initial and recurrent embodied energy. The initial and recurrent embodied energy were distributed over an economic life of 60 years, showing that the average annual energy consumption is 1,200.34 GJ and 1,257.51 GJ for initial and recurrent embodied energy respectively. On average,

recurrent embodied energy represented a proportion of 52 percent of total embodied energy consumption, whilst initial embodied energy is 48 percent. Over a 60-year life span, the average annual recurrent embodied energy is approximately 5 percent more than the average annual initial embodied energy. They do not represent a large difference in usage. However, initial embodied energy will have a higher proportion if the life span is reduced. Therefore, initial embodied energy is a significant component in energy analysis.

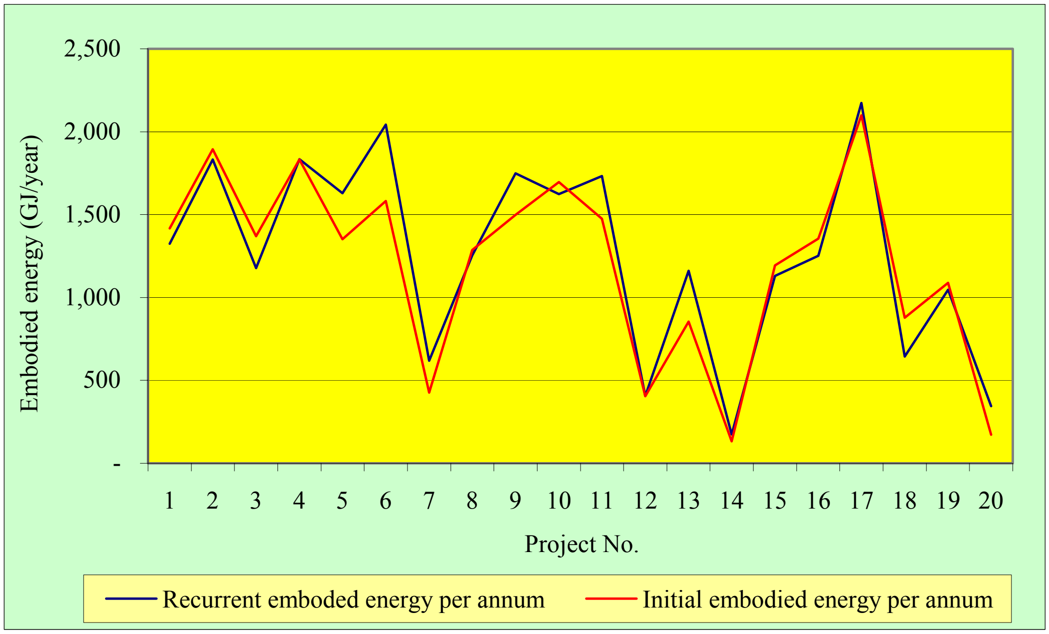
Table 7.6 Summary of initial and recurrent embodied energy per annum (60-year life span)

Project No.	Initial embodied energy			Recurrent embodied energy		
	Total	Annual	Proportion	Total	Annual	Proportion
1	84,997.11	1,416.64	51.67	79,497.89	1,324.96	48.66
2	113,623.34	1,893.72	50.82	109,975.72	1,832.93	49.18
3	82,137.20	1,368.95	53.78	70,597.64	1,176.63	46.22
4	109,947.52	1,832.46	49.99	110,012.39	1,833.54	50.01
5	81,056.76	1,350.95	45.33	97,774.72	1,629.58	54.67
6	94,865.80	1,581.10	43.64	122,518.39	2,041.97	56.36
7	25,597.36	426.62	40.79	37,163.73	619.40	59.21
8	77,188.74	1,286.48	50.65	75,216.66	1,253.61	49.35
9	89,882.33	1,498.04	46.13	104,969.72	1,749.50	53.87
10	101,805.15	1,696.77	51.12	97,370.76	1,622.60	48.88
11	88,482.53	1,474.71	45.99	103,914.59	1,731.91	54.01
12	24,279.01	404.65	49.89	24,383.46	406.39	50.11
13	51,265.71	854.43	42.38	69,709.54	1,161.83	57.62
14	7,954.98	132.58	43.26	10,433.52	173.89	56.74
15	71,630.45	1,193.84	51.37	67,820.21	1,130.34	48.63
16	81,318.63	1,355.31	51.98	75,121.86	1,252.03	48.02
17	125,984.76	2,099.75	49.13	130,433.53	2,173.89	50.87
18	52,684.17	878.07	57.69	38,639.08	643.98	42.31
19	65,348.86	1,089.15	51.01	62,754.48	1,045.91	48.99
20	10,352.83	172.55	33.33	20,704.25	345.07	66.67
Mean	72,020.21	1,200.34	48.00	75,450.61	1,257.51	52.00
Standard deviation	33,823.87	563.73	5.45	34,966.99	582.78	5.45

Figure 7.8 (see next page) shows that there were 12 projects with recurrent embodied energy that exceeded the annual initial embodied energy. The study shows that recurrent embodied energy is an important area for further research as it occupied a large part of the annual embodied energy consumption. The option of low energy intensity and long-lasting building materials may be used to minimise energy intake, both during construction and use.

This information is useful for facilities managers because previously the energy implications for replacing building services, and fixtures and fittings were unknown (Treloar et al., 1999). Greater emphasis should now be given to optimising building services, fixtures, fittings and furniture use in terms of environmental performances and energy efficiency. The material energy intensities need to be updated and validated as national, technological and regional averages for Australian and imported products.

Figure 7.8 Comparison of annual initial and recurrent embodied energy



7.3.2 Operational energy

Operational energy measures the energy consumed during the operational stage of a building. The estimation of operational energy varies in accordance with fuel types, efficiency of equipment, weather conditions, operational hours, economic life and activities inside the building. Chapter Six detailed the data collection method and operational energy calculation. The maintenance cycle of materials and components was based on the information contained in Table 6.3 of Chapter Six.

As shown in Table 7.7, the total operational energy consumption for the 20 projects was 199,946.82 GJ and 37,155.66 GJ for electricity and gas respectively, making a total of

237,102.48 GJ based on primary energy term. The total operational energy covered a 60-year economic life of a school building. From the table, it is clear that electricity (84 percent of total energy consumption) was the main source of fuel, with consumption being almost six times more than gas (16 percent).

Table 7.7 Summary of operational energy by fuel types over a 60-year life span

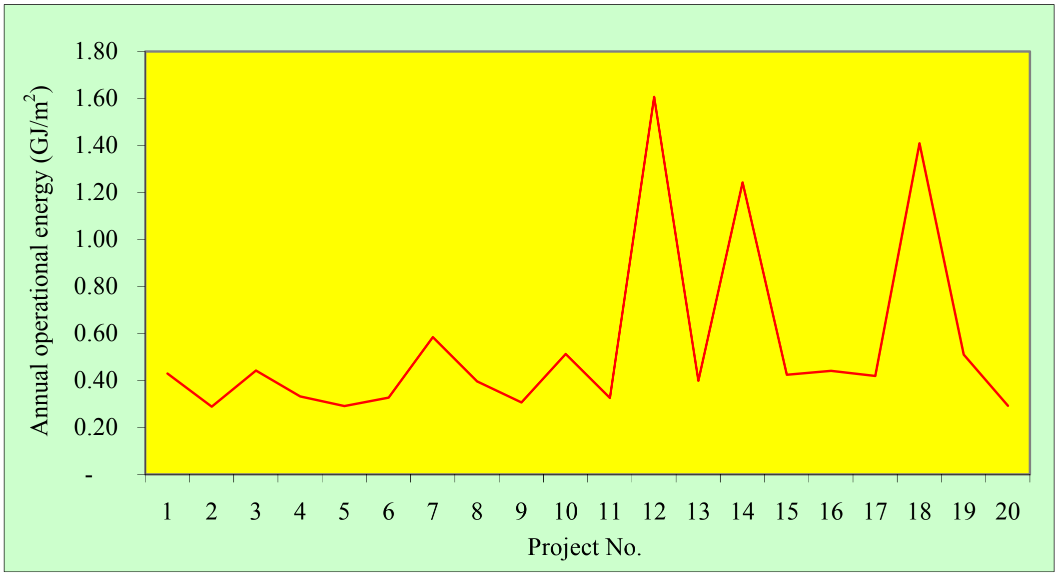
Project No.	Electricity (GJ)	Gas (GJ)	Total operational energy (GJ)
1	206,040.95	46,366.73	252,407.68
2	181,053.74	52,607.78	233,661.52
3	186,705.49	27,914.27	214,619.77
4	201,560.52	48,516.21	250,076.73
5	174,913.91	24,073.13	198,987.05
6	271,655.47	29,234.13	300,889.61
7	132,452.22	52,196.59	184,648.82
8	184,508.51	19,816.70	204,325.21
9	187,094.66	38,527.46	225,622.13
10	285,128.19	45,165.55	330,293.74
11	209,860.77	47,947.23	257,808.00
12	247,556.30	45,536.13	293,092.42
13	183,580.43	37,073.40	220,653.84
14	85,181.97	11,352.45	96,534.42
15	186,941.87	38,464.24	225,406.11
16	200,933.73	23,555.39	224,489.12
17	363,530.25	29,663.29	393,193.54
18	279,715.21	64,177.22	343,892.44
19	189,997.72	39,728.64	229,726.36
20	40,524.41	21,196.67	61,721.07
Mean	199,946.82	37,155.66	237,102.48
Proportion (%)	84.33	15.67	100

Table 7.8 and Figure 7.9 (see next page) show the annual consumption of operational energy per square metre of gross floor area. In Figure 7.9, a majority of the projects ranged between 0.30 to 0.50 GJ/m^2 with six projects outside this range. The average annual operational energy consumption for the 20 projects was 3,951.71 GJ and corresponded with an average of 0.55 GJ/m^2 in primary energy terms.

Table 7.8 Summary of operational energy

Project No	Operational energy			
	Annual		60 years	
	GJ	GJ/m^2	GJ	GJ/m^2
1	4,206.79	0.43	252,407.68	25.76
2	3,894.36	0.29	233,661.52	17.28
3	3,577.00	0.44	214,619.77	26.52
4	4,167.95	0.33	250,076.73	19.90
5	3,316.45	0.29	198,987.05	17.46
6	5,014.83	0.33	300,889.61	19.61
7	3,077.48	0.58	184,648.82	35.05
8	3,405.42	0.40	204,325.21	23.73
9	3,760.37	0.31	225,622.13	18.40
10	5,504.90	0.51	330,293.74	30.73
11	4,296.80	0.33	257,808.00	19.51
12	4,884.87	1.61	293,092.42	96.41
13	3,677.56	0.40	220,653.84	23.93
14	1,608.91	1.24	96,534.42	74.54
15	3,756.77	0.42	225,406.11	25.43
16	3,741.49	0.44	224,489.12	26.41
17	6,553.23	0.42	393,193.54	25.15
18	5,731.54	1.41	343,892.44	84.58
19	3,828.77	0.51	229,726.36	30.56
20	1,028.68	0.29	61,721.07	17.51
Mean	3,951.71	0.55	237,102.48	32.92
Standard deviation	1,265.57	0.39	75,934.39	23.31

Figure 7.9 Annual operational energy consumption per square metre of gross floor area



The main focus of research in energy studies was on commercial and residential buildings' operational energy (Edwards et al., 1994; Pullen & Perkins, 1995; Treloar, 1996b; Adalberth, 1997b; Pullen, 2000b; Treloar et al., 2001b). The research of operational energy for school projects is rare in Australia. A study carried out by Pullen (2000c), discovered that a university building consumed approximately 1.57 GJ/m^2 per year. In addition, a survey of operational energy in Australian higher education buildings found operational energy ranging between 0.30 and 1.00 GJ/m^2 (cited in Pullen, 2000c). Therefore, the result obtained in this study compares favourably with the results from other studies.

The resulting annual average energy consumption in primary energy terms of 0.55 GJ/m^2 in the high school projects compares with Pullen's study of university buildings. The differences may partially be explained by the different usage of the buildings. As for high schools, the usage is on a regular basis from 8.30am to 4.00pm during the day for about 44 weeks every year, representing about 85 percent of full occupancy. For tertiary education, the building usage is different. Evening classes and 24-hour computer laboratories are inevitable and more energy is needed to maintain these functions and activities. Further, the facilities and equipment in university buildings are far more advanced and sophisticated such as laboratories and workshops, compared with high school buildings. However, both types of building consume energy throughout the year to maintain activities.

The results obtained in this study were at the lower end of the range of energy consumed by commercial buildings (0.50 to 1.00 GJ/m^2) and lower than residential developments (0.70 to 0.80 GJ/m^2) quoted in the literature (Oppenheim, 1995; Cole & Kernan, 1996; Treloar et al., 1999; Pullen, 2000b & c). For a detailed discussion, refer to Chapter Three. However, such comparisons are difficult to make as the type of construction, nature of usage and facilities were completely different.

7.3.3 Comparing embodied energy and operational energy

Table 7.9 shows the comparison between embodied energy and operational energy. The average energy consumption was 147,470.82 GJ and 237,102.48 GJ representing 38 and

62 percent respectively for embodied and operational energy over the total energy consumption for a 60 year building life span. This indicates that the embodied energy amounted to nearly 62 percent of the operational energy over the building's lifetime. Alternatively expressed, approximately 37 years of operational energy was equivalent to the total embodied energy. The result was similar to the results obtained in the literature (refer to Chapter Three). The range of operational energy to embodied energy in the literature was from 15 to 37 years (Pullen & Perkins, 1995; Oppenheim & Treloar, 1995; Treloar, 1996b; Cole & Kernan, 1996; Pierquet et al., 1998; Pullen, 2000b). The average ratio of operational energy and embodied energy in the study was 1.6:1 which was lower than the 4:1 to 10:1 ratio suggested in the literature over a 50-year life span (Pullen, 2000b). It may be because items such as building services and fixtures and fittings were included in the calculation of embodied energy in the case studies, but were not usually included in the energy studies in the literature.

Table 7.9 Summary of embodied and operational energy

Project No.	Embodied energy (GJ)			Operational energy (GJ)		
	Total	Annual	GJ/m^2	Total	Annual	GJ/m^2
1	164,496.00	2,741.60	16.79	252,407.68	4,206.79	25.76
2	223,599.07	3,726.65	16.54	233,661.52	3,894.36	17.28
3	152,734.84	2,545.58	18.87	214,619.77	3,577.00	26.52
4	219,959.91	3,666.00	17.51	250,076.73	4,167.95	19.90
5	178,831.49	2,980.52	15.69	198,987.05	3,316.45	17.46
6	217,384.19	3,623.07	14.17	300,889.61	5,014.83	19.61
7	62,761.09	1,046.02	11.91	184,648.82	3,077.48	35.05
8	152,405.40	2,540.09	17.70	204,325.21	3,405.42	23.73
9	194,852.05	3,247.53	15.89	225,622.13	3,760.37	18.40
10	199,175.91	3,319.38	18.53	330,293.74	5,504.90	30.73
11	192,397.13	3,206.62	14.56	257,808.00	4,296.80	19.51
12	48,662.46	811.04	16.01	293,092.42	4,884.87	96.41
13	120,975.24	2,016.25	13.12	220,653.84	3,677.56	23.93
14	18,388.51	306.48	14.20	96,534.42	1,608.91	74.54
15	139,450.66	2,324.18	15.73	225,406.11	3,756.77	25.43
16	156,440.49	2,607.34	18.40	224,489.12	3,741.49	26.41
17	256,418.29	4,273.64	16.40	393,193.54	6,553.23	25.15
18	91,323.25	1,522.05	22.46	343,892.44	5,731.54	84.58
19	128,103.34	2,135.06	17.04	229,726.36	3,828.77	30.56
20	31,057.09	517.62	8.81	61,721.07	1,028.68	17.51
Mean	147,470.82	2,457.85	16.02	237,102.48	3,951.71	32.92
Standard deviation	67,899.87	1,131.66	2.86	75,934.39	1,265.57	23.31

Figure 7.10 compares the operational energy with initial and recurrent embodied energy for the 20 school projects. The figures indicate that embodied energy was a significant part of the life cycle energy analysis of the 20 high school projects and may need to be further considered when designing school projects. The total initial and recurrent embodied energy was almost equivalent to the total operational energy.

Figure 7.10 Summary of energy consumption for 20 high schools in NSW

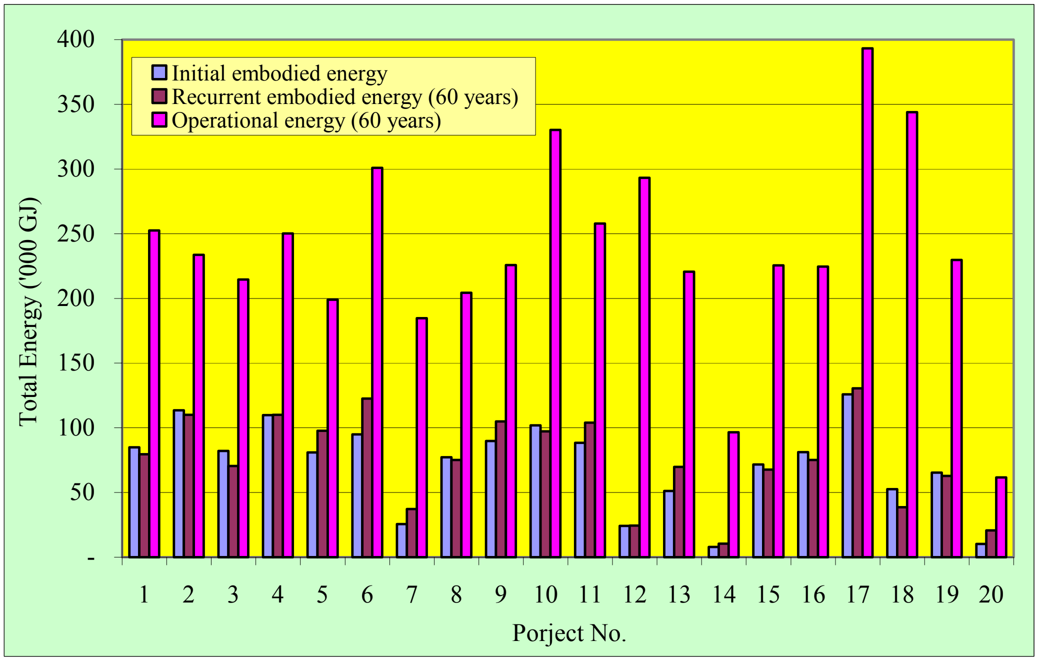
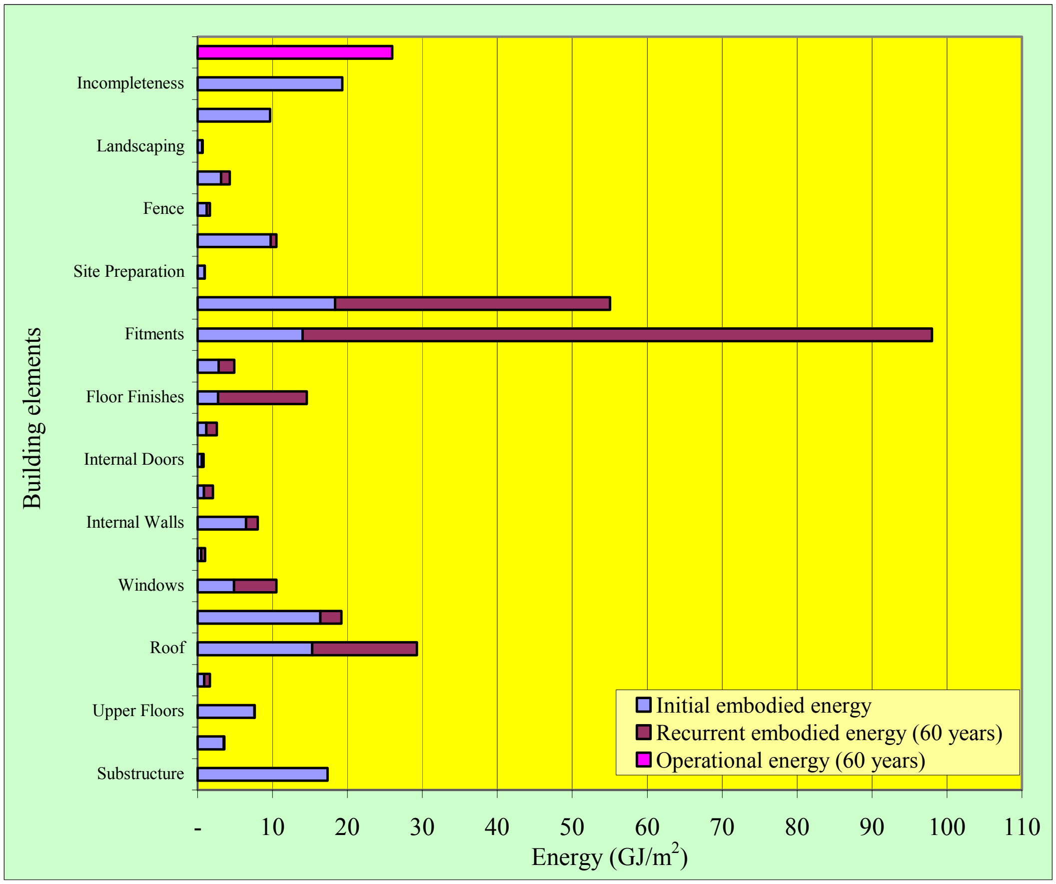


Figure 7.11 (see next page) compares operational energy with initial and recurrent embodied energy. The figure presents each component of the building's life cycle including operational energy, a factor for incompleteness in the embodied estimates, direct energy of the construction process, and the initial and recurrent embodied energy of building elements. The fixtures and fittings, and building services were the two highest consumers of both initial and recurrent energy. The embodied energy content of the roof was almost equivalent to the operational energy, followed by external walls, substructure, floor finishes and windows. Apart from substructure, the other three elements attracted a high input of recurrent embodied energy, an area that would benefit from further research.

Figure 7.11 Life-cycle energy analysis of 20 high schools in NSW



7.4 EXTERNAL BENEFITS

As discussed previously, external benefits measure the contribution of positive effects of a project to the environment. External benefits comprise largely subjective and community-centred issues such as efficiency, productivity, image, social welfare and other intangible attributes.

As discussed in Chapter Six, external benefits were evaluated using a multi-criteria analysis approach. Professionals including project managers, architects, engineers and construction managers, conducted the assessment of external benefits. As discussed in the literature review in Chapter Two, environmental issues are areas that are difficult to handle and quantify and multi-criteria analysis is a way of assessing such issues in a non-monetary approach.

The assessment was based on participant's professional knowledge and experience to rate 20 sub-criteria of external benefits in relation to the school projects using a five-point scale (details see Appendix D). A scale of one represents the lowest degree of benefits whilst a scale of five is the highest. The results obtained in Table 7.10 were based on the principle that the higher the score, the better the contribution of the project to the environment. The method of scoring and weighting criteria in external benefits was discussed in detail in Chapter Six. The weighted scores range from 159 to 360.3, which indicated that the score of the best project was more than double the score of the worst project.

Table 7.10 also compares the weighted actual score with the weighted maximum and mid score. The weighted maximum score was obtained by multiplying the highest score of each criterion (scale of five) with the appropriate weights. The weighted mid score was obtained by multiplying the appropriate weight with a scale of three which was the mid-way between the lowest and the highest in the rating scale.

Table 7.10 Summary of weighted value score of external benefits

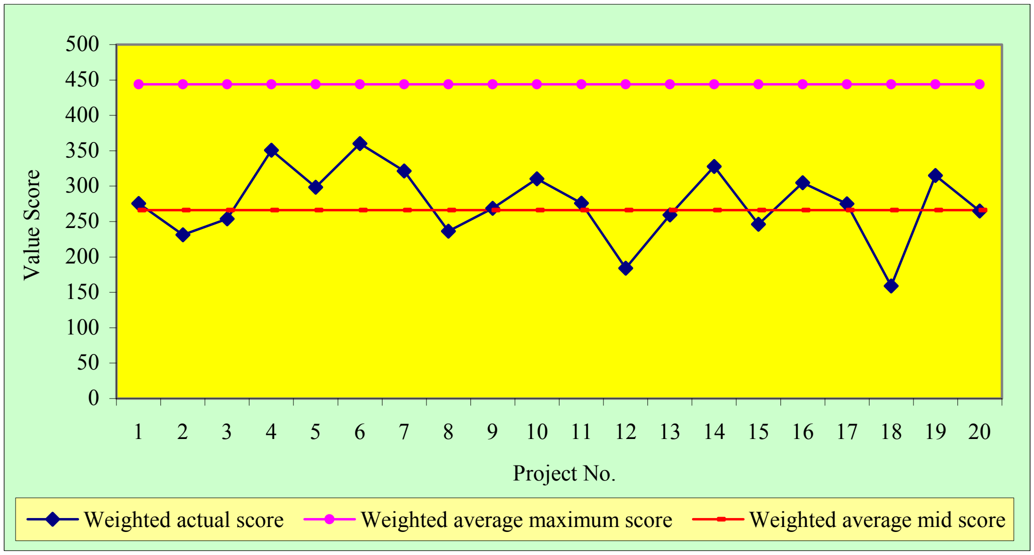
Project No.	Weighted actual score	Weighted mid score	Weighted maximum score
1	275.50	272.30	453.80
2	231.50	274.50	457.50
3	254.00	270.00	450.00
4	350.90	270.00	450.00
5	298.50	263.00	437.50
6	360.30	287.00	477.50
7	321.50	265.50	442.50
8	236.50	270.00	450.00
9	268.50	261.00	435.00
10	310.50	261.00	435.00
11	276.00	267.00	445.00
12	184.00	243.00	405.00
13	259.50	262.50	437.50
14	328.00	228.00	380.00
15	246.00	267.00	445.00
16	305.00	258.00	430.00
17	275.00	286.50	477.50
18	159.00	279.00	465.00
19	315.00	271.50	452.50
20	265.00	268.50	447.50
Mean	277.85	266.27	443.69
Standard deviation	53.85	13.25	22.03

Since there was no information on benchmarking the acceptable level of external benefits for analysis, the weighted average mid score (the average score of 266.27), was used to represent the minimum acceptable level of external benefits in the case studies. The highest weighted average across the 20 projects was 443.69, representing the highest level of achievement in the evaluation of external benefits. However, it is a highly unlikely outcome as no single project can score maximum in all criteria and trade-off principles will always take place in most of the decision-making processes.

Projects that fall below the weighted average score of 266.27 will be considered as unacceptable and may require further investigation in the evaluation process. The approach of the analysis is intended to provide an indicative direction for the evaluation of external benefits in project appraisal, but there are other variables which also need to be considered before a decision is made.

Figure 7.12 presents the comparison of the weighted actual score with the weighted average maximum and mid score graphically. From the figure, the projects that fall below the weighted average mid score were projects 2, 3, 8, 12, 13, 15, 18 and 20. Five projects were found to be well below the weighted average minimum score of 266.27, whilst the other three projects were marginally outside. The result has indicated that most projects have generated positive effects on the environment

Figure 7.12 Comparison of weighted value score of external benefits



7.5 ENVIRONMENTAL IMPACT

Environmental impact deals with a development's negative long-term influence on the environment. The analysis of environmental impact comprises evaluating wastes and emissions generated during the manufacture of building materials and components, the site process, and disposal of construction wastes. It appraises projects on a life cycle basis from the initial stage of manufacturing building materials and components, design, construction through to the final completion of work on site. The impacts that generated during the operational period and subsequent demolition of the buildings have not been included in this study.

Evaluating environmental impact uses the same principle and methodology as used in evaluating external benefits. It is evaluated using a multi-criteria analysis to rate the level of impact of 26 sub-criteria of environmental impact to each project using a five-point scale (details see Appendix D). Chapter Six details the assessment carried out by professionals in the construction industry. The method of scoring and weighting of criteria in environmental impact was also discussed in detail in Chapter Six.

The results obtained from the evaluation indicated that the lower the weighted value score, the lesser the impact generated through project development to the environment. As shown in Table 7.11, the weighted actual score ranged from 149 to 250, which indicated that the best project scored approximately 68 percent better than the worst project.

Table 7.11 also compares the weighted actual score with the weighted minimum and mid score. The weighted minimum score was based on the scenario that all criteria generated the minimum impact to the environment and was represented as a scale of one. The weighted actual score was obtained by multiplying the scale by the appropriate weights. The weighted mid-score took the mid level of the rating scale of three. Again, the weighted mid and minimum score was obtained by multiplying the appropriate weights by the scale.

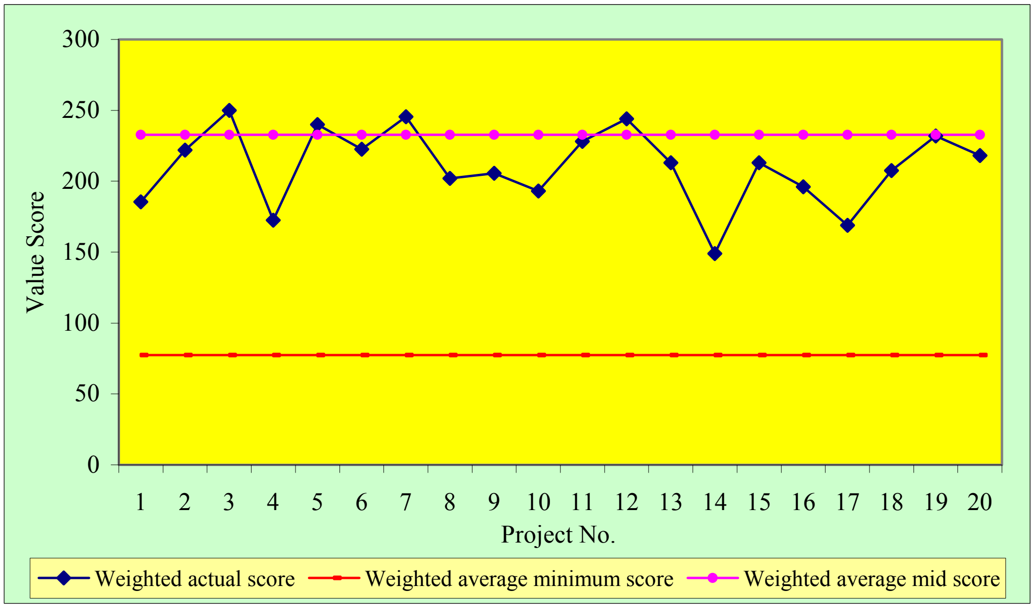
The weighted average mid score of 232.70 represents the maximum level of impact that a project can generate. Projects that score above this level will be considered as unacceptable and require further investigation in the evaluation process. The intention of establishing a level of acceptance was to provide an indicative direction in the appraisal of projects in the case studies.

Table 7.11 Summary of weighted value score of environmental impact

Project No.	Weighted actual score	Weighted mid score	Weighted minimum score
1	185.50	230.00	76.50
2	222.00	243.00	81.00
3	250.00	242.00	80.50
4	172.50	224.00	74.50
5	240.00	240.00	80.00
6	222.58	236.00	78.80
7	245.50	246.00	82.00
8	202.00	231.00	77.00
9	205.50	230.00	76.50
10	193.00	227.00	75.50
11	228.00	240.00	80.00
12	244.00	239.00	79.50
13	213.00	228.00	76.00
14	149.00	213.00	71.00
15	213.00	242.00	80.50
16	196.00	225.00	75.00
17	168.95	223.00	74.30
18	207.50	219.00	73.00
19	232.00	239.00	79.50
20	190.00	237.00	79.00
Mean	210.40	232.70	77.51
Standard deviation	27.24	9.03	3.00

Figure 7.13 (see next page) presents the comparison of weighted actual score with the weighted average minimum and mid score graphically. Figure 7.13 shows that the majority of projects were found close to the weighted average mid score. Four projects (nos. 3, 5, 7 and 12) fell marginally above the weighted average mid score of 232.70. The result reflected a phenomenon that when evaluating impact, mid range is usually the choice as the level of impact is complicated to understand and to quantify, and it involves predicting future potential impact.

Figure 7.13 Comparing the weighted value score of environmental impact



7.6 ANALYSIS OF PROJECTS BY AGE AND LOCATION

7.6.1 Introduction

In the previous sections, descriptive statistics were used to analyse the properties and characteristics of the four criteria in the sustainability index. This section takes the analysis further, examining the variations of the four criteria by separating the 20 projects according to their age and location. The purpose of undertaking these analyses is to further investigate whether the age and location of projects will have significant effects on the performance of the four criteria. This section is broadly divided into two parts. The first part examines the four criteria according to the completion year. The second part compares the four criteria by examining their geographical location. A two-sample 't' test for differences in two means was used to test the significant difference in the analysis.

7.6.2 Analysis of projects by age

The 20 projects in the case studies were divided into two groups for the analysis. The first group contained projects that were completed before 1997. The second group contained projects that were constructed between 1997 and 2002. There were nine projects in the first group and 11 in the second.

For the past few years, the NSW government has required environmental studies to be undertaken on all public projects during the feasibility stage. The projects included in the second group had been subject to environmental studies and environmental design concepts such as solar chimneys and sun shields had also been incorporated in the design development. Therefore, the more recently completed projects that contained environmental design can be compared with projects that were based on a traditional approach. The first group mainly contained medium to small-scale projects. The second group included seven (out of eight) large-scale projects (with gross floor area exceeding 10,000m^2) and contained more recently completed projects incorporating environmental design.

Tables 7.12 and 7.13 summarise the results of the four criteria for the projects completed before 1997 and between 1997 and 2002.

Table 7.12 Summary of projects completed before 1997

Project No.	Building costs ($/m^2)		Energy consumption (GJ/m^2)		External benefits	Environmental impact
	Construction cost	Building life cost	Embodied	Operational	Weighted value score	Weighted value score
1	1,444.49	1,677.65	16.79	25.76	275.50	185.50
2	1,322.21	1,339.46	16.54	17.28	231.50	222.00
3	1,441.70	1,509.90	18.87	26.52	254.00	250.00
8	1,582.46	1,578.48	17.70	23.73	236.50	202.00
12	1,197.65	2,689.55	16.01	96.41	184.00	244.00
13	1,188.97	1,899.46	13.12	23.93	259.50	213.00
14	1,499.27	3,163.29	14.20	74.54	328.00	149.00
15	1,813.08	1,555.72	15.73	25.43	246.00	213.00
19	1,312.41	1,639.06	17.04	30.56	315.00	232.00
Mean	1,422.47	1,894.73	16.22	38.24	258.89	212.28
Standard deviation	197.54	614.90	1.74	27.55	43.66	31.11

Table 7.13 Summary of projects completed between 1997 and 2002

Project No.	Building costs ($/m²)		Energy consumption (GJ/m²)		External benefits	Environmental impact
	Construction cost	Building life cost	Embodied	Operational	Weighted value score	Weighted value score
4	1,360.12	1,832.92	17.51	19.90	350.90	172.50
5	1,211.29	1,491.91	15.69	17.46	298.50	240.00
6	1,157.38	1,647.69	14.17	19.61	360.30	222.58
7	1,326.54	2,528.54	11.91	35.05	321.50	245.50
9	1,313.01	1,617.00	15.89	18.40	268.50	205.50
10	1,435.17	1,828.79	18.53	30.73	310.50	193.00
11	1,225.08	1,788.30	14.56	19.51	276.00	228.00
16	1,631.76	1,629.12	18.40	26.41	305.00	196.00
17	1,263.39	1,612.80	16.40	25.15	275.00	168.95
18	1,803.92	3,286.54	22.46	84.58	159.00	207.50
20	666.95	2,597.04	8.81	17.51	265.00	218.00
Mean	1,308.60	1,987.33	15.85	28.56	290.02	208.87
Standard deviation	286.68	566.37	3.61	19.46	53.88	25.09

The projects in the first group have higher average construction cost per square metre of floor area than the projects in the second group. The average construction cost per square metre of $1,422.47/m^2 and $1,308.60/m^2 respectively for projects completed before and after 1997 show that older projects were about 9 percent more expensive to construct. The outcome may be due to economies of scale, as the bigger the project the cheaper will be the unit cost. As previously described, the projects in the second group were mainly large scale projects with gross floor area exceeding 10,000m^2 whilst the projects completed before 1997 were smaller scale with the smallest one less than 1,500m^2. Therefore, the cost per square metre was lower for the more recently completed projects. The construction cost for the projects completed between 1997 and 2002 has higher dispersion around the mean with a standard deviation of $286.68/m^2 than the older projects that have a standard deviation of $197.54/m^2.

Nevertheless, the projects completed before 1997 were slightly less expensive to run and maintain than the projects completed after 1997 over a 60-year period (see Tables 7.12 and 7.13). The average building life cost per square metre of $1,894.73/m^2 and $1,987.33/m^2 respectively for projects completed before and after 1997, represented approximately 5 percent less for older projects. It indicates that larger projects were more expensive to maintain per square metre than smaller projects, but the difference was only slight.

In embodied energy analysis, projects completed after 1997 are more efficient than older projects per square metre of floor area. The average embodied energy per square metre of floor area was 16.22 GJ/m^2 and 15.85 GJ/m^2 respectively for projects completed before and after 1997 (see Tables 7.12 and 7.13). The embodied energy consumption for the projects completed before 1997 consumed approximately 2 percent more than the recent projects. This may be because there has been more research to study embodied energy in building materials and components, thus more low embodied energy intense materials have been used in construction. Technological advances in manufacturing building materials have also contributed to reduce the embodied energy consumption of building materials and components. The more recently completed projects have benefited from these outcomes.

In Table 7.14, the annual operational energy shows that the older projects consumed less operational energy than the projects completed after 1997. The average annual energy consumption was 3,648.94 GJ and 4,199.43 GJ for the projects completed before and after 1997 respectively. The older projects have used less operational energy than the newer project by about 15 percent. This is because the projects completed after 1997 were bigger and definitely require more energy to operate and maintain the buildings and the activities inside.

Table 7.14 Summary of annual operational energy by age

Operational energy (GJ/year)	
Projects completed before 1997	**Projects completed between 1997 and 2002**
1,608.91	1,028.68
3,405.42	3,077.48
3,577.00	3,316.45
3,677.56	3,741.49
3,756.77	3,760.37
3,828.77	4,167.95
3,894.36	4,296.80
4,206.79	5,014.83
4,884.87	5,504.90
	5,731.54
	6,553.23
Mean: 3,648.94 Standard deviation: 878.21	Mean: 4,199.43 Standard deviation: 1,508.70

However, as the results show in Tables 7.12 and 7.13, the consumption of operational energy drops when floor area is taken into consideration. The average operational energy was found to be 38.24 GJ/m^2 and 28.56 GJ/m^2 for projects completed before and after 1997 respectively. The projects completed before 1997 consumed approximately

34 percent more operational energy per square metre of floor area than the recently completed projects. This indicates that even though the annual operational energy is higher for the more recently completed projects, they are more energy efficient with lesser amount of energy required to service the same area.

However, there are many other factors such as weather conditions, efficiency of equipment, frequency of maintenance and usage that may also affect the operational energy consumption in addition to the size of the projects. These factors are difficult to assess unless a comprehensive energy audit is undertaken for each project. However, energy auditing is not within the scope of the study and no further consideration or adjustment for these factors has been made in this research.

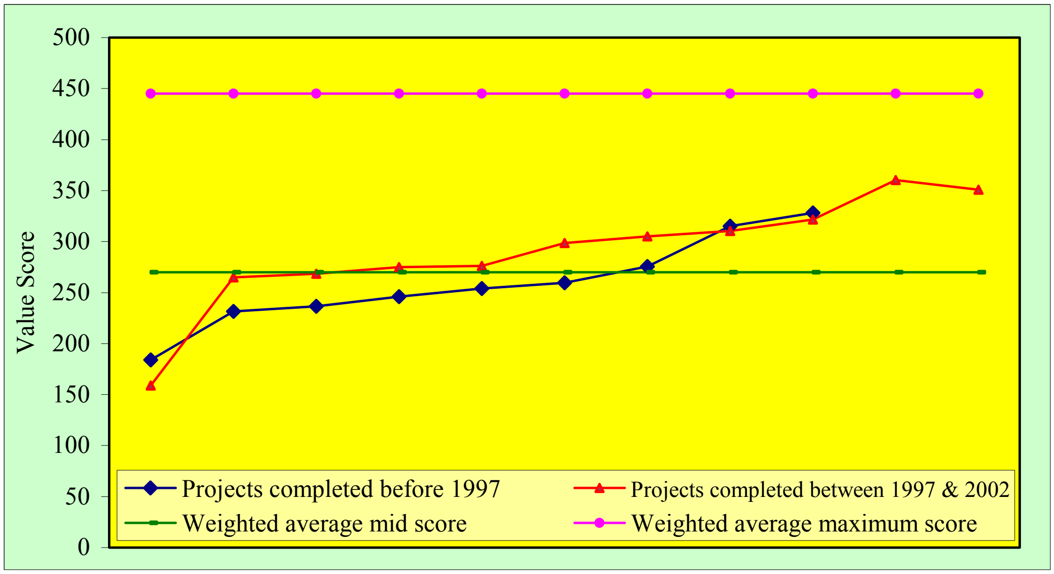
In Tables 7.12 and 7.13, the operational energy consumption for projects 12, 14 and 18 are higher than the other projects. The high operational energy consumption is caused by these three projects having boarding facilities, therefore the energy required for accommodations and cooking facilities and for longer operational hours has been included.

Tables 7.12 and 7.13 also present the value score for the external benefits and environmental impact analysis for the two groups of projects. On average, the projects completed more recently have higher scores in external benefits than the older projects. The above analysis is presented graphically in Figure 7.14 to highlight the comparison. It shows that projects completed between 1997 and 2002 have a higher value score of external benefits than projects completed before 1997. The weighted average value score of 258.89 and 290.02 respectively for projects completed before and after 1997 represent approximately a 12 percent difference.

Figure 7.14 also presents the comparison of the actual weighted value score with the weighted average mid and maximum value score. The weighted average mid score forms the level of acceptance for the analysis of external benefits. Projects that fall below the weighted average mid score will be considered as unacceptable (see Section 7.4 for details). For the more recently completed projects, only two out of 11 projects were found below the weighted average mid score, meaning that approximately 18 percent of the projects did not perform satisfactorily in the external benefits analysis.

However, for the older projects, six out nine projects were found outside the region, representing approximately 67 percent. As the results indicate, the more recently completed projects contributed more positively to the environment. This may be due to the fact that the projects completed before 1997 were six to 18 years old and environmental design may not have been considered in the design and construction of these projects. For the projects completed between 1997 and 2002, the then Department of Public Works and Services implemented environmental studies in the design development.

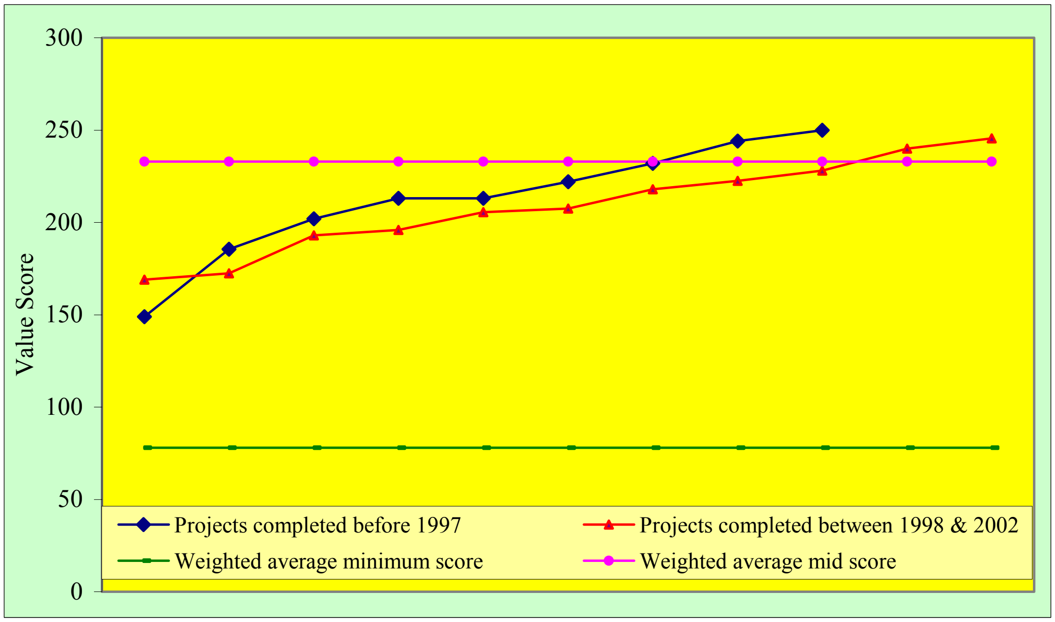
Figure 7.14 Comparison of weighted value score of external benefits by age



Tables 7.12 and 7.13 also analysed environmental impact by age of projects. The projects recently completed have a slightly lower impact than the older projects in generating negative effects on the environment. The weighted average value score of 212.28 and 208.87 respectively for projects completed before and after 1997, represented approximately a 2 percent difference.

Figure 7.15 is a graphical presentation of the projects' environmental impact analysis. The figure presents the comparison of weighted actual value score with the weighted average mid and minimum value scores. Projects that fall above the weighted average mid score will be considered as unacceptable (see Section 7.5 for details). There is no obvious difference between the two groups by age. The line graphs are closely positioned with the graph of projects completed before 1997 located just above the graph of the more recently completed projects. It indicates that the more recent projects have generated slightly less impact to the environment. Altogether, only two projects from each group were above the weighted mid score and therefore deemed unacceptable.

Figure 7.15 Comparison of weighted value score of environmental by age



A two-sample 't' test for differences in two means was conducted to compare statistics computed from the two groups of projects by age. The purpose of the 't' test was to make inferences about possible differences in the parameters of the two groups. Table 7.15 summarises the results for the variables as detailed in Tables 7.12 and 7.13.

Table 7.15 Summary of two-sample 't' test for differences in two means by age

Results	Const. cost	Building life cost	Embodied energy	Operat. energy	External benefits	Env-al impact
Projects completed before 1997						
Sample size	9	9	9	9	9	9
Sample mean	1,422.47	1,894.73	16.22	38.24	258.89	212.28
Sample standard deviation	197.54	614.90	1.74	27.55	43.66	31.11
Projects completed between 1997 and 2002						
Sample size	11	11	11	11	11	11
Sample mean	1,308.60	1,987.33	15.85	28.57	290.02	208.87
Sample standard deviation	286.68	566.37	3.61	19.46	53.88	25.09
Degrees of freedom	18	18	18	18	18	18
Pooled variance	63,001.700	346,253.700	8.590	547.720	2,460.010	779.870
Diff. in sample means	113.870	-92.600	0.370	9.670	-31.130	3.410
t-Test statistic	1.009	-0.350	0.281	0.919	-1.396	0.272
Critical value	±2.1009	±2.1009	±2.1009	±2.1009	±2.1009	±2.1009
p-value	0.326	0.730	0.782	0.370	0.179	0.789
Significant difference	No	No	No	No	No	No

Note:
Const. cost = Construction cost
Operat. energy = Operational energy
Env-al impact = Environmental impact
Diff. in sample means = Difference in sample means

The mean hypothesis test was undertaken using a two-tailed test at a 5 percent level of significance (i.e. $\alpha=0.05$). According to the results revealed in Table 7.15, with the critical values of ±2.1009 and 18 degrees of freedom, there was no significant difference between the two groups by age. With all the *p*-values greater than the level of significance, the null hypotheses could not be rejected in any tests.

7.6.3 Analysis of projects by location

The 20 projects have also been separated into two groups by location. The classification of projects by location was in accordance with the details provided by the Department of Education and Training in New South Wales[11]. The projects were divided into Sydney and country regions. The purpose of comparing projects by location is to identify whether there are variations in the analysis outcomes due to geographical location. Tables 7.16 and 7.17 (see next page) show the summary of projects by location. There were eight projects located in the Sydney region and 12 projects scattered around the New South Wales countryside (refer to Figure 6.1 in Chapter Six for a location map).

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[11] Department of Education and Training, NSW—http://www.det.nsw.edu.au

Table 7.16 Summary of projects in Sydney region

Project No.	Building cost ($\$/\text{m}^2$)		Energy consumption (GJ/m^2)		External benefits	Environmental impact
	Construction cost	Building life cost	Embodied	Operational	Weighted value score	Weighted value score
2	1,322.21	1,339.46	16.54	17.28	231.50	222.00
4	1,360.12	1,832.92	17.51	19.90	350.90	172.50
5	1,211.29	1,491.91	15.69	17.46	298.50	240.00
8	1,582.46	1,578.48	17.70	23.73	236.50	202.00
9	1,313.01	1,617.00	15.89	18.40	268.50	205.50
11	1,225.08	1,788.30	14.56	19.51	276.00	228.00
15	1,813.08	1,555.72	15.73	25.43	246.00	213.00
19	1,312.41	1,639.06	17.04	30.56	315.00	232.00
Mean	1,392.46	1,605.36	16.33	21.53	277.86	214.38
Standard deviation	204.44	157.34	1.06	4.67	41.59	21.38

Table 7.17 Summary of projects in the country region

Project No.	Building cost ($\$/\text{m}^2$)		Energy consumption (GJ/m^2)		External benefits	Environmental impact
	Construction cost	Building life cost	Embodied	Operational	Weighted value score	Weighted value score
1	1,444.49	1,677.65	16.79	25.76	275.50	185.50
3	1,441.70	1,509.90	18.87	26.52	254.00	250.00
6	1,157.38	1,647.69	14.17	19.61	360.30	222.58
7	1,326.54	2,528.54	11.91	35.05	321.50	245.50
10	1,435.17	1,828.79	18.53	30.73	310.50	193.00
12	1,197.65	2,689.55	16.01	96.41	184.00	244.00
13	1,188.97	1,899.46	13.12	23.93	259.50	213.00
14	1,499.27	3,163.29	14.20	74.54	328.00	149.00
16	1,631.76	1,629.12	18.40	26.41	305.00	196.00
17	1,263.39	1,612.80	16.40	25.15	275.00	168.95
18	1,803.92	3,286.54	22.46	84.58	159.00	207.50
20	666.95	2,597.04	8.81	17.51	265.00	218.00
Mean	1338.10	2172.53	15.81	40.52	274.78	207.75
Standard deviation	284.68	643.68	3.64	27.70	57.94	31.17

The projects in the Sydney region were only slightly more expensive to build than the projects constructed in the country. The average cost per square metre of floor area was $\$1,392.46/\text{m}^2$ and $\$1,338.10/\text{m}^2$ respectively for projects in Sydney and the country, representing only about 4 percent difference. In addition, the standard deviations around the mean were $\$204.44/\text{m}^2$ and $\$284.68/\text{m}^2$ respectively for Sydney and country projects, indicating a lower dispersion for the Sydney projects. This may be because the Sydney projects were constructed in a built-up area where space on site was rather limited and building regulations, such as noise control, pollution control and working hours, were stricter.

However, in the building life cost analysis the projects in the Sydney region were much cheaper to run and maintain than the projects located in the country. The cost per square metre of floor area was $1,605.36/m^2 and $2,172.53/m^2 respectively for projects in Sydney and the country regions, representing a 35 percent difference. The standard deviation around the mean was also much higher for the country projects. It may be because some country projects are located far away from the sea, and exposed to more extreme temperature conditions. As such, more expenditure may possibly be required to provide heating, air-conditioning, cooling and hot water during the operational period. In addition, the country projects had a larger land area which may require more operational cost to maintain and repair the external facilities and features.

In terms of embodied energy, the country projects were slightly more efficient than the Sydney projects. The average embodied energy of 16.33 GJ/m^2 and 15.81 GJ/m^2 respectively for Sydney and country projects represented an approximate 3 percent difference by location. This may be explained because seven out of 11 more recently completed projects (approximately 64 percent) were located in the country. As the previously results show, more recently completed projects were more efficient in embodied energy consumption. Even though the Sydney projects have a higher consumption of embodied energy, the standard deviation around the mean is lower for the Sydney projects.

Table 7.18 (see next page) shows operational energy consumption by fuel type and by location. On average, projects in the Sydney region consumed 228,201.64 GJ (38.50 percent of total) and country region projects consumed 243,036.37 GJ (61.50 percent of total) representing an approximate 7 percent difference between the Sydney and country projects over a 60-year life span. The table also shows that on average, gas accounted for less than 10 percent of the energy consumption in both locations.

Table 7.18 Summary of operational energy by fuel types and by location

	Total (GJ)	Average (GJ)	Proportion (%)
Sydney region (8 projects)			
Electricity	1,515,931.70	189,491.46	31.97
Gas	309,681.39	38,710.17	6.53
Total	1,825,613.09	228,201.64	38.50
Country region (12 projects)			
Electricity	2,483,004.62	206,917.05	52.36
Gas	433,431.82	36,119.32	9.14
Total	2,916,436.44	243,036.37	61.50

Table 7.19 shows the annual operational energy consumption of projects by location. The annual operational energy of the Sydney projects ranged between 3,316.45 and 4,296.80 GJ, averaging 3,803.36 GJ. For the country projects, the range is bigger, being from 1,028.68 GJ to 6,553.23 GJ, averaging 4,050.61 GJ. There is around 7 percent difference between the two groups of projects by location. In addition, the standard deviation around the mean for the projects in Sydney was much smaller than for the country projects.

The higher operational energy consumption for the country projects may be due to the more extreme temperature conditions throughout the year requiring more energy for heating and air-conditioning.

Table 7.19 Summary of annual operational energy by location

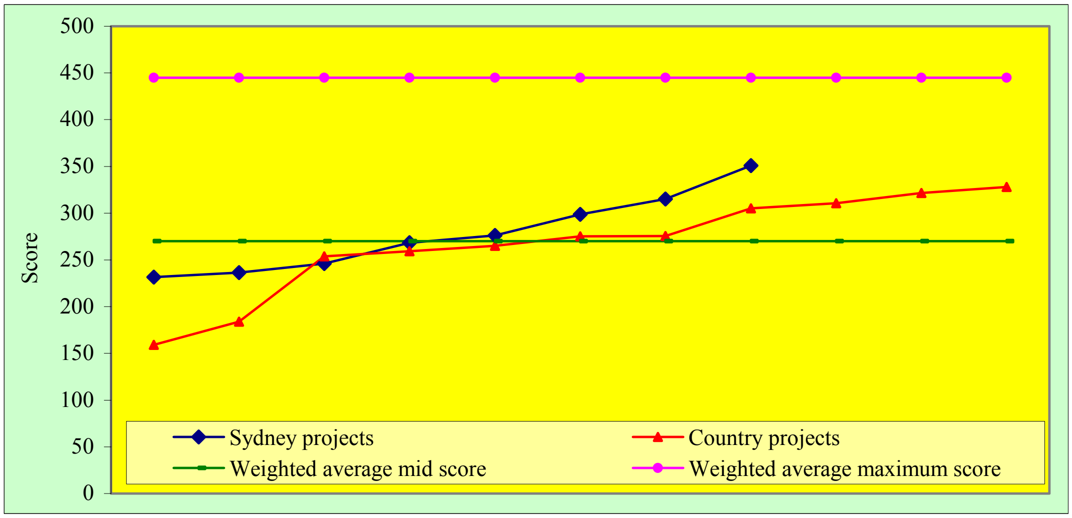
Operational energy	
Sydney region (GJ/Year)	**Country region (GJ/Year)**
3,316.45	1,028.68
3,405.42	1,608.91
3,756.77	3,077.48
3,760.37	3,577.00
3,828.77	3,677.56
3,894.36	3,741.49
4,167.95	4,206.79
4,296.80	4,884.87
	5,014.83
	5,504.90
	5,731.54
	6,553.23
Mean: 3,803.36 Standard deviation: 334.83	Mean: 4,050.61 Standard deviation: 1,633.56

When considering gross floor area, it was apparent that Sydney projects were also more energy efficient than the country projects (see Tables 7.16 and 7.17). The Sydney projects consumed 21.53 GJ/m^2 whilst the country projects consumed 40.52 GJ/m^2, representing about an 88 percent difference. This huge difference in consumption may be due to three country projects (nos. 12, 14 and 18) with boarding facilities that have more extensive external areas and may need more energy to run and for maintenance.

When analysing external benefits, the Sydney projects scored slightly better than the country projects (see Tables 716 and 7.17). The average weighted value scores of 277.86 and 274.78 respectively for the Sydney and country projects showed about a 1 percent difference. Based on the 20-project sample, this shows that the Sydney projects' better performance provided better quality of life, employment opportunities and social benefits. Figure 7.16 graphically represents this analysis. Projects that fall below the weighted mid score will be considered as unacceptable (see Section 7.4 for details).

Based on the sample, three out of eight Sydney projects were below the weighted average mid score, representing about 38 percent, showing no positive contribution to the environment. For country projects, four out of 12 projects were below the weighted mid score, representing about 33 percent. The two groups were also analysed using a two-sample 't' test for differences in two means in the later part of this section.

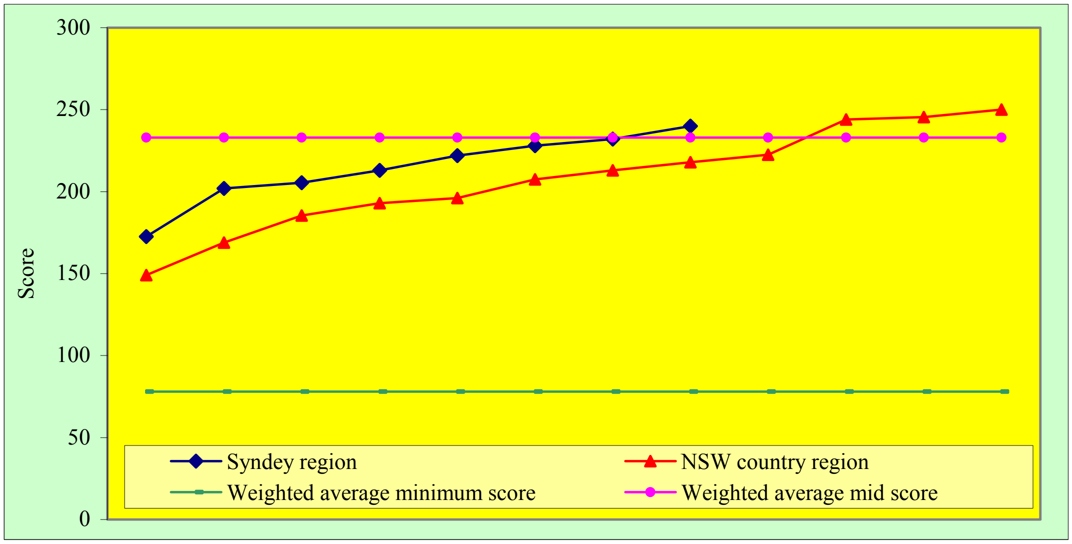
Figure 7.16 Comparison of weighted value score of external benefits by location



On average, the country projects have a lower value score than the Sydney projects when analysing environmental impact (see Table 7.16 and 7.17). The weighted value score of 214.38 and 207.75 for projects in the Sydney and country regions respectively represented only about 3 percent difference. This may be due to the country projects having more space in which to carry out activities and thus less destruction has occurred during the construction and operational periods. In the Sydney region, projects were usually found in built-up areas where noise, air and water pollution had more effect during construction.

Figure 7.17 presents the analysis as a graph, showing that projects which fall above the weighted mid score will be considered as unacceptable (see Section 7.5 for details). As indicated in the graph, the country projects generated less impact on the environment than the Sydney projects. The graph shows that three out of 12 country projects were above the level of weighted average mid score, amounting to approximately 25 percent. However, there was only one out of eight projects located in the Sydney region above the weighted mid score, amounting to approximately 12.5 percent.

Figure 7.17 Comparison of weighted value score of environmental impact by location



A two-sample ‘t’ test for differences in two means was conducted to compare statistics computed from the two groups of projects by location. The purpose of the ‘t’ test was to make inferences about possible differences in the parameters of the two groups. Table 7.20 summarises the results for the variables as detailed in Tables 7.16 and Table 7.17

Table 7.20 Summary of two-sample test for differences in two means by location

Results	Const. cost	Building life cost	Embodied energy	Operat energy	External benefits	Env-al impact
Sydney region						
Sample size	8	8	8	8	8	8
Sample mean	1,392.46	1,605.36	16.33	21.53	277.86	214.38
Sample standard deviation	204.44	157.34	1.06	4.67	41.59	21.38
Country region						
Sample size	12	12	12	12	12	12
Sample mean	1,338.10	2,172.53	15.81	40.52	274.78	207.75
Sample standard deviation	284.68	643.68	3.64	27.70	57.94	31.17
Degrees of freedom	18	18	18	18	18	18
Pooled variance	65,779.980	262,825.200	8.530	477.380	2,724.200	711.490
Diff. in sample means	54.360	-567.170	0.520	-18.990	3.080	6.630
t-Test statistic	0.464	-2.424	0.389	-1.904	0.129	0.523
Critical value	±2.1009	±2.1009	±2.1009	±2.1009	±2.1009	±2.1009
p-value	0.648	0.026	0.701	0.073	0.899	0.607
Significant difference	No	Yes	No	No	No	No

Note:
Const. cost = Construction cost
Operat. cost = Operational cost
Env-al impact = Environmental impact
Diff. in sample means = Difference in sample means

The mean hypothesis test was undertaken using a two-tailed test at a 5 percent level of significance (i.e. α=0.05). According to the results shown in Table 7.20, given the critical values of ±2.1009 with 18 degrees of freedom, a significant difference between the two groups is found only for building life cost. The *p*-value of building life cost is less than the level of significance, so the null hypothesis is rejected. However, the *p*-values for all the other tests are greater than the level of significance so the null hypothesis cannot be rejected.

7.6.4 Summary

In conclusion, the age of projects did not greatly affect the overall performance of projects in the sample. The more recently completed projects generally achieved somewhat better results than the older projects in terms of building cost, energy consumption and environmental performances. The results only showed a slight difference and these may reflect the effects of environmental considerations in the design and construction of the projects completed after 1997. The result, however, did not demonstrate that completion year of projects had a significant effect on the overall performance of projects in the sample.

Similar results can also be drawn for analysing the projects by their geographical location. Based on the sample of 20 high school projects, the Sydney projects perform slightly better than the country projects. The location has only a mild effect on the construction cost, energy consumption and the environmental performances of buildings, but it has a significant effect on the building life cost. Most of the country projects are far away from the sea where transportation is more difficult, land is more extensive and the extreme temperature conditions may have contributed to the higher building life cost.

7.7 ANALYSIS OF RELATIONSHIPS FOR BUILDING COST AND ENERGY CONSUMPTION WITH GROSS FLOOR AREAS

7.7.1 Introduction

Following the results obtained from the statistical analysis of the previous section for the four criteria, this section further analyses the four criteria in terms of their relationship to the gross floor area. Regression analysis and correlation were used to analyse the relationship and the degree of closeness. The purpose of using regression analysis and correlation was to determine whether there was an apparent relationship between the two variables and examined the degree of association between the variables being observed on the regression equation. This section is broadly divided into two parts. The first part examines the relationship between building cost and gross floor area whilst the second part focuses on the relationship between energy consumption and gross floor area.

7.7.2 Analysis of relationships for building cost and gross floor area

i) Regression analysis between construction cost and gross floor area

Table 7.21 shows the summary of results for the regression analysis between construction cost and gross floor area (GFA). As indicated in the table, construction cost demonstrates a strong positive relationship with the GFA. The correlation coefficient of 0.95 for construction cost to GFA reveals a strong association between the two variables. The coefficient of determination (R^2=0.90) implies that 90 percent of the variations in the construction cost can be explained by the variations in the size of the project. It means that the bigger the project the more expensive it is to build.

The linear regression model for construction cost and GFA is:

$$y = 1237.466x + 1032700.850 \tag{7.1}$$

where x was GFA and y was construction cost. Also from the table, the small *p*-value (*p* less than 5%) leaves a very small probability that GFA does not contribute information to predict construction cost of high school projects.

Table 7.21 Results of regression analysis for construction cost and gross floor area

Regression statistics						
Multiple R	0.950454					
R square	0.903364					
Adjusted R sq	0.897996					
Standard error	1710601.6					
Observations	20					
ANOVA						
	df	SS	MS	F	Signif. F	
Regression	1	4.92375E+14	4.924E+14	168.266586	1.4265E-10	
Residual	18	5.26708E+13	2.926E+12			
Total	19	5.45045E+14				
	Coefficients	Standard error	t stat	*p*-value	Lower 95%	Upper 95%
Intercept	1032700.85	950727.1740	1.086222	0.291714	-964704.371	3030106.07
x	1237.466390	95.396946	12.97176	1.4265E-10	1037.045	1437.880

ii) Regression analysis between building life cost and gross floor area

Table 7.22 shows the summary of results for the regression analysis between building life cost and GFA. As indicated in the table, building life cost demonstrates a strong positive relationship with the GFA. The correlation coefficient of 0.94 for building life cost to GFA reveals a strong association between the two variables. The coefficient of determination (R^2=0.88) implies that 88 percent of the variations in the building life cost can be explained by the variations in the size of the project. It means that the bigger the project the more expensive it is to operate and maintain.

The linear regression model for building life cost and GFA is:

$$y = 1302.505x + 4095055.505 \quad (7.2)$$

where x was GFA and y was building life cost. Also from Table 7.22, the small *p*-value (*p* less than 5%) leaves a very small probability that GFA does not contribute information to predict building life cost of high school projects.

Table 7.22 Summary of results of regression analysis building cost

Results	Building life cost and GFA	Total building cost and GFA	Construction cost and building life cost
Multiple R	0.936718	0.976821	0.865182
R square	0.877440	0.954180	0.748539
Adjusted R square	0.870631	0.951634	0.734569
Standard error	2057419.46	2352448.76	2947024.39
Observations	20	20	20
t statistic	11.351964	19.360790	7.319960
***p*-value**	1.22691E-09	1.68629E-13	8.4792E-07
Lower 95%	1061.448667	2264.348109	0.658806
Upper 95%	1543.561518	2815.594853	1.189211
Intercept	4095055.510	5127756.350	4592210.560
x	1302.505	2539.971	0.924

iii) Regression analysis between building cost and gross floor area

Table 7.22 shows the relationship between total building cost (building cost is the sum of construction cost and building life cost) and GFA using regression analysis. The correlation coefficient of 0.98 indicates a strong association between the two variables. The coefficient of determination (R^2=0.95) implies that 95 percent of the variation in total building costs can be explained by the variations in the size of projects.

The linear regression model for construction cost and GFA is:

$$y = 2539.971x + 5127756.350 \quad (7.3)$$

where x was GFA and y was total building cost. Also from Table 7.22, the small *p*-value (*p* less than 5%) leaves a very small probability that GFA does not contribute information to predict building cost of high school projects.

iv) Regression analysis between construction cost and building life cost

Table 7.22 also shows the results for the regression analysis between construction cost and building life cost. In the analysis, construction cost is the independent variable and the building life cost is the dependent variable. The purpose of the analysis is to determine the probability of a relationship between construction and building life costs. From the table, the correlation coefficient obtained was 0.87, which indicates a positive correlation between the two variables. The coefficient of determination (R^2 = 0.75) implies that 75 percent of the variation in building life cost can be explained by the variation of construction cost. That means the more money spent on the construction the more expenditure will be spent on operating and maintaining the project during the operational period. As derived from the specifications of the sample, the 20 high school projects have more glazing area and use less durable flooring materials such as carpets and vinyl. In conjunction with heavy traffic during school terms, these types of flooring materials require more regular cleaning, maintenance and replacement. In addition, the glazed area also increases heat loss and gain, which may result in more energy cost cleaning costs.

The linear regression model for construction and building life cost is:

$$y = 0.924x + 4592210.559 \tag{7.4}$$

where x was construction cost and y was building life cost. Also from Table 7.22, the small *p*-value (*p* less than 5%) leaves a very small probability that construction cost does not contribute information to predict building life cost of high school projects.

7.7.3 <u>Analysis of relationships for energy consumption and gross floor area</u>

i) Regression analysis between embodied energy and gross floor area

Table 7.23 presents the results for the analysis of relationship between embodied energy and GFA. The table shows a correlation coefficient of 0.96 and reveals a strong positive correlation between the two variables. The coefficient of determination (R^2=0.93) implies that 93 percent of the variation in the consumption of embodied energy can be explained by the variation in the size of the project. The result indicates that floor area is a good indicator for embodied energy consumption for the design of future school projects.

The linear regression model for embodied energy and GFA is:

$$y = 15.919x + 2229.570 \quad (7.5)$$

where x was GFA and y was embodied energy. Also from the table, the small *p*-value (*p* less than 5%) leaves a very small probability that GFA does not contribute information to predict embodied energy of high school projects.

Table 7.23 Results of regression analysis for embodied energy and gross floor area

Regression statistics						
Multiple R	0.964452					
R Square	0.930167					
Adjusted R sq	0.926288					
Standard error	18434.85					
Observations	20					
ANOVA						
	df	SS	MS	F	Signif. F	
Regression	1	81480276903	81480276903	239.7582	7.567E-12	
Residual	18	6117183475	339843526.4			
Total	19	87597460377				
	Coefficients	Standard error	t stat	*p*-value	Lower 95%	Upper 95%
Intercept	2229.5696	10245.81555	0.217608	0.830182	-19296.11	23755.246
x	15.918856	1.0280756	15.484128	7.57E-12	13.758947	18.078764

ii) Regression analysis between operational energy and gross floor area

Table 7.24 shows the summary of results for the regression analysis between operational energy and GFA. However, as indicated in the table, although the relationship between operational energy and GFA was positively correlated, it was not very strong. The correlation coefficient of 0.51 indicates that a relationship existed between the two variables. The coefficient of determination (R^2=0.26) implies that only 26 percent of the variation in the consumption of operational energy can be explained by the variation in the size of the projects. However, many other factors may have affected the energy efficiency of buildings such as equipment efficiency, activities and climate. An energy audit may be required for further analysis.

There are three projects in the case studies that include boarding facilities with accommodation and cooking requirements. However, such energy cannot be separated from the information for analysis. This may have affected the results as operating hours are longer than normal school hours. Refer to Section 7.6.2 for further details and discussion.

The linear regression model for operational energy and GFA is:

$$y = 9.426x + 151099.459 \tag{7.6}$$

where x was GFA and y was operational energy. Also from Table 7.24, the small *p*-value (*p* less than 5%) leaves a very small probability that GFA does not contribute information to predict operational energy of high school projects.

Table 7.24 Summary of results of regression analysis for energy consumption

Results	Operational energy and GFA	Total energy and GFA	Embodied energy and operational energy
Multiple R	0.510663	0.811698	0.593795
R square	0.260777	0.658853	0.352592
Adjusted R square	0.219709	0.639900	0.316625
Standard error	67075.95	77081.03	62772.30
Observations	20	20	20
t statistic	2.519899	5.896031	3.131004
***p*-value**	0.021403	1.395E-05	0.005774
Lower 95%	1.567260	16.313875	0.218471
Upper 95%	17.285093	34.376189	1.109645
Intercept	151099.4588	153329.028	139173.3147
x	9.426176	25.345021	0.664058

iii) Regression analysis between energy consumption and gross floor area

Table 7.24 also presents the analysis of the results for the relationship between energy consumption (total energy is the sum of embodied and operational energy) and GFA. The correlation coefficient of 0.81 indicates a strong positive correlation between energy consumption and the size of the projects. The coefficient of determination (R^2=0.66) implies that 66 percent of the variance in the energy consumption can be explained by the size of the project.

The linear regression model for total energy and GFA is:

$$y = 25.345x + 153329.028 \tag{7.7}$$

where x was GFA and y was total energy. Also from Table 7.24, the small *p*-value (*p* less than 5%) leaves a very small probability that GFA does not contribute information to predict total energy of high school projects.

iv) Regression analysis between embodied energy and operational energy

Table 7.24 also shows the regression analysis between embodied energy and operational energy. The correlation coefficient of 0.59 indicates the correlation between the variable was positive. The coefficient of determination (R^2=0.35) implies that only 35 percent of the variation in the operational energy can explained by variation in the embodied energy. Theoretically, as embodied energy goes up, operational energy should come down. However this may not be the case for the sample of 20 high school projects in this research. The specification for the high school projects indicated that high embodied energy intensity materials such as glass, aluminium, bricks, concrete and metal deck roofing are common. In addition, the 12 country projects (60 percent) are located far from the sea and are therefore possibly more prone to extreme temperatures throughout the year requiring more operational energy due to increased heating and cooling. Therefore, as the embodied energy increases the operational energy does not necessarily decrease. Other factors may also need examination.

The linear regression model for embodied and operational energy is:

$$y = 0.66 + 139173.315 \tag{7.8}$$

where x was embodied energy and y was operational energy. Also from Table 7.24, the small *p*-value (*p* less than 5%) leaves a very small probability that embodied energy does not contribute information to predict operational energy of high school projects.

7.7.4 Summary

As the results indicate, building cost and energy usage displayed a strong positive relationship with project size. Based on the results of the analysis in this section, the floor area is a good indicator for both building cost and energy usage. Therefore, floor area can be used to estimate building cost and energy consumption. On the other hand, the increase in the size of projects also increases the costs of building and operation. There are other factors that may also need to be considered in the determination of these costs such as specifications, methods of construction, longevity of materials and components, and site locations. However, the consideration of these variables is not within the scope of study in this research.

7.8 CONCLUSION

This chapter discussed the results of data analyses using various statistical methods. Descriptive statistics have been used to reveal the characteristics of data and to summarise the features of the four criteria in the case studies of building cost, energy consumption, external benefits and environmental impact as presented in Sections 7.2 to 7.5. The analysis also reviewed the characteristics in accordance with the age and geographical location (see Section 7.6). Finally, in Section 7.7, regression analysis was used to examine the relationships between building costs, energy consumption and the gross floor area.

The next chapter will discuss the relationship between the four criteria in the sustainability index for project appraisal. Different decision models for the four criteria will be developed and hypotheses will also be tested for validity and robustness of the models.

CHAPTER EIGHT

DEVELOPING DECISION MODELS AND VERIFYING THE SUSTAINABILITY INDEX

8.1 INTRODUCTION

In the previous chapter data were analysed, discussed and presented using descriptive statistics and linear regression. The relationships for the building cost and energy usage with gross floor area were also established in Chapter Seven. This chapter takes the analysis further and aims to establish linear and multiple models for decision-making using simple and multiple regression methods.

All models were analysed and tested for statistical reliability. The hypotheses as detailed in Chapter Six were also tested and are presented in this chapter. This chapter has been divided into three sections. The first section explains the development of six simple linear models using linear regression analysis for the four criteria. The second section presents the development of a multiple model using multiple regression analysis. Testing of hypotheses has also been included for the models in both sections one and two. The last section verifies the sustainability index on an industrial project with three different design options in New South Wales. The purpose of the final section is to demonstrate that the sustainability index is able to provide rankings of a development with competing alternatives. Finally, the conclusion summarises the main findings of this chapter.

8.2 DEVELOPING THE LINEAR REGRESSION MODELS AND TESTING THE HYPOTHESES

8.2.1 Introduction

In this section, linear regression is used to examine the relationship between the four criteria. It is important to understand how these variables interact with each other. It is intended to create mathematical models based on these variables so that economic and environmental effects can be predicted. Linear regression provides a technique for building statistical predictors with a measure of the error of prediction. The results in this section will support the development of a sustainability index to assess building performance and rank alternatives by combining these four variables into a single decision-making tool as developed and discussed in Chapter Five. Two criteria will be used at a time to develop a model. The results of the analysis are used to justify trade-off principles in the sustainability index.

Since the 20 high school projects vary in sizes, locations and completion years, analysis and comparisons between dwellings will be complex. Therefore, the four variables are expressed as unit quantity per square metre of gross floor area in order to set them on the same terms for comparison. Pearson's product moment correlation coefficient (r) is used to provide a quantitative measure of the strength of the linear relationship between two variables in order to draw conclusion about their movement. The coefficient of determination (R^2) is also used to consider how much the errors of prediction of y, the dependent variable, are reduced by using the information provided by x, the independent variable. It also describes how well the model fits the data.

The hypotheses (H1 to 6) as established in Chapter Six Section 6.3 will be tested for the existence of correlation between the two variables in order to confirm the validity of the model. The outcomes in the analysis will demonstrate that the variables interact with each other to confirm the validity of the four criteria in the sustainability index for project appraisal.

8.2.2 Regression model (Model 1) for building cost and energy consumption and test of hypothesis (H1)

i) Regression analysis for building cost and energy consumption

Table 8.1 summarises the results of analysing the relationship between building cost ($\$/m^2$) and energy consumption (GJ/m^2) of 20 high school projects.

Table 8.1 Results of regression analysis for building cost and energy consumption

Regression statistics						
Multiple R	0.835840					
R Square	0.698628					
Adjusted R sq	0.681886					
Standard error	15.735190					
Observations	20					
ANOVA						
	df	SS	MS	F	Signif. F	
Regression	1	10331.42	10331.4200	41.7269	4.46E-06	
Residual	18	4456.73	247.5961			
Total	19	14788.16				
	Coefficients	Standard error	t stat	*p*-value	Lower 95%	Upper 95%
Intercept	-72.358650	19.339540	-3.741487	0.001494	-112.998960	-31.727740
x	0.037163	0.005753	6.459638	4.46E-06	0.025076	0.049249

The linear regression model for building cost and energy consumption was found to be:

$$y = 0.037x - 72.359 \qquad (8.1)$$

where x is $\$/m^2$ of building cost and y is GJ/m^2 of energy consumption. From the table it is indicated that building cost is positively correlated with energy consumption.

The regression statistics (refers to Table 8.1) shows that the correlation coefficient (r) is 0.836. The result indicates a strong positive relationship between the two variables. The coefficient of determination (R^2) is 0.699 which means that approximately 70 percent of the variations in energy consumption can be explained by the variations in the building cost.

As the model showed a strong positive correlation between the two variables, it indicates that if more money is spent on a development (includes construction and building life cost), more energy will be required to build and maintain the building. However as the literature described, if more money was spent on building, future energy costs could be reduced. The additional money could be spent on technology which could minimise operating energy, such as adding insulation to the external walls and roof, and using double glazing on windows. However, this opportunity has been ignored and wasted on high embodied energy intensity building materials in the school projects. From the specifications of the 20 high school projects, high energy intensity materials such as a reinforced concrete, bricks, glass, aluminium and metal decking were used which overshadowed the savings in operational energy. This type of specification is typical for high school designs in New South Wales. They are expensive to use and high in embodied energy intensity. In the sustainability index embodied energy is quantified and incorporated into the decision-making model. Projects are ranked in accordance with total energy consumption. Therefore the sustainability index helps to identify high-energy projects in the decision-making process.

Additional information about the relationship was also be obtained by forming a confidence interval for the slope (β_1). A 95 percent confidence was $b_1 \pm (t_{0.025})Sb_1$ (where b_1=sample slope and Sb_1=standard error of the slope). The value of $t_{0.025}$, based on n-2=18df (degrees of freedom), was 2.101, therefore, the 95 percent lower and upper confidence intervals from Table 8.1 were 0.025076 and 0.049249 $\$/m^2$. The estimated interval enclosed the mean increase in energy consumption per additional $\$/m^2$ building cost of a high school project. Since β_1 is positive, energy consumption increases as building cost increases.

The coefficient of correlation (r=0.836) between building cost and energy consumption indicates a probability that building cost is positively associated with energy consumption. The correlation coefficient (r) was tested to determine whether there was any evidence of a statistically significant association between the two variables using the testing for the existence of correlation.

ii) Testing the hypothesis (H1) of the relationship between building cost and energy consumption

H_0 = The building cost will exhibit no relationship with energy consumption.

H_a = The building cost will exhibit a relationship with energy consumption.

The null and alternate hypotheses as developed in Chapter Six were tested for correlation. The coefficient of correlation ($r=0.836$) between building cost and energy consumption indicated a strong probability that they are related. The correlation coefficient (r) was tested to determine whether there is any evidence of a statistically significant association between the two variables.

The hypothesis was tested at a significance level of 5 percent (i.e. $\alpha=0.05$) and a two-tailed test. The null hypothesis (H_0) is that x (total building cost) contributes no information for the prediction of y (the energy consumption) using the straight-line model. The alternative hypothesis (H_a) is to examine if the two variables (x and y) are linearly related. The two hypotheses were:

$H_0 : \rho = 0$
$H_a : \rho \neq 0$

Table 8.1 shows the value of t statistic was:

$t = 6.459$.

The *p*-value of the test reported on the same table was:

$p = 4.46\text{E-}06$.

This small *p*-value leaves a very small probability that building cost does not contribute information to predict energy consumption of high school projects. The energy consumption increases as the building cost increases.

8.2.3 Regression model (Model 2) for building cost and external benefits and test of hypothesis (H2)

i) Regression analysis for building cost and external benefits

Table 8.2 summarises the results of analysing the relationship between building cost (\$/m^2) and external benefits (value score/m^2).

Table 8.2 Summary of results of regression analysis for Model 2 to 6

Models Results	Model 2	Model 3	Model 4	Model 5	Model 6
Multiple R	0.608716	0.758933	0.485604	0.751117	0.882755
R square	0.370535	0.575979	0.235811	0.564178	0.779256
Adjusted R square	0.335566	0.552423	0.193356	0.539965	0.766992
Std. error	0.041935	0.017396	0.046206	0.017636	0.012552
Observation	20	20	20	20	20
t statistic	3.255112	4.944772	2.356773	4.827135	7.971344
***p*-value**	0.004396	0.000105	0.029964	0.000135	2.58E-07
Lower 95%	0.000018	0.000018	0.000097	0.000395	0.328577
Upper 95%	0.000082	0.000045	0.001694	0.001005	0.563761
Intercept	-0.120283	-0.071472	-0.000517	-0.002856	0.012546
x	4.9908E-05	3.145E-05	0.000895	0.000700	0.446169

The linear regression model for building cost and external benefits is:

$$y = 4.9908\text{E-}0.5x - 0.1203 \tag{8.2}$$

where x is the \$/m^2 of building cost and y is the value score/m^2 of external benefits. The level of external benefits that can be generated in a project development can be predicted by the amount of money spent on the development throughout the building's economic life span.

Table 8.2 shows that the regression analysis results for model 2 has r=0.609 and R^2=0.371. The result indicates that there is a moderate relationship between the two variables. It means that approximately 37 percent of the sample variations in external benefits can be explained by variations in the building cost.

The positive relationship indicated that an increase in the building cost would bring improvements in the environment quality. This means that even though more money will be spent on the initial construction and operation of a building, the environment will be cleaner and the community will enjoy more environmental benefits. The sustainability index quantifies building cost and external benefits and incorporates them into the decision-making process. The index helps to identify options with high external benefits in a development. The positive outcome from the analysis indicates that more money spends on a development such as technology, aesthetics image and other social benefits will improve the environmental quality.

Additional information about the relationship was obtained from the confidence interval for the slope (β_1). With a 95 percent confidence level, the lower and upper confidence intervals (see Table 8.2) were 0.000018 and 0.000082 $/m^2. The estimated interval enclosed the mean increase in the external benefits per additional $/m^2 of building cost of a high school project. Since β_1 is positive, increases in the total building cost will generate increased external benefits.

The coefficient of correlation (r=0.609) between building cost and external benefits indicated a probability that building cost are positively associated with external benefits. The correlation coefficient (r) was tested to determine whether there was any evidence of a statistically significant association between the two variables using the testing for the existence of correlation.

ii) Testing the hypothesis (H2) of relationship between building cost and external benefits

H_0= The building cost will exhibit no relationship with external benefits.
H_a = The building cost will exhibit a relationship with external benefits.

The hypothesis was tested at a significance level of 5 percent (i.e. $\alpha=0.05$) and a two-tailed test. The two hypotheses were $H_0 : \rho=0$ and $H_a : \rho\neq0$. Table 8.2 shows that the value of the t statistic was t=3.255 and the two-tailed *p*-value of the test was *p*=0.004396. This small *p*-value leaves a very small probability that building cost contributes no information towards predicting external benefits of high school projects. This implies that since $t=3.255$ exceeds $t_{18}=2.101$, the null hypothesis of a zero linear correlation between the two variables can be rejected at a 5 percent level of significance. Thus, reject H_0 and it is evident that there is an association between the two variables.

8.2.4 Regression model (Model 3) for building cost and environmental impact and test of hypothesis (H3)

i) Regression analysis for building cost and environmental impact

Table 8.2 summarises the results of regression analysis for the relationship between building cost ($\$/m^2$) and environmental impact (value score/m^2). The linear regression model for total building cost and environmental impact is:

$$y = 3.145E\text{-}0.5x - 0.0715 \tag{8.3}$$

where x is the $\$/m^2$ of building cost and y is the value score/m^2 of environmental impact. The model indicates that the more money spends on a project the more environmental impact it will generate.

The regression statistics for Model 3 (refer to Table 8.2) shows that $r=0.759$ and $R^2=0.576$, suggesting a moderate correlation between the two variables. It means that the variations in building cost can explain approximately 58 percent the variations in environmental impact.

Environmental issues are complex in nature and accurate estimation of such issues is almost impossible. Any techniques or models that try to capture the extent of environmental issues will only be indicative. As for environmental impact, it varies from project to project and from location to location. It is also greatly affected by the time frame for it is very difficult to capture anything that is likely to happen in the distant future. As such, the analysis only provides an indicative relationship between a development’s total building cost and its environmental impact. However, the result indicates that more money spends on a development is likely to bring along with negative effects on the environment. Therefore, the decision on the type of materials to be used and the site operation will require significant consideration in order to minimise impact on the environment.

The environmental impact as included in the sustainability index measures items such as the negative effects generated during the design and manufacturing of building materials, recycling and disposal of waste, and the construction process. The sustainability index quantifies these effects and incorporates them into the decision-making framework. The outcome in the index helps to identify and eliminate alternatives that have detrimental effects on the environment.

The lower and upper confidence intervals at 95 percent were 0.000018 and 0.000045. The estimated interval enclosed the mean increase in the value score/m^2 of environmental impact for an additional \$/m^2 of building cost. Since β_1 is positive, the environmental impact increases as building cost increases.

The coefficient of correlation (r=0.759) between building cost and environmental impact indicates a strong probability that building cost is positively associated with environmental impact. The correlation coefficient (r) was tested to determine whether there was any evidence of a statistically significant association between the two variables using the same test as used in Model 2.

ii) Testing the hypothesis (H3) of a relationship between building cost and environmental impact

H_0 = The building cost will exhibit no relationship with environmental impact.
H_a = The building cost will exhibit a relationship with environmental impact.

The hypothesis was tested at a significance level of 5 percent ($\alpha=0.05$) and a two-tailed test. The two hypotheses were $H_0 : \rho=0$ and $H_a : \rho\neq0$. Table 8.2 shows that the value of t statistic was t=4.945 and the two-tailed *p*-value of the test was reported to be *p*=0.000105. This small *p*-value indicates a very small probability that building cost does not contribute information to assist in predicting the environmental impact of high school projects. This implies that since $t=4.945$ exceeds $t_{18}=2.101$, the null hypothesis of a zero linear correlation between the two variables can be rejected at a 5 percent level of significance. Thus, there is evidence that there is association between the two variables.

8.2.5 Regression model (Model 4) for energy consumption and external benefits and test of hypothesis (H4)

i) Regression analysis for energy consumption and external benefits

The relationship between energy consumption (GJ/m^2) and external benefits (value score/m^2) for the 20 high school projects was represented in Model 4 in Table 8.2. The linear regression model for total energy consumption and external benefits is:

$$y = 0.0009x - 0.0005 \tag{8.4}$$

where x is GJ/m^2 of energy consumption and y is the value score/m^2 of external benefits. The regression statistics for Model 4 (refer to Table 8.2) shows that $r=0.486$ and $R^2=0.236$ demonstrating a positive, but weak, correlation between the two variables. It means that the variations in energy consumption can explain approximately 24 percent of variations in external benefits.

The sustainability index quantifies energy consumption and external benefits, and uses the results to rank alternatives in a development. External benefits in the case studies examine aesthetic impact, functional layout, employment opportunities, social benefit and environment quality. From the literature increased energy consumption will reduce the benefit to the environment associated with a development, as energy consumption has a significant connection to environmental degradation (see Chapter Three Section 3.3 for a detailed discussion). However, the result indicates a positive relationship between the two variables that external benefits increases as the energy consumption increases. The result may be because of the analysis is based on a sample of 20 high school projects. An increase in energy consumption brings along with benefits associated with indoor comfort, education service, employment opportunity and recreational facilities that overshadowed the impact of energy consumption.

Additional information about the relationship could also be obtained by forming a confidence interval for the slope. The lower and upper confidence intervals at a 95 percent confidence were 0.000097 and 0.001694. The estimated interval enclosed the mean increase in the value score/m^2 of external benefits per additional GJ/m^2 of total energy consumption of a high school project. Since β_1 is positive, external benefits increase as energy consumption increases.

The coefficient of correlation (r=0.486) between energy consumption and external benefits indicates a probability that energy consumption is positively associated with external benefits. The correlation coefficient (r) was tested to determine whether there was any evidence of a statistically significant association between the two variables.

ii) Testing the hypothesis (H4) of a relationship between energy consumption and external benefits

H_0 = The energy consumption will exhibit no relationship with external benefits.
H_a = The energy consumption will exhibit a relationship with external benefits.

The hypothesis was tested at a significance level of 5 percent and a two-tailed test. The two hypotheses were $H_0 : \rho=0$ and $H_a : \rho\neq0$. Table 8.2 shows that the value of the t statistic was t=2.357 and the two-tailed *p*-value of the test was reported to be *p*=0.029964. This small *p*-value means there is very little probability that energy consumption does not contribute information for predicting external benefits of high school projects. This implies that since t=2.357 exceeds t_{18}=2.101 the null hypothesis of a zero linear correlation between the two variables can be rejected at a 5 percent level of significance.

8.2.6 Regression model (Model 5) for energy consumption and environmental impact and test of hypothesis (H5)

i) Regression analysis for energy consumption and environmental impact

The relationship between energy consumption (GJ/m^2) and environmental impact (value score/m$^{2)}$ was shown in Table 8.2. The linear regression model for total energy consumption and environmental impact is:

$$y = 0.007x - 0.0029 \qquad (8.5)$$

where x is the GJ/m^2 of energy consumption and y is the value score/m^2 of environmental impact. The regression statistics for Model 5 (refer to Table 8.2) shows that r=0.751 and R^2=0.564. The result indicates a positive relationship between the two variables. It means that approximately 56 percent of the sample variations in environmental impact can be explained by variations in the energy consumption.

The sustainability index quantifies energy consumption and environmental impact and helps to identify options with high environmental impact of a development. The positive relationship between the two variables indicates that environmental impacts increases as the energy consumption increases. The result obtained from the analysis agrees with the literature review as previous studies indicate that energy consumption is closely related to environmental pollution such as air pollution, greenhouse effects and the environmental damages caused by energy production and usage (refers to Chapter Three Section 3.3 for details). The energy consumption has more to do with environmental degradation than improving its quality. In the sample the high school projects use high embodied energy building materials such as aluminium, bricks, glass and so on that generate negative effects on the environment.

The lower and upper confidence intervals at a 95 percent confidence were 0.000395 and 0.001005. The estimated interval enclosed the mean increase in the value score/m^2 of environmental impact per additional GJ/m^2 total energy consumption of a high school project. Since β_1 is positive, environmental impact increases as total energy consumption increases.

The coefficient of correlation ($r=0.751$) between energy consumption and environmental impact indicates a probability that energy consumption is positively associated with environmental impact. The correlation coefficient (r) was tested to determine whether there was any evidence of a statistically significant association between the two variables.

ii) Testing the hypothesis (H5) of a relationship between energy consumption and environmental impact

H_0 = The energy consumption will exhibit no relationship with environmental impact.

H_a = The energy consumption will exhibit a relationship with environmental impact.

The hypothesis was tested at a significance level of 5 percent and a two-tailed test. The two hypotheses were $H_0 : \rho=0$ and $H_a : \rho\neq0$. Table 8.2 shows that the value of the t statistic was $t=4.827$ and the two-tailed *p*-value of the test was $p=0.000135$. This small *p*-value means that it is likely that total energy consumption will contribute information for predicting environmental impact from high school projects. This implies that since $t=4.827$ exceeds $t_{18}=2.101$ the null hypothesis of a zero linear correlation between the two variables can be rejected at a 5 percent level of significance.

8.2.7 Regression model (Model 6) for external benefits and environmental impact and test of hypothesis (H6)

i) Regression analysis for external benefits and environmental impact

Table 8.2 demonstrates the relationship between external benefits (value score/m^2) and environmental impact (value score/m^2). The linear regression model for external benefits and environmental impact is:

$$y = 0.4462x - 0.0125 \tag{8.6}$$

where x is external benefits and y is environmental impact. The regression statistics for Model 6 (refer to Table 8.2) shows that $r=0.883$ and $R^2=0.779$. The result reveals a strong correlation between the two variables. It means that approximately 78 percent of the variations in environmental impact can be explained by the variations in external benefits. The result indicates that an increase in the external benefits would increase the degradation of the environment.

The coefficient of correlation (r=0.883) between external benefits and environmental impact indicates a probability that external benefits are positively associated with environmental impact. The correlation coefficient (r) was tested to determine whether there is any evidence of a statistically significant association between the two variables.

ii) Testing the hypothesis (H6) of a relationship between external benefits and environmental impact

H0 = The external benefits will exhibit no relationship with environmental impact.

Ha = The external benefits will exhibit a relationship with environmental impact.

The hypothesis was tested at a significance level of 5 percent and a two-tailed test. The two hypotheses were H_0: $\rho=0$ and H_a: $\rho\neq0$. Table 8.2 shows the value of the t statistic was t=7.971 and the two-tailed *p*-value of the test was *p*=2.58E-07. This small *p*-value makes it probable that external benefits contribute information for predicting environmental impact from high school projects. This implies that since t=7.971 exceeds t_{18}=2.101, the null hypothesis of a zero linear correlation between the two variables can be rejected at a 5 percent level of significance.

iii) Curvilinear regression analysis between external benefits and environmental impact

Figure 8.1, however, indicates a curvilinear relationship between external benefits and environmental impact in which environmental impact (y) increases at a changing rate for various values of external benefits (x). Table 8.3 presents the results of a curvilinear regression analysis for Model 6.

Therefore, the curvilinear regression equation can be expressed as:

$$y_i = -0.00923+1.22721x_{1i}-2.91058x_{1i}^2 \qquad (8.7)$$

Where: y_i = predicted the average value score of environmental impact
x_{1i} = the average value score of external benefits

Table 8.3 Results of curvilinear regression analysis for external benefits and environmental impact

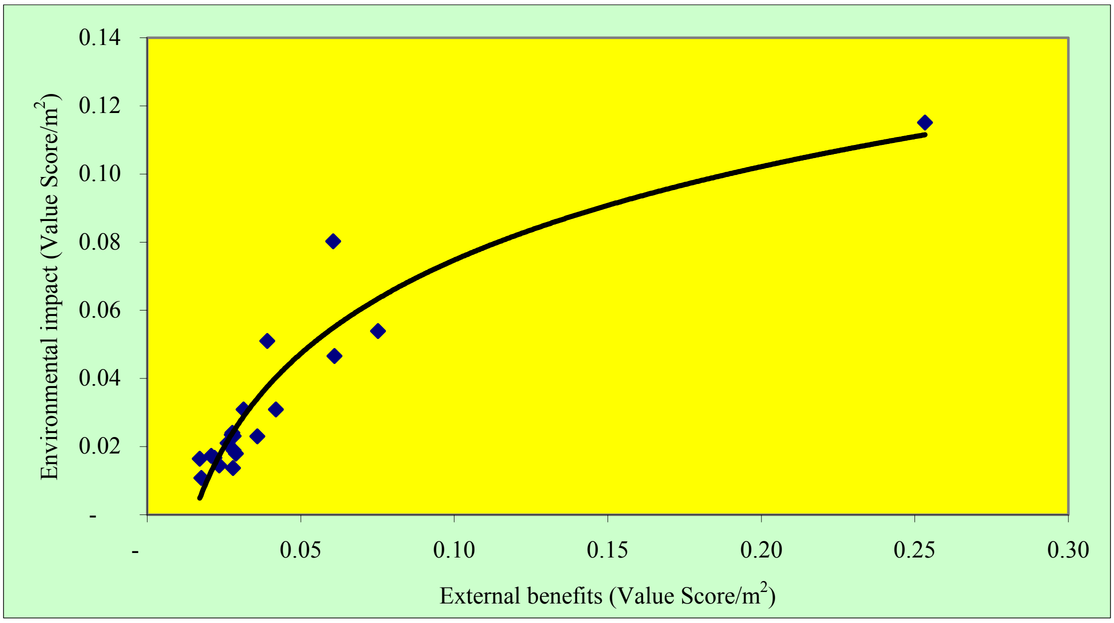
Regression statistics						
Multiple R	0.940486					
R Square	0.884515					
Adjusted R sq	0.870928					
Standard error	0.009342					
Observations	20					
ANOVA						
	df	SS	MS	F	Signif. F	
Regression	2	0.011363	0.005681	65.1027	1.08E-08	
Residual	17	0.001484	8.73E-05			
Total	19	0.012846				
	Coefficients	Standard error	t statistic	*p*-value	Lower 95%	Upper 95%
Intercept	-0.009226	0.006199	-1.488496	0.154936	-0.022305	0.003851
B/m^2	1.227209	0.202744	6.053000	1.29E-05	0.799456	1.654962
B/$m^{2\wedge2}$	-2.910582	0.739414	-3.936337	0.001064	-4.740610	-1.350553

The curvilinear regression model was tested for significance using a F-test to determine whether there is a significant overall relationship between the two variables. The null hypothesis (H_0=ß$_1$=ß$_2$=0) shows there is no overall relationship between the two variables whilst the alternative hypothesis (H_a=ß$_2$ and/or ß$_1$≠0) denotes an overall relationship. At a 5 percent level of significance, because the *p*-value=1.08E-08 < 0.05 (refer to Table 8.3), the null hypothesis (H_0) is rejected and it is concluded that there is a significant overall relationship between external benefits and environmental impact.

In addition, a test has also been conducted to examine whether there is a significant difference between the linear model (equation 8.6) and the curvilinear model (equation 8.7) by determining the regression effect of adding the curvilinear term. The null hypothesis (H_0), including the curvilinear effect, does not significantly improve the model (ß$_2$=0) whilst the alternative hypothesis (H_a), including the curvilinear effect, significantly improves the model (ß$_2$≠0). At a level of significance of 5 percent, because the *p*-value=0.001064<0.05 (refer to Table 8.3), the null hypothesis (H_0) was rejected. It can therefore be concluded that the curvilinear model is significantly better than the linear model in representing the relationship between external benefits and environmental impact.

The purpose of undertaking the curvilinear analysis was to explore if there was a more accurate model than the linear model to represent the relationship between external benefits and environmental impact as per square metre of gross floor area. Figure 8.1 indicates an increase in the value score/m^2 of environmental impact, but the increase is reduced as the value score/m^2 of external benefits increases. Therefore, as the tests revealed, there is a significant overall curvilinear relationship, instead of a linear relationship, between the two variables.

Figure 8.1 Regression analysis of external benefits (value score/m^2) and environmental impact (value score/m^2)



Environmental issues and their relationships with human activities are complex in nature. The frequent outcome is that an improvement in the environmental quality will somehow sacrifice the natural resources and may also generate pollutants to the atmosphere. This analysis supports this paradigm. Therefore a trade-off principle is applied in evaluating economic and environmental effects in project appraisal.

8.3 DEVELOPING THE MULTIPLE REGRESSION MODEL AND TESTING THE HYPOTHESIS

8.3.1 Introduction

The previous section focused on developing linear models between the four criteria and testing the six models to determine the existence of correlation at a 5 percent level of significance. The aim of this section is to develop a multiple regression model where energy consumption is the dependent variable whilst building cost, environmental impact and external benefits are the independent variables. The purpose of developing a multiple regression model is to examine the true nature of the relationship between the dependent and independent variables. The hypothesis (H7) as established in Chapter Six Section 6.3 will be tested using a test of hypothesis on the slope and an F test for the entire regression model. The outcomes in the analysis will demonstrate if there is a significant relationship amongst the four criteria so as to confirm the validity of the model of the sustainability index for project appraisal.

8.3.2 Multiple regression model (Model 7) for the prediction of energy consumption and test of hypothesis (H7)

i) Multiple regression analysis for energy consumption, building cost, external benefits and environmental impact

In the previous section, the relationship between two variables was examined. The results of the correlation were all positive and ranged from a moderate to strong association. However, a realistic probabilistic model to aid the decision-making process for a project would need to include more than one variable in order to provide a good predictive model. Therefore, in this section multiple regression was used to incorporate all the variables into a model to make an accurate prediction of values.

In this model, total energy consumption is a dependent variable whereas total building cost, external benefits and environmental impact are independent variables. All the variables are expressed in unit per square metre of gross floor area as previously explained.

The multiple regression model was of the form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon$$

Where y = energy consumption
β_0 = y-intercept
β_1 = slope of y with variable x_1
β_2 = slope of y with variable x_2
β_3 = slope of y with variable x_3
x_1 = building cost ($\$/m^2$)
x_2 = environmental impact (value score/m^2)
x_3 = external benefits (value score/m^2)
ε = random error

Table 8.4 Results of multiple regression analysis

Regression statistics						
Multiple R	0.906670					
R Square	0.822050					
Adjusted R sq	0.788684					
Standard error	12.824665					
Observations	20					
ANOVA						
	df	SS	MS	F	Signif. F	
Regression	3	12156.602710	4052.200903	24.637629	3.0798E-06	
Residual	16	2631.552551	164.472034			
Total	19	14788.155260				
	Coefficients	Standard error	t stat	*p*-value	Lower 95%	Upper 95%
Intercept	-44.106089	20.221219	-2.181178	0.044437	-86.973149	-1.239028
$\$/m^2$	0.023656	0.007349	3.218757	0.005362	0.008076	0.039237
R/m^2	994.215795	299.489728	3.319699	0.004336	359.326078	1629.105512
B/m^2	-355.885157	124.236477	-2.864579	0.011237	-619.254663	-92.515651

From Table 8.4 the multiple regression model is:

$$y = -44.106 + 0.024x_1 + 994.215x_2 - 355.885x_3 + \varepsilon \qquad (8.8)$$

The multiple regression model represents that y values (energy consumption as per square metre of gross floor area) is the function of the independent variables. In the table, the adjusted R^2=0.789 implies that there is a strong fit of the model to the data.

This high R^2 value implies that 79 percent of the sample variations in energy consumption are attributable to the independent variables of building cost, external benefits and environmental impact as expressed per square metre of gross floor area.

The model indicates that energy consumption (GJ/m^2) is estimated to increase with each increase in average building cost ($\$/m^2$) and value score/$m^2$ environmental impact, but the response is inverse with each increase in average value score/m^2 of external benefits.

ii) Testing the hypothesis (H7) of energy consumption as a function of building cost, external benefits and environmental impact

H_0 = The energy consumption will exhibit no relationship with building cost, external benefits and environmental impact.

H_a = The energy consumption will exhibit a relationship with building cost, external benefits and environmental impact.

In order to examine the robustness of the multiple regression model, a hypothesis test was performed on the slope and an F test was performed for the entire regression model. The aim of testing the hypothesis for the slope in multiple regression is to determine if the population slope β_1, β_2 and β_3 are zero. The purpose is to determine whether the independent variables have significant effect on the dependent variable. The null hypothesis is hypothesised that x_1 is of no value for predicting the response y given that x_2 and x_3 are available (i.e. $H_0 : \beta_1=0$). The alternative hypothesis is hypothesised as x_1 is of some value for predicting the response y given that x_2 and x_3 are available (i.e. $H_a : \beta_1 \neq 0$).

The hypotheses were tested at a level of significance of 5 percent (i.e. $\alpha=0.05$). From the t distribution table for 16 degrees of freedom, the critical values of t are ±2.12. Table 8.4 shows the computed t statistic for β_1 was 3.219 and the *p*-value 0.005. Since $t=3.219 < t_{16}=2.12$ or the *p*-value of $0.005 < 0.05$, the null hypothesis was rejected. It is, therefore, concluded that there is a significant relationship between independent variable x_1 (building cost) and the dependent variable y (energy consumption).

The same test was applied to β_2, and β_3 at the same level of significance. Table 8.4 shows the computed t statistics for β_2, and β_3 were 3.320 and -2.865 respectively. Since the t statistics for β_2 was greater than $t_{16}=2.12$ and the t statistics for β_3 was smaller than $t_{16}=-2.12$ with all the *p*-values less than 0.05, the null hypotheses were rejected. It is, therefore, concluded that there are significant relationships between x_2 and x_3 for environmental impact and external benefits and the dependent variable y (energy consumption).

The confidence intervals for β_1, β_2, and β_3 can also be obtained from Table 8.4. It is because the critical values of t at the 95% confidence level with 16 degrees of freedom is 2.12, the confidence intervals were:

$$0.008076 \leq \beta_1 \leq 0.039237$$

$$359.326078 \leq \beta_2 \leq 1629.105500$$

$$-619.254663 \leq \beta_3 \leq -92.515651$$

From the hypothesis-testing viewpoint, because these confidence intervals do not include zero, it is concluded that the regression coefficients β_1, β_2, and β_3 have significant effect on the prediction of the dependent variable y.

The multiple regression model was also tested for overall utility by using the F test. The F test is used to determine whether the model is adequate for predicting y values. It is also sufficient to determine whether there is a significant relationship between the dependent variable and the set of independent variables.

The hypothesis was tested for the significance of the multiple regression model at a 5 percent significance level. The null hypothesis is hypothesised that there is no linear relationship between the dependent variable and the independent variables (i.e. H_0: $\beta_1=\beta_2=\beta_3=0$). The alternative hypothesis is hypothesised that there is a linear relationship between the dependent variable and at least one of the independent variables (i.e. H_a : β_1, β_2 & $\beta_3 \neq 0$).

The reject region is if $F > F_{0.05,}$ where $\nu 1=3$ and $\nu 2=16$ and $F_{0.05}=3.24$. Table 8.4 shows that the computed F was 24.637. Since this value greatly exceeded the tabulated value of 3.24, it was concluded not to accept the null hypothesis. The result indicated that the data provided a probability that at least one of the model coefficients β_1, β_2 and β_3 is non-zero. Therefore, the global F test indicated that the model was useful for predicting the amount of energy consumption in high school projects.

The proper use of multiple regression analysis requires that several assumptions about the nature of the data be satisfied. These assumptions were tested and found to be satisfied. The error term was normally distributed with a mean = 0 and there was no significant multicollinearity between the independent variables. There was no homoscedasity and serial correlation of error terms. Detail analyses are included as Appendix F in the thesis.

8.3.3 Summary

This and the previous sections have developed six linear regression models to examine the hypothesised relationships, and one multiple regression model with energy consumption being the dependent variable. The hypotheses and the utility of the models have been tested and confirmed to display significant correlation. The probability as derived in the analysis, has revealed that the four criteria are interacting with each other. The analyses carried out in this section are important as they provide a valid platform for the four criteria to be incorporated into the sustainability index. The analysis has proved that trade-off principles may have to be applied when using sustainability index model. The trade-offs are handled by developing the weighting system for the four criteria and details have been discussed in Chapter Five Section 5.3.

The next section will demonstrate the practical aspect of the sustainability index. The model of the sustainability index will also be used to assess and rank a low-rise industrial project with three design options.

8.4 VERIFYING THE SUSTAINABILITY INDEX

8.4.1 Introduction

The sustainability index has been developed and discussed in previous chapters. The data for the four criteria, financial return, energy consumption, external benefits and environmental impact, have been collected for 20 high school projects. The last section analysed the data collected and discussed and tested the relationship between these variables. This section sets out to demonstrate how the sustainability index can be used to rank projects with competing alternatives.

8.4.2 Proposed development

The project is a low-rise industrial building used as a hardware warehouse for storing goods and materials and as a retail outlet for local residents. The development is located in the light industrial area of the upper North Shore at Mt Colah (NSW) with low density residential development surrounds the area. The proposed development has easy access via the main road and located near public transport next to the Pacific Highway and close to the train station. Its convenient location has provided an additional shopping facility for local residents.

Table 8.5 summarises the design details for the three options of the proposed development. From the table, the design of the three options was based on the standard practices and construction details commonly used in Australia. The generally flat site is around 4,082m^2 with shrubs and vegetation on the northern side. The proposed development consists of a free-standing industrial warehouse with attached office space; there are three design options.

Option A comprises a single-level warehouse and a two-storey office area constructed by structural steel portal frame with Colorbond metal sheeting for the walls and roof decking. The office area has a reinforced concrete frame with face brick veneer cladding and Colorbond metal roof decking. Option B comprises a single-level warehouse and office area and is constructed by tilt-up concrete panels painted on the outside. The roof consists of Colorbond metal roof decking on structural steel trusses.

Option C comprises two-storey design for both the warehouse and office. The construction is reinforced concrete columns and beams. The external wall has face brickwork to warehouse area and a full height glazed curtain wall to the office area with terra cotta roof tiles. All three options have two full height roller shutter doors, aluminium windows, solid-core timber external doors, and hollow-core timber internal doors.

Table 8.5 Summary of design details for the proposed development

Elements	Option A	Option B	Option C
Warehouse:			
Storey	Single	Single	Two
Storey height	6m	6m	6m
Dimension	30 x 14m	45 x 28m	30 x 14m
Area	420m^2	1,260m^2	420m^2
Car parking	500m^2	500m^2	1,000m^2
Driveway	120m^2	120m^2	120m^2
Walkway for pedestrians	100m^2	100m^2	100m^2
General landscaping	2,736m^2	1,682m^2	2,236m^2
Sub-structure	RC slab on ground	RC slab on ground	RC slab on ground
Frame	Structural steel portal frame	Tilt-up panels	Insitu concrete columns and beams
Roof	Colorbond roof deck on steel trusses with skylights	Colorbond roof deck on steel trusses with skylights	Terra cotta roof tile on timber trusses with skylights
External wall	Colorbond metal sheeting	Tilt-up panels and painted	Face brick
Windows	Aluminium window/louvre	Aluminium window/louvre	Aluminium window/louver
External doors	2 roller shutter doors, solid core door	2 roller shutter doors, solid core door	2 roller shutter doors, solid core door
Internal wall	Nil	Nil	Nil
Internal door	Hollow core doors	Hollow core doors	Hollow core doors
Wall finishes	Self finish	Fairface concrete	Self finish
Floor finishes	Steel trowel finish	Steel trowel finish	Steel trowel finish
Ceiling finishes	Nil	Nil	Nil
Office:			
Storey	Two	Single	Two
Storey height	2.40m	2.40m	2.40m
Dimension	14 x 14.7m	28 x 15m	14 x 14.7m
Area	206m^2	420m^2	206m^2
Sub-structure	Stiffened raft slab	Stiffened raft slab	Stiffened raft slab
Upper floors	RC slab	RC slab	RC slab
Frame	Insitu concrete	Tilt-up panels	Insitu concrete
Roof	Colorbond roof deck on steel roof trusses	Colorbond roof deck on steel roof trusses	Terra cotta tiles on timber roof trusses
External walls	Face brick veneer	Tilt up slabs and painted	Full height glazing
Windows	Aluminium	Aluminium	Aluminium
External doors	Solid core timber	Solid core timber	Solid core timber
Internal wall	Solid brickwork	Plasterboard metal stud partition	Plasterboard timber stud partition
Internal doors	Hollow core timber	Hollow core timber	Hollow core timber
Wall finishes	Painted plaster n general area, ceramic wall tiles in wet areas	Painted in general areas, ceramic wall tiles in wet areas	Painted plasterboard in general area, ceramic wall tiles in wet areas
Floor finishes	Heavy duty wool carpet in general area, ceramic tiles in wet areas	Vinyl in general area, ceramic tiles in wet areas	Timber flooring in general area, ceramic tiles in wet areas
Ceiling finishes	Suspended painted ceiling	Suspended painted ceiling	Suspended painted ceiling

Table 8.6 shows the summary of gross floor areas for the three options. From the table, option B has the largest gross floor area, about 102 and 34 percent more than options A and C respectively in total floor area. Option B's warehouse floor area has one and half times and three times more space than options C and A respectively. In the warehouse design, only option C has two-storeys whilst options A and B are single level. The three options have similar office space, but only option B has a single storey design.

Table 8.6 Summary of gross floor areas (GFA) for the proposed development

Option	Warehouse		Office		Total (m^2)
	Storey	GFA (m^2)	Storey	GFA (m^2)	
A	Single	420	Two	412	832
B	Single	1,260	Single	420	1,680
C	Two	840	Two	412	1,252

8.4.3 Data collection and analysis

Data for the four criteria incorporated in the sustainability index were collected based on the methodology as detailed in Chapter Six. A set of outline proposal drawings and specifications was received from the architect's office for the three design options. Financial return was calculated based on the outline proposal and specification and priced as at December 2003. The income incurred from the development is the monthly rent at a current market rate of \$15/m^2 in the upper North Shore area.

Table 8.7 summarises the financial return for the three options of the proposed development. With regards to construction cost, option A is the most expensive option to build and to maintain per square metre of gross floor area. Option B demonstrates the most favourable design in terms of generating expected expenditure (costs) and contributing the expected income (benefits) over a 40-year economic life span.

Table 8.7 Summary of financial return for the proposed development

Option	Construction cost		Building life cost		Income (40 years)
	Total	\$/m^2	Total (40 years)	\$/m^2	
A	1,159,740.50	1,393.92	2,042,606.70	2,455.06	7,088,640
B	1,420,426.44	845.49	2,606,153.74	1,551.28	14,313,600
C	1,540,567.51	1,230.49	2,331,622.40	1,862.32	10,663,632

The discounted cash flow approach is used to bring costs and benefits into an equivalent monetary value so that the overall net benefit of the three options can be calculated and compared. The net present value (NPV) and benefit cost ratio (BCR) of the three options are shown in Table 8.8. The construction industry uses NPV to aid the decision-making process in deciding whether or not to go ahead with a project. The higher the NPV the better the development option (Abelson, 1996; Ding, 1999a). Calculating BCR indicates the significance of the result where a BCR of greater than one indicates an attractive option. In the table, option B exhibited the highest NPV and BCR for the 5, 10 and 15 percent discount rate. At a discount rate of 15 percent, both option A and C exhibited a negative NPV which means that the options become not feasible.

Table 8.8 Summary of net present value (NPV) and benefit cost ratio (BCR) for the proposed development

Option	5% discount rate		10% discount rate		15% discount rate	
	NPV ($)	BCR	NPV ($)	BCR	NPV ($)	BCR
A	785,786.47	1.41	(68,221.39)	0.96	(409,044.78)	0.71
B	3,078,639.67	2.27	1,071,038.77	1.55	273,350.85	1.16
C	1,679,124.39	1.69	251,567.04	1.13	(318,610.30)	0.83

With regards to the discount rate applied to the three options, the BCRs for option B are all greater than one, meaning that it is an acceptable option. The other options have lower BCRs progressing to less than 1. If the decision to proceed with the project is based on the option with the highest NPV (or BCR), then the table indicates that option B is the best choice among the three designs.

Table 8.9 presents the summary of energy consumption, external benefits and environmental impact for the three options of the development. The energy consumption was also presented as per square metre of gross floor area to enable comparisons to be made. The energy consumption was measured over the proposed development's 40-year life span. The energy consumption was measured as the total energy usage of initial and recurrent embodied energy, and operational energy.

The initial and recurrent embodied energy were calculated using the embodied energy coefficients used previously in this study. In measuring the initial embodied energy, an allowance of 6 percent for on-site process, 19 percent of building services and 20 percent of incompleteness were made. A further 1 GJ/m^2 was allowed for furniture and fittings for the office areas in accordance with the discussions in Chapter Six. With regard to calculating recurrent embodied energy, the building services assumed to be replaced every 30 years whilst furniture and fittings were replaced at every 10 years.

There is no data on operational energy consumption of warehouses available in the literature and research studies. The operational energy has therefore been derived from the energy bills of existing warehouses in the upper North Shore area and extended to cover a 40-year economic life span. Due to the diversified usage of warehouse, the energy bills obtained from existing projects were confined to the type of warehouses that are currently used for materials and components storage with general lighting systems and natural ventilation for the warehouse and air-conditioning in the office areas.

External benefits and environmental impact have been evaluated using the multi-criteria approach outlined in Chapter Six. Seven members of the development's design team, consisting of an architect, quantity surveyor, contractor, engineer, project manager and two representatives from the client, evaluated the project.

Table 8.9 shows that option B demonstrated the lowest energy consumption per square metre of gross floor area. However, for both external benefits and environmental impact, option C has demonstrated a more environmentally friendly design with the highest benefit generated and lowest level of environmental impact.

Table 8.9 Summary of energy consumption, external benefits and environmental impact for the proposed development

Option	Energy consumption (GJ)				External benefits (value score)	Environmental impact (value score)
	Embodied energy	Operational energy	Total	GJ/m^2		
A	10,978.69	9,984.00	20,962.69	25.20	194.81	203.19
B	16,508.15	16,800.00	33,308.14	19.83	196.63	204.50
C	15,809.54	11,808.00	27,617.53	22.06	210.19	195.69

8.4.4 Calculating the sustainability index

The four criteria of financial return, energy consumption, external benefits and environmental impact have been collected and calculated in the previous section. The four criteria were combined in the sustainability index. Table 8.10 presents the two-dimensional evaluation matrix for the four criteria as in the rows, whilst the three design alternatives are in the columns. The weights for the four criteria were derived from the pairwise evaluation matrix as assessed by the design team members. In accordance with the assessment results, external benefits was the most important criterion followed by environmental impact. Financial return shown as BCR was the least important criterion.

Table 8.10 Two-dimensional evaluation matrix for the proposed development

Criteria	Alternatives						Weights
	A		B		C		
	Raw	Standardised	Raw	Standardised	Raw	Standardised	
BCR (ratio : 1)	1.41	0.621	2.27	1.000	1.69	0.744	2.00
Energy consumption (GJ/m^2)	25.20	1.000	19.83	0.787	22.06	0.875	2.17
External benefits (value score)	194.81	0.927	196.63	0.935	210.19	1.000	3.16
Environmental impact (value score)	203.19	0.994	204.50	1.000	195.69	0.957	2.67
Sustainability Index	**4.19**		**5.42**		**5.03**		

Note:

1. Standardised score was calculated using the following formula as detailed in Voogd, 1983, p. 79

$$\text{Standardised score } i = \frac{\text{'raw' score } i}{\text{maximum 'raw' score}}$$

2. Sustainability index was calculated using weighted summation method as detailed in Chapter Five. For example the SI for option A was calculated as 0.621 x 2 +(1-1) x 2.17 + 0.927 x 3.16 + (1-0.994) x 2.67 = 4.19

Since the four criteria were in different measurement units they were standardised before being multiplied with the weights. As discussed in Chapter Five, the sustainability index is the function of the four criteria. It is calculated for each option by multiplying each value by the weight, followed by summing the weighted scores for all criteria using the weighted summation method. The best design option has the highest score in the sustainability index. The amalgamation method yields a single index of alternative worth, which allows the options to be ranked. The higher the sustainability index, the better the option.

The sustainability index as calculated for the three options was 4.19, 5.42 and 5.03 for options A, B and C respectively. In respect to the principle of a sustainability index, the ranking for the three options for the proposed development is B>C>A. Option B emerges as the best option amongst the rival alternatives.

The table shows that option B has the highest BCR at 5 percent and remains the highest for 10 and 15 percent. Option B also consumes the least amount of energy. In external benefits, Option B's performance is second best. But even though Option B does not perform as well as the other two on environment impact, the overall performance is compensated for by its outstanding performances in the BCR, energy consumption and external benefits assessments.

This example verifies that the sustainability index is able to provide rankings in project appraisal and the outcome of ranking for the proposed development appears to the best alternative. The sustainability index's significant contribution is that it assesses projects not only on the financial return, but most importantly also includes energy consumption as well as social and environmental issues in the decision-making framework. The sustainability index demonstrates a valid methodology to be used to incorporate environmental values in project appraisal and to rank the alternatives in project appraisal.

This section demonstrates that the four criteria can be combined together to rank projects and also remain constant for any type of construction. The sustainability index has demonstrated a more environmentally friendly practice, and a more responsible attitude towards the environment.

8.5 CONCLUSION

This chapter presented the data analysis for the sample of 20 high school projects in the sustainability index. The linear and multiple regression relationships were established and tested to validate the four criteria in the sustainability index. The hypotheses as developed in Chapter Six were also tested and revealed that the four criteria are important components to be considered when measuring sustainability in project appraisal. Finally, this chapter also demonstrated the use of the sustainability index to rank projects alternatives.

The next chapter presents the importance of benchmarking in construction and the process of further developing the sustainability index into a benchmarking tool. A computer program will be presented in the next chapter to highlight the practical aspect of the sustainability index when using it as a decision-making tool.

CHAPTER
NINE

DEVELOPING SINDEX—A BENCHMARKING TOOL IN CONSTRUCTION

9.1 INTRODUCTION

Construction has long been criticised as being fragmented with poor productivity when compared with other sectors of the economy (Harvey, 1987; Li et al., 2001). The industry, which is made up of predominantly medium to small firms employing a large proportion of labourers, has contributed to the low productivity and poor quality of work. The construction process involves various parties that possess different skills or knowledge such as development, design, construction and budgeting (Harvey, 1987; Bennett, 2003). The parties are joined together directly or indirectly by building contracts. Because of the diversity in the nature of construction, they tend to have their own goals and objectives, and together the diverse cultural and behavioural characteristics of these many parties can lead to conflicts.

As discussed in Chapter Three, there is a growing concern about the relationship between construction activities and environmental degradation. Research shows that construction is contaminating the environment, in terms of consuming renewable and non-renewable resources such as timber and metal, polluting the air, water and land, and generating waste (Hill & Bowen, 1997; Barrett et al., 1999; Cole, 1999a; Holmes & Hudson, 2000; Morel et al., 2001; Scheuer et al., 2003). With concern increasing over global environmental degradation and human health, there is a demand for more environmentally sustainable design and construction. There is no doubt that the construction industry needs to share the task of protecting the environment and more sustainable construction practices are required to achieve this goal. With this in mind, there is a need for an environmental assessment tool that can be used to co-ordinate, integrate and stimulate environmental awareness among practitioners in the construction industry. Developing the sustainability index is a way of achieving sustainable goals in construction by combining economic, social and environmental criteria in the decision-making processes of development.

The sustainability index is a mathematical model that incorporates environmental issues into the decision process to improve the environmental performance of projects. However, Scheuer et al. (2003) suggest that environmental performance of building projects is difficult to evaluate when compared with evaluating products in other industries. This is because building projects are mostly large in scale and employ a complex array of materials. In addition, functions and production processes are less standardised. Finally, the unique character of each building project also contributes to the difficulties of evaluating performance. Therefore, there is a need to develop benchmarks in construction to evaluate environmental performance.

This chapter aims at presenting the development of an environmental benchmarking tool called SINDEX. SINDEX is a computer-based tool for modelling sustainability using multiple criteria. It is based on the sustainability index developed in this research. This chapter presents and discusses the underling principle of SINDEX, its use and its benefits as a benchmarking tool for the construction industry.

9.2 THE NEED FOR ENVIRONMENTAL BENCHMARKING IN CONSTRUCTION

Benchmarking has been widely used throughout the world (Camp, 1998). Recent research carried out by Jarrar and Zairi (2001) discovered that benchmarking is readily accepted and used in many industries and is gaining global economic recognition. Camp (1998) defined benchmarking as the search for industry best practices that will lead to superior performance. Camp’s definition emphasises the value of learning in order to achieve superiority through a structured and systematic manner. Li et al. (2001) further state that the value of benchmarking is to learn best practices internally or externally for the purpose of achieving superiority.

Benchmarking has already been used by other economic sectors such as manufacturing, commercial, transportation and communication as a tool for performance comparison, to increase competitiveness and to maintain continuous improvement (Best Practice Program, 1993; Szekely et al., 1996; Camp, 1998; Codling, 1998; McCabe 2001; Dey, 2002; Jenkins & Hine, 2003). Since the benefits of using benchmarking in other industries are very evident, potential benefits may also be gained within the construction industry by benchmarking performance of projects and facilities on the environment. The fundamental purpose of setting environmental benchmarks in construction is to identify, understand and implement best practice that may be significant in promoting sustainable goals in construction.

Environmental benchmarking encourages changes towards more environmentally friendly design and construction of projects and facilities. Davies (2001) states that companies are increasingly recognising that good environmental sense is also good business sense. It is through the process of developing benchmarking that standards can be improved and measures can be put in place. Additionally, it reinforces the commitment to change by the parties involved in the industry.

Environmental benchmarking, as Szekely et al. (1996) suggest, is a means to make significant improvement in environmental performance whilst remaining competitive. Environmental benchmarking is a structured approach to examine and compare environmental performance of projects and facilities. The objective is to identify and assess the ability for integrating environmental aspects into design and to bring eco-design to designers' attention. It is seen as an ideal link between incorporating environmental awareness and design into the current practice by creating a platform for discussion and implementation.

The other objective of developing environmental benchmarking is to set environmental goals and to ensure consideration of the environment and sustainable development in the construction industry (McCabe, 2001). It is important to have a clear vision of the desired outcome of a project, and to make environmental consideration an integral part of design by helping designers to understand and reduce a development's impact on the natural environment over its life cycle. It may also be useful for the government when making macro-level decisions about environmental policy, to determine whether environmental targets are being attained and to ensure that regulations are being complied with (Davies, 2001).

The values of environmental benchmarking are many. Environmental benchmarking as a means of evaluating the achievement of best practice helps to shift the focus from just achieving profitability to achieving a higher standard of environmental performance (Davies, 2001; McCabe, 2001; Jenkins & Hine, 2003). It enables environmental problems to be identified in order to minimise risks from poor environmental performance. It is fundamentally important as a way to respond and to satisfy the need for a more sustainable construction.

Environmental benchmarking also helps to pursue a clearer definition of environmental issues, against which performance objectives can be prepared and monitored (Szekely et al., 1996; Jasch, 2000). Since the benchmarking process is an ongoing process, it enables knowledge of improved performance from projects or consultants to be transferred during the benchmarking process (Li et al., 2001; Jenkins & Hine, 2003). Additionally, the ability to evaluate a project's environmental performance facilitates achieving sustainable goals in the construction industry and reduces environmental impact.

In construction, environmental management systems (ISO14001) and environmental performance evaluations (ISO14031) have been adopted as benchmarking tools (Jasch, 2000; Matthews, 2003). However, both approaches have shortcomings. Environmental management systems (EMS) mainly consist of policies, procedures and audit protocols to investigate environmental burdens and encourage continual improvement of environmental performance. Nevertheless, as Matthews (2003) describes, the EMS is insufficient to be used as a benchmarking tool without further adjustment because it does not provide a platform for setting common goals and, as the central theme of benchmarking is to enable comparison, it is bound to fail. EMS also lacks procedures for collecting data on performance and, as such, results of progress are not disclosed or shared. Environmental performance evaluation (EPE) is adopted when EMS is not used as a way to assist in identifying environmental aspects (Jasch, 2000). It is implemented on an ongoing basis to measure progress between the environmental target and the actual performance.

Given their deficiencies, the construction industry needs better tools than EMS and EPE that practitioners can use to benchmark environmental performance of projects. The sustainability index developed in this research is a way of achieving this goal. The four criteria measured in the sustainability index can be used to set benchmarks for projects to achieve, and to compare performance of projects. By further developing the sustainability index into a benchmarking tool using computer technology, SINDEX was developed to satisfy such needs. SINDEX is intended to be used as an environmental tool to benchmark economic, social and environmental performance of projects.

9.3 THE DEVELOPMENT OF A SUSTAINABILITY BENCHMARKING TOOL—SINDEX

9.3.1 Introduction

As discussed in Chapter Five, developing a sustainability index is a way of promoting sustainable goals in construction as it uses a multi-criteria approach that measures economic, social and environmental issues for appraising projects and facilities. The sustainability index has been taken further in this research, using computer technology to develop a benchmarking tool to be used in the construction industry in order to aid design and the projects sustainability assessment.

SINDEX is a sustainability modelling tool used to calculate and benchmark sustainable performance of proposed buildings, and new and existing facilities. SINDEX uses the concept of the sustainability index in this research and computer technology to develop a practical tool that can be used widely by practitioners in the construction industry. As discussed in Section 9.2, the benefit of environmental benchmarking is so evident that SINDEX's contribution could be significant.

The software was developed by the author and Professor Craig Langston in mid 2003 in response to a request from the Australian Institute of Quantity Surveyors (AIQS) to develop a computer-based tool for sustainability modelling to be used by practitioners both in Australia and overseas. The work has clear international application.

SINDEX calculates a sustainability index as developed in this research for ranking and selecting projects. Since its completion, AIQS has distributed SINDEX to its 267 members and other organisations such as the Australian Greenhouse Office, Royal Australia Institute of Architects and Institute of Engineers of Australia.

SINDEX was developed to assist practitioners and designers to consider the four criteria as identified in this research in the feasibility of project or facility design. Benchmarks for the four criteria are set across projects to enable accept or reject decisions to be made, as well as relative ranking of projects.

The four criteria included in the sustainability index are the four input screens in SINDEX:

- Maximise wealth—Financial return
- Minimise resources—Energy consumption
- Maximise utility—External benefits
- Minimise impact—Environmental impact

The measurement of each criterion follows the methodology as detailed in this thesis in units best suited to its quantification.

9.3.2 Maximise wealth (Financial return)

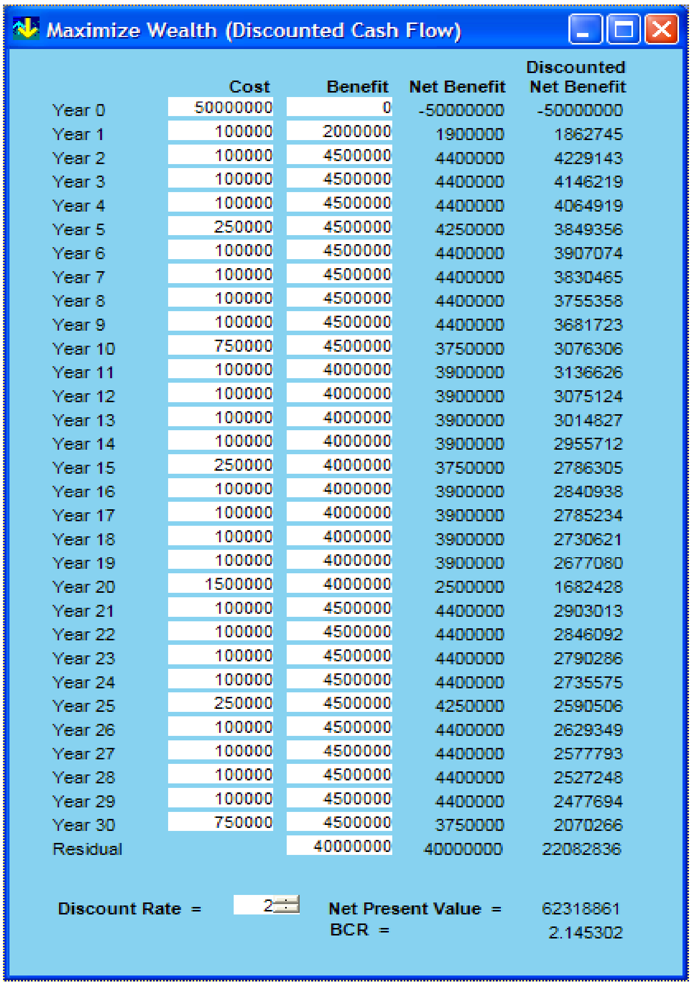
To maximise wealth, as the ultimate objective of every development, is an economic criterion. Its benchmark is based on the calculation of benefit-cost ratio (BCR). BCR is calculated as the discounted project income divided by the discounted life-cost measured over the economic life a development. The higher the ratio the better the return on investment. A ratio of 1:1 indicates the financial break-even point. The costs and benefits are measured in terms of present value. Project costs include acquisition expenses during the feasibility stage and the subsequent cleaning, operating, maintenance and replacement cost per year during the occupancy stage of a building. Project benefits are all incomes such as sale, rent and other possible funding such as government subsidy, grants, etc. The criterion is calculated as:

$$\frac{\text{Tangible discounted benefits}}{\text{Tangible discounted costs}} \times 100$$

A benefit-cost ratio of 1 is translated into a score of 100, which is the minimum for this criterion but a value of higher than 100 is obviously preferred.

In SINDEX, a life span of a 30 years is pre-set for evaluation. Therefore, the input screen will not accept a life span of more than 30 years. Project costs and benefits are entered into the ‘maximise wealth’ input screen with whole numbers. A 3 percent discount rate is set as a default to calculate the cash flow. However, a discount rate between 0 and 6 percent can also be used in this calculation. The Maximise Wealth input screen will automatically generate the net benefit and the discounted net benefit. The net present value and BCR are shown at the bottom of the screen (see Figure 9.1 on next page).

Figure 9.1 Input screen of maximise wealth



	Cost	Benefit	Net Benefit	Discounted Net Benefit
Year 0	50000000	0	-50000000	-50000000
Year 1	100000	2000000	1900000	1862745
Year 2	100000	4500000	4400000	4229143
Year 3	100000	4500000	4400000	4146219
Year 4	100000	4500000	4400000	4064919
Year 5	250000	4500000	4250000	3849356
Year 6	100000	4500000	4400000	3907074
Year 7	100000	4500000	4400000	3830465
Year 8	100000	4500000	4400000	3755358
Year 9	100000	4500000	4400000	3681723
Year 10	750000	4500000	3750000	3076306
Year 11	100000	4000000	3900000	3136626
Year 12	100000	4000000	3900000	3075124
Year 13	100000	4000000	3900000	3014827
Year 14	100000	4000000	3900000	2955712
Year 15	250000	4000000	3750000	2786305
Year 16	100000	4000000	3900000	2840938
Year 17	100000	4000000	3900000	2785234
Year 18	100000	4000000	3900000	2730621
Year 19	100000	4000000	3900000	2677080
Year 20	1500000	4000000	2500000	1682428
Year 21	100000	4500000	4400000	2903013
Year 22	100000	4500000	4400000	2846092
Year 23	100000	4500000	4400000	2790286
Year 24	100000	4500000	4400000	2735575
Year 25	250000	4500000	4250000	2590506
Year 26	100000	4500000	4400000	2629349
Year 27	100000	4500000	4400000	2577793
Year 28	100000	4500000	4400000	2527248
Year 29	100000	4500000	4400000	2477694
Year 30	750000	4500000	3750000	2070266
Residual		40000000	40000000	22082836

Discount Rate = 2

Net Present Value = 62318861

BCR = 2.145302

9.3.3 Minimise resource (Energy consumption)

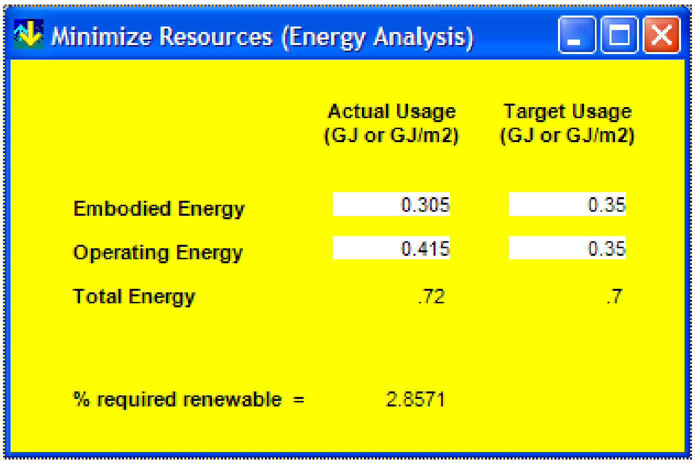
Resource consumption is reflected in the calculation of total energy usage over the full life cycle of a development. Minimising resources is another economic criterion and it is derived from the sum of embodied energy used in construction and maintenance plus the operational energy consumed over the project's economic life. All energy values are entered as GJ or GJ/m^2.

Actual energy usage is benchmarked against target energy usage using the following formula:

$$\frac{\text{Actual energy usage}}{\text{Target energy usage}} \times 100$$

Actual energy usage is calculated based on the methodology detailed in the case studies (see Chapter Six) while the target energy usage is either based on normal practice or legislated limits. A benchmark of 100 is used with the outcome; the lower the better. In SINDEX both embodied and operational energy usage are entered in the 'Minimise Resources' input screen (see Figure 9.2).

Figure 9.2 Input screen for minimise resources



	Actual Usage (GJ or GJ/m2)	Target Usage (GJ or GJ/m2)
Embodied Energy	0.305	0.35
Operating Energy	0.415	0.35
Total Energy	.72	.7

% required renewable = 2.8571

9.3.4 Maximise utility (External benefits)

Utility is defined as functional performance and it includes non-monetary benefits such as functionality, aesthetics, thermal performance, indoor air quality, adaptive reuse potential, flexibility, storage potential and plan efficiency. The functional performance is identified, based on the type of construction and its impacts to the community. Identifying and assessing criteria can be carried out using the methodology detailed in Chapter Five of this thesis. SINDEX can accommodate up to 12 performance criteria.

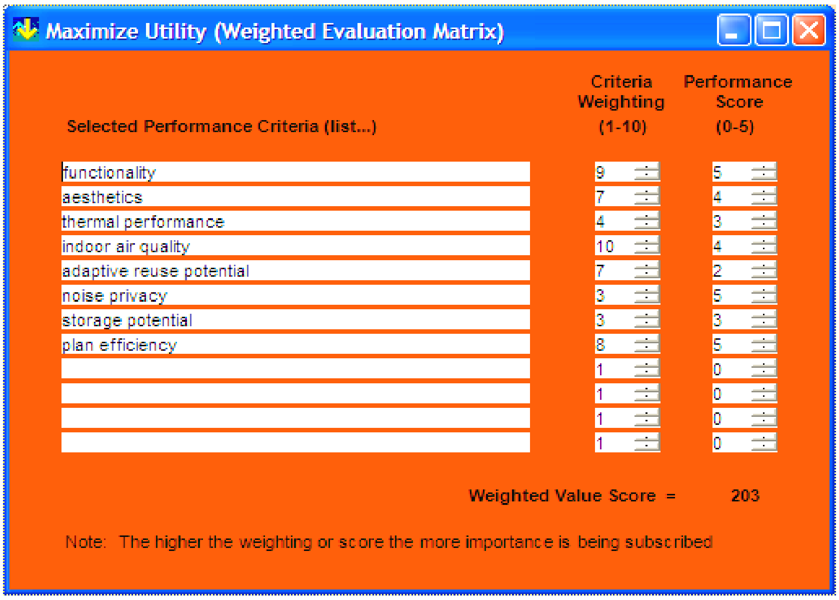
Functional performance is a social criterion and is an area that designers, developers and users want to maximise. It is calculated using a weighted scoring approach. In SINDEX, the criteria for maximum utility are inserted in the input screen and rated on a scale of one to five with one being the lowest. The criteria are also weighted in accordance with their level of importance on a development. A scale of one to 10 is used with one being the least important and the scale is used to weight each criterion.

Weight is multiplied by the score, summed across all criteria and expressed relative to maximum score using the following formula:

$$\frac{\text{Weighted score}}{\text{Maximum score}} \times 100$$

Evaluation is based on the higher the total value score the better the performance of the project. A benchmark is set at 50 as being satisfactory and less than that is considered as unacceptable (see Figure 9.3).

Figure 9.3 Input screen for maximise utility



Maximize Utility (Weighted Evaluation Matrix)

Selected Performance Criteria (list...)	Criteria Weighting (1-10)	Performance Score (0-5)
functionality	9	5
aesthetics	7	4
thermal performance	4	3
indoor air quality	10	4
adaptive reuse potential	7	2
noise privacy	3	5
storage potential	3	3
plan efficiency	8	5
	1	0
	1	0
	1	0
	1	0

Weighted Value Score = 203

Note: The higher the weighting or score the more importance is being subscribed

9.3.5 Minimise impact (Environmental impact)

The Minimise Impact screen measures the loss of habitat and is also a social criterion, estimating the likelihood of environmental damage being incurred over the economic life of the project. Loss of habitat includes non-monetary impacts such as loss of biodiversity, global warming, ozone depletion and other damage. These criteria are assessed using a questionnaire format across the five areas of manufacture, design, construction, usage and demolition. The context of site is included as optional and it is up to the assessor to decide whether to include this as part of the assessment process.

Each area is further divided into several sub-criteria and they are assessed by ticking the box to reflect possibility of their existence. The following assessment scale is used to reflect the level of impact probability of damage:

Minimal	20% probability
Moderate	40% probability
Significant	60% probability
Extensive	80% probability
Unacceptable	100% probability

The result of each relevant area is then averaged to give an overall impact assessment with a set benchmark of 50. The lower the probability of impact the better (see Figure 9.4).

Figure 9.4 Input screen for minimise impact

	YES?
Manufacture	
Does the manufacturer have an environmental management plan?	☐
Are new raw materials a renewable resource?	☐
Does the manufacturing process involve hazardous materials?	☐
During manufacture, are greenhouse gas emissions minimal?	☐
Does the manufacturing process generate untreated pollution?	☐
Are product components manufactured from recycled materials?	☐
Are the majority of raw materials imported from overseas?	☐
Is manufacturing waste sent to landfill?	☑
Are significant amounts of manufacturing waste recycled?	☐
Are most products packaged?	☐
Design	
Is environmental performance a specific design objective?	☑
Was the product evaluated using a life-cost approach?	☑
Was embodied energy considered in the decision process?	☑
Are there significant heritage implications to be considered?	☐
Construction	
Will the construction process generate untreated pollution?	☐
Will environmental impacts during construction be monitored?	☑
Will construction waste be primarily recycled?	☑
Usage	
Does the intented function use water efficiently?	☑
Will pollutants be discharged directly into the environment?	☐
Is waste recycled?	☐
Are significant energy minimization strategies in place?	☐
Is noise transmitted to surrounding spaces?	☐
Demolition	
Are most demolished materials recyclable?	☐
Does non-recyclable waste involve hazardous materials?	☐
Are all components sent to landfill biodegradable?	☐
Has a deconstruction plan been developed?	☐
Context (optional) included? ● yes ○ no	
Is the site in a remote location?	☐
Is the site environmentally-sensitive or protected?	☐
Was an environmental impact statement prepared for the project?	☐
Are there rare or endangered species near the site?	☐
Will the site's natural features be significantly disturbed?	☐
Is site stability and erosion control a particular objective?	☑
Are affected site areas reinstated upon completion of construction?	☑

Risk Assessment = moderate

9.3.6 Sustainability index as an environmental benchmarking tool

Before combining the four criteria, a weighting has to be applied to each criterion. Weighting can be introduced to reflect the level of importance of the criteria. If weighting is not used, it is assumed that all criteria are equally important. SINDEX allows for economic criteria to be weighted differently from social criteria according to project motivation. In SINDEX the weight is included by a user-defined emphasis between economic criteria (akin to measuring value for money) and social criteria (akin to measuring living standards). By using the balance control pointer at the front page the weighting between economic and social criteria can be adjusted to such as 75:25 or 25:75 so that all four criteria play a part in the final outcome. A 50:50 proportion is the default in the software to reflect equal weighting for all four criteria, but any combination can be applied.

The four criteria are combined into an indexing algorithm that ranks projects and facilities on their contribution to sustainability. In the software, the sustainability index (SI) is calculated from the following formula:

$$\begin{aligned} SI &= \text{Value for money} + \text{Standard of living} \\ &= \frac{\text{Financial return}}{\text{Energy consumption}} + \frac{\text{External benefits}}{\text{Environmental impact}} \end{aligned}$$

The sustainability index is the function of value for money and the standard of living. Value for money is based on the ratio of economic return to the energy consumption. Standard of living is assessed in accordance with the ratio of positive environmental effects to the loss of habitat, i.e. environmental impact.

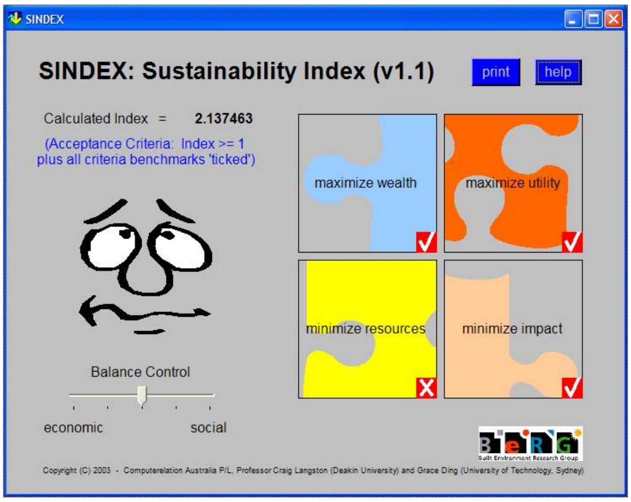
Benchmarks are preset for each criterion and a value of one is considered to be the notional performance benchmark. This benchmark allows developers to decide to either accept or reject a proposal. Projects that fall far below the pre-set benchmarks will require further investigation. The calculated index is shown on the main page of the program for a value ranged from zero to more than four with the higher the index the better the result. A caricature face is employed to give an overall summary of the outcome from ‘crying’ (an unsustainable project) to ‘excited’ (a well-balanced project). Figures 9.5 and 9.6 show the main page of SINDEX and the summary of icons to indicate the outcome.

The preset benchmarks are:

- Maximise wealth—BCR=1,
- Minimise resources—‘actual’ equals ‘target’,
- Maximise utility—50 percent of the maximum score, and
- Minimise impact—50 percent risk exposure.

Benchmarks serve to ensure that similar projects can be compared and evaluated and allow regulatory authorities to specify the minimum performance thresholds they determine are in the national interest.

Figure 9.5 Main page of SINDEX



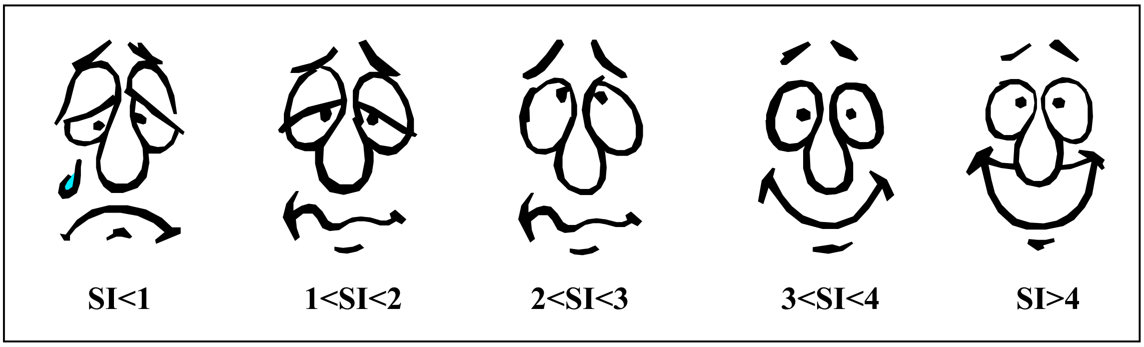
SINDEX: Sustainability Index (v1.1)

Calculated Index = 2.137463

(Acceptance Criteria: Index >= 1
plus all criteria benchmarks 'ticked')

Copyright (C) 2003 - Computerelation Australia P/L, Professor Craig Langston (Deakin University) and Grace Ding (University of Technology, Sydney)

Figure 9.6 Summary of characterised faces to show evaluation outcome



9.4 THE BENEFITS OF USING SINDEX IN CONSTRUCTION

The sustainability index is a structured approach to examine and compare environmental performance of projects with competing alternatives, helping to select the optimum design. The development of SINDEX provides a modelling tool to enable decision-makers to integrate issues of sustainable development into the project appraisal process. Assessing building environmental performances can be laborious and time consuming. The complex assessment process can also put people off from considering environmental issues. It is particularly serious in the construction industry, as the construction period is always tight. SINDEX uses computer technology to calculate a sustainability index to select projects, dramatically reducing the assessment process. Data on each criterion is inserted into the spaces on the input screens and a sustainability index is calculated with automatically generated reports. The flexibility and ease of use will greatly promote the incorporation of social and environmental issues into the decision-making process of project appraisal.

SINDEX ranks projects based on the benchmarks preset in the software. An index of one is the basis for making accept/reject decisions. Some projects may be ruled out if any of the four criteria fall below these set benchmarks. However, solutions may be investigated to remedy the situation while still keeping the index as high as possible. Therefore, SINDEX serves as a reference point against which a building's environmental performance is assessed, compared and recorded. The preset benchmarks for the four criteria in SINDEX can be viewed as the common economic and environmental goals for projects to achieve. This is particularly important as it sets a clear vision of a desirable outcome and makes environmental consideration as an integral part of the decision-making process. A clear environmental goal in project appraisal is significant in promoting sustainable construction practices.

SINDEX overcomes the weaknesses of environmental building assessment methods such as BREEAM by quantifying the four criteria in units best suited in their quantification. The actual measurement of the four criteria reveals the global carrying capacity of resources and is also capable of measuring progress toward sustainability.

The database as generated through the use of SINDEX provides a comprehensive and concise set of information that may be significant for further research in the area. More discussion can be found in Chapter Ten.

9.5 CONCLUSION

Environmental benchmarking needs to be seen in a spirit of continuous improvement. It will not be done only once, as objectives will change as well as environmental requirements and standards. However, environmental benchmarking must take place at a rapid pace and it can occur at any point along the life cycle. In order to sustain the environment, the development process must become more considerate towards sustainability ideals. If environmental quality is to be maintained, benchmarks need to be set to measure progress between the environmental target and actual performance.

The sustainability index is an important part of this research, combining economic, social and environmental criteria into a composite index system for project appraisal. The sustainability index was developed to fill the gap between existing project appraisal techniques and the increasing demand for sustainable development in the construction industry. The framework of the sustainability index can be used as a foundation for setting benchmarks in construction.

SINDEX is based on the principles and methodology of the sustainability index. It is a sustainability modelling tool developed to help promote sustainable practice in the construction industry. SINDEX, whilst is easy to use, is also useful as a means of evaluating environmental performance of projects. SINDEX, on one hand, helps to simplify the project appraisal process, and on the other serves as a benchmarking tool to set targets for measuring project performance.

CHAPTER
TEN

SUMMARY AND CONCLUSIONS

10.1 INTRODUCTION

This chapter presents a summary of the study. It embraces the findings from the literature review, the environmental awareness survey of construction industry professionals and the development of a model to calculate a sustainability index. This conclusion links and integrates the research findings. The recommendations provide suggestions for future research which have emerged as a result of the findings of this study.

This thesis critically examines the environmental problems associated with construction activities, and investigates ways of improving sustainable practices in the construction industry. It also investigates environmental building assessment methods used in construction and their deficiencies as a tool to evaluate a building's sustainable performance.

In acknowledging the importance of considering environmental effects in project appraisal, the conventional economic approach of decision-making in construction was critically examined and discussed. This was explored by identifying and measuring the principal sustainable development determinants that embrace environmental considerations within a sustainable appraisal framework for projects.

The remainder of this chapter has been divided into several sections to discuss and summarise the research findings. It includes a review of aims and objectives for this research, a summary of the research, conclusions, policy implications arising from the study, limitations and areas for further research.

10.2 REVIEW OF AIMS AND OBJECTIVES

This thesis has satisfied the aims and objectives specified in the introduction. It has identified four sustainable development determinants and developed a sustainability index for project appraisal. This index is a multi-dimensional approach to assess the complexity and importance of projects and facilities for sustainability and profitability. The sustainability index strikes a balance by considering the key variables of economic, social and environmental criteria to select the best option among alternatives. The research has satisfied the aims and objectives as outlined at the beginning.

10.2.1 Impacts of development

The first research aim was to investigate the impacts of development on the environment. The literature review in Chapters Two and Three discovered that the environment has an inherent connection with economic growth. The growth of the economy will be jeopardised if the environment continues to deteriorate and natural resources overused. The literature shows that the global environment has degraded through various human activities and the environment will become unhabitable if environmental protection and conservation are not considered in project development. The literature also reveals that construction plays a significant role in degrading the environment through on-site building activities and energy consumption during occupancy. In the literature, there is a clear call for construction to adopt more sustainable practices. The literature has also revealed that more research is needed to identify the energy intensity of materials and components. This will supply valuable information to designers and manufacturers, enabling them to reduce energy consumption as there is significant energy embodied in the life cycle of materials and components.

10.2.2 Aid to decision-making

The second research aim is to review the literature and suggest ways to improve the conventional decision-making methodology used in construction. In Chapter Two, the conventional economic approach of cost benefit analysis was examined and found wanting. Its deficiency, the methodological framework which monetarises environmental issues, was discussed at length. It was discovered that this deficiency has caused environmental degradation because the true prices have not been reflected in the decision-making process. The literature has revealed that cost benefit analysis fails as an evaluation tool if environmental values are not incorporated in the decision-making model. The literature also revealed that decisions are seldom single-dimensional, as cost benefit analysis does not capture the complex nature of the environment. Finally, emerging environmental building assessment methods were investigated and discussed in Chapter Two.

The literature has revealed that environmental building assessment methods are insufficient in incorporating environmental issues in the decision-making process, as most of them are single-dimensional. As derived from the literature, a multi-dimensional assessment model is required to effectively appraise project sustainability. The concept and methodology of multi-criteria analysis was presented and discussed in Chapter Four, forming the foundation on which the sustainability index was developed.

10.2.3 Identifying sustainable determinants for project appraisal and modelling decision-making

The third and the fourth research aims were to identify principal sustainable development determinants for modelling decision-making for built projects and facilities. With reference to the deficiency of environmental building assessment methods and the need for a multi-dimensional approach in project appraisal in the literature, a sustainability index for project appraisal was developed in Chapter Five. A list of criteria was identified from the literature and responses from a questionnaire were used to rank the principal criteria to be incorporated in the sustainability index. Based on the survey results, the list of sustainable development determinants was narrowed down and grouped into the four criteria:

- financial return,
- energy consumption,
- external benefits, and
- environment impact.

The development of a sustainability index that incorporates economic, social and environmental criteria into a composite index was presented and discussed in Chapter Five in line with the fourth aim set out in the introduction.

10.2.4 Verifying the decision-making model

The fifth aim of this research was to test the effectiveness and usefulness of the sustainability index. The purpose was to test relationships between the four criteria and a sample of 20 public school projects was used. The research methodology and data collection were presented in Chapter Six. Data for the four criteria were collected and measured using units best suited to their quantification. Chapters Seven and Eight analysed the data using linear and multiple regression methods. The results indicated a strong relationship between the criteria and that the variation of one criterion can be explained by the variation of another. These relationships had not been previously established. The analysis has proved that trade-off principles may have to be applied when using a sustainability index. A weighting system applied to the four criteria solves this problem.

The sustainability index was further verified by applying it to another project with three design options. The results indicate that the sustainability index is able to rank the options and obtain a best solution for the development. In Chapter Nine, the sustainability index was further extended to develop benchmarks to be used in the construction industry. The sustainability index was developed into computer software called SINDEX to aid the ranking process. The development of SINDEX highlights the practical aspect of the sustainability index to be used in ranking projects as well as setting benchmarks for the construction industry.

10.2.5 Concluding remarks

This thesis, therefore, has:

- successfully explored the relationship between project development and environmental degradation,
- developed a sustainability index that is a function of financial return, energy consumption, external benefits and environmental impact, and
- developed a methodology to evaluate and incorporate environmental effects in a sustainability index for project appraisal.

Environmental issues are of growing concern and should be incorporated into the decision-making process of selecting the best option among alternatives. This study provides a platform for this procedure to be carried out in the most effective way. In the sustainability index, the approach has been used to develop a computer model, SINDEX, which is powerful yet so simple that it can be used by every member of the design team, the developer and the contractors when considering a multi-dimensional approach to project appraisal. In addition, the development of SINDEX has dramatically simplified the evaluation procedure in project appraisal, which will ultimately improve the quality of decision-making and promote sustainability goals in the construction industry.

10.3 SUMMARY OF RESEARCH

The purpose of this research was to identify those factors that are critical for developing an assessment model for appraising a project's sustainability. This model incorporated environmental values into the decision-making process in order to promote sustainable practices in construction. The conventional approach, which considered only economic returns as based on market transactions, was shown to no longer be feasible. The deterioration of environmental goods and services due to construction activities has become an important consideration in every development. Environmental goods and services are externalities and intangibles that cannot be sufficiently handled by the current economic approach, but need to be included for a total assessment.

Even though a development generates nett profit in the long run, it may be undesirable if it causes environmental deterioration. Therefore, the ultimate target, of this research, was to develop a sustainability index to assess the environmental performance of buildings. The sustainability index is a composite index that measures economic return as well as a development's environmental impact. The study involved identifying the principal sustainable development determinants investigating methods of quantification and, finally, developing a sustainability index to combine the determinants into a single decision-making tool.

The sustainability index is a decision-making tool that uses a composite index to rank the development options of a project. The process enables the principle of trade-off to take place in the decision-making process and to enable environmental values to be part of the consideration in selecting a development option. This makes it possible to optimise financial return, maximise resource consumption and minimise detrimental effects to the natural and man-made world.

The research was divided into three parts: a literature review, an environmental awareness survey of the construction industry in NSW, and an examination of the relationships between criteria using a sample of 20 NSW public high school projects. The literature discussed the impacts of construction activities on the environment. It also investigated the use of environmental building assessment methods in appraising the sustainability of projects and facilities. The study also critically examined the use of a multi-dimensional evaluation approach, as opposed to the conventional single dimensional methods, in assessing the sustainable performance of buildings.

From the discussions in the literature review, the sustainable development determinants were identified and an industry survey was formulated and carried out to examine the environmental awareness among construction industry professionals. Simultaneously, these professionals ranked the identified sustainable development determinants in order to determine the principal variables to be included in the sustainability index.

The literature review and the industry survey provided the foundation for the case studies that formed the major part of this research. The survey indicated that financial return, energy consumption, external benefits and environmental impact were the principal determinants for appraising project sustainability. The ultimate goal of this research was to develop a model to calculate a sustainability index to assess environmental performance of built projects and facilities. The sustainability index formed the base for the case studies. The case study examined 20 public high school projects of various sizes, locations and ages. The aim was to quantify the four criteria of the sustainability index and to examine their relationships in the model. The probabilistic results of statistical analysis of data indicated that the four criteria were highly correlated with each other, and the sample variation in one criterion could be explained by the variation in the other. The results also indicated that the correlated relationships allowed a trade-off principle to be applied in the sustainability index. The hypotheses as specified in Chapter Six were tested and discussed.

The sustainability index was finally validated by a study of another project. It was demonstrated by assessing a low-rise industrial building with three design options. The four criteria included in the sustainability index were assessed and quantified. Members of the development design team and representatives from the developer carried out the environmental appraisal. The data on the four criteria were used to calculate the sustainability index of each option and the decision was made in accordance with the ranking. The result indicated that the sustainability index was able to rank development options. The sustainability index being developed in this research is a multi-criteria approach for project appraisal, which extended the conventional economic methodology to encompass energy usage and environmental values into the appraisal framework.

The sustainability index has also been developed into a benchmarking tool in this research using a computer application. The development of computer software, entitled SINDEX, has already been used in the construction industry throughout Australia as a tool for ranking projects with alternatives. The development of SINDEX highlighted the practical aspect of the sustainability index in assessing buildings' sustainability performance and to promote sustainable practices in the construction industry.

10.4 CONCLUSIONS

The primary aim of this research, to develop a sustainability index for project appraisal, has been achieved. The mathematical model of a sustainability index was presented, discussed and tested in the thesis using a sample of 20 high school projects. The sustainability index was also further verified by applying it to an industrial building project with three alternative design options. The result indicated that the sustainability index ranked the options, aiding the decision-making process.

The sustainability index is a composite index that combines economic, social and environmental criteria into an indexing algorithm to rank projects and facilities on their contribution to sustainability. There is a worldwide trend in environmental assessment away from purely the qualitative descriptions of environmental practices towards a more comprehensive, quantitative interpretation of environmental performance by using input-output material flow analysis and environmental indicators. The sustainability index, as a tool for environmental performance evaluation, has used the material flow model as a basis for developing an indicator that provides an operational framework and guidance for making decisions. The demand for a standardisation of a framework of accounts for economic development and environmental concerns is growing and the sustainability index was developed to satisfy this demand.

The sustainability index reflects the possibility of using a composite index to incorporate environmental issues that cannot really be measured by other evaluation methods. Other evaluation methods such as BREEAM and CPA (see Chapter Four) assess environmental issues on a 'feature-specific' basis where points are awarded for the presence or absence of desirable features. However, environmental issues were successfully measured and incorporated using the methodology established in this research into the sustainability index. Another achievement of the research was using a multi-dimensional approach for decision-making. The sustainability index is a multi-dimensional assessment method that assesses projects for economic values as well as environmental, and the trade-off principle in the approach concerns equity for generations today and in the future. The sustainability index also provides an opportunity for public participation in the decision-making process. This is another area in which most evaluation methods are deficient.

The development of a sustainability index can be used as the basis for benchmarking buildings allowing decisions to be made to improve the quality of the built environment. The benchmarks of the four criteria developed in this research can be set as a common target for comparison. The demonstration of benchmarking projects using a sustainability index was presented in the development of SINDEX. Benchmarks for the four criteria were established in SINDEX and projects can be ranked accordingly. The development of the sustainability index helps to make better decisions as environmental issues are successfully measured and incorporated into the decision-making methodology. There is, therefore, no doubt that a better decision can be arrived at that will improve the overall quality of the built environment.

10.5 POLICY IMPLICATIONS

Sustainable development is of growing importance to the world because the current exploitation and uncaring use of resources, together with the pollution generated, cannot continue at present rates. The development of the sustainability index demonstrates a significant contribution to enhance sustainable development and exhibits a way to bridge the gap between the current methodology of project appraisal and sustainable requirements in construction. The sustainability index will have an important part to play in the future to ensure that sustainability is achieved in construction.

If sustainable construction is to be achieved, it has to adopt more long-term sustainable strategies at the feasibility stage of a development to promote environmental protection and conservation. These strategies must focus on continual improvement through the consideration of social and environmental matters in the decision process. Therefore, the construction has to place a higher priority on environmental considerations in projects and ensure that the concept of sustainability is valued and rewarded as well as practised at all levels throughout the project's entire life span.

At the same time, profit cannot be the key consideration in project appraisal as in the conventional appraisal approach, but also has to consider the impacts a development may have on the environment. If the construction industry wants to facilitate a change in the customary and traditional way of thinking and doing things, focusing on financial return, it may have to allow for the consideration of environmental sustainability in the decision-making process.

As discussed, the benefits of using benchmark systems in other industries are so evident that potential benefits may also be gained in construction. It is, therefore, also important for the construction industry to establish a benchmarking system to assess buildings' sustainability performance. The development of benchmarks in construction relies heavily on the participation and co-operation of the practitioners in the construction industry. Hence, the construction industry can become more aware of the benefits of research and development and establish a more co-operative approach to encourage and promote more sustainable practices in a development's design process and site operation.

As indicated in the research, construction is a major consumer of energy. If the construction industry wants to minimise energy usage, it has to adopt continual research into the energy consumption of different types of constructions for both embodied and operational energy. This knowledge will provide important information to the manufacture and selection of building materials and components to minimise energy intensity.

The assessment of environmental performance of a project is largely voluntary. In order to have better protection and conservation of the environment it is important for the regulatory authorities to assist by increasing the statutory requirements for sustainable performance in the design and construction of a project.

Furthermore, to effect efficient sustainability assessment, it is important to develop a computer application of the sustainability index, providing an alternative way to improve environmental performance by making it publicly available and to simplify the evaluation process. SINDEX is a successful version of the computer application of the sustainability index. The development of SINDEX was based on the research grant received from the Australian Institute of Quantity Surveyors and more research grants may be made available to carry out further research and development in the sustainable practice of construction.

This thesis demonstrates that incorporating environmental issues is important in achieving sustainable performance of projects and facilities in construction. These should be considered in the future decision-making processes by ensuring that the four criteria are appraised in every development at the feasibility stage. In a deteriorating environment, this proactive strategy is essential for ensuring a superior environment for generations to come.

10.6 LIMITATIONS OF THIS RESEARCH

The research carried out in this thesis is significant and the findings from the study are useful for the construction industry, helping them to incorporate environmental issues into project appraisal. However, there are limitations associated with this study. These principally relate to identifying key sustainable development determinants using a questionnaire of construction industry professionals in NSW. Therefore, the research results may only be valid for the characteristics and culture of the construction industry in NSW.

The case study was undertaken on 20 public high school projects. Even though the methodology will remain appropriate for any type of project, the results may be confined to this type of construction. It is, therefore, important that the results be tested on other types of construction with a different sample size. In addition, economic and environmental variables as identified in this research may be confined to the time of the research, as people's perception of environmental awareness and conditions may change.

Finally, it is appreciated that there are deficiencies with a survey procedure. In this instance, the survey of the study was based on data collected from a sample obtained from a composite sampling method and, prior to the survey, a pilot study was undertaken. The participants for the survey were derived from random sampling of members from the respective professional institutes to form a composite sample. This sampling method does not include practitioners who are not members of the professional institutes. The sample size may need to be extended to include more practitioners in the construction industry in order to minimise sampling error.

However, it is also acknowledged that there were time, administrative and financial constraints. However, the importance of the study remains, for the limitations do not detract from them, but merely provide scope for further research.

10.7 RECOMMENDATIONS FOR FURTHER RESEARCH

As indicated above, this investigation has identified four principal sustainable development determinants that can promote sustainable performance of projects. During the study, some observations indicated the need for further study outside the scope and the aims of this research. However, the scope of this research has meant that the in-depth investigation that many of the research issues warranted was not possible. Accordingly, it is recommended that further research is necessary to extend and to modify the findings in this research.

Building professionals' perception in relation to the importance of the environment in a development was an area of concern. From the literature, the perception that building professionals have on the environment is that the consideration of environmental issues means higher building costs, and higher cost means lower returns making it undesirable given the main concern is to make money. Even though most of the building professionals recognised the importance of environmental issues in the industry survey (see Chapter Five), they retain this perception that looking after the environment will inevitably cost more. When it comes to practically incorporating environmental consideration in project selection, environmental issues rank as the least important. Maximum financial return remains a deep-rooted requirement of a development in construction. Therefore, research needs to be undertaken to investigate this perception and to recommend a range of actions to foster a serious attitude change among building professionals.

The trade-off principle as applied in the sustainability index needs further investigation. The principle of trade-off is important especially when resources are scarce and a best solution is required to maximise the limited supply of resources. The principle of trade-off for the four criteria in the sustainability index varies in accordance to project objectives, attitudes and goals. The trade-off principle, as reflected by the weighting system derived from the investigation, may only apply to the sample of case studies in this research. However, for private developments, project objectives, attitudes and goals may be totally different from public projects. Research, therefore, needs to be undertaken to investigate further the trade-off principle in project appraisal for both public and private projects, and to recommend ways of identifying trade-off to suit different project objectives.

This thesis has focused on developing a sustainability index to facilitate appraisal of a project's sustainability. One of the difficulties of applying the sustainability index to assess environmental building performance is the unique nature of projects in construction. The relative importance of the four criteria may vary according to the types of construction. Further research can be developed to explore the changes of the four criteria in the context of their impact on different types of development. It is, therefore, significant for the sustainability index to be tested on different types of construction in order to establish the relative importance for each criterion in calculating the sustainability index. The development of the sustainability index is important in every type of development and to promote sustainable practices among building professionals.

Twenty high school projects were used as a sample for the research and that was the sample available at the time of the research. It is, therefore, valuable for the sustainability index to be tested on a larger sample size and to further investigate the results obtained in this research. Private practices, large construction companies, architectural firms or development companies may be sources for providing projects for further research.

Furthermore, the sustainability index can also be tested in different geographic areas and with different design characteristics. The study carried out in this research was based on high school projects in New South Wales. Geographical and regional variations may emerge in the use of the sustainability index. Therefore, further research can be carried out using projects from different states across Australia. The results may reveal some interesting outcomes and can be compared with each other to further enhance the development of the sustainability index.

This area of research can, of course, be expanded to investigate other countries besides Australia, with the opportunity to draw some interesting international comparisons. The development of the sustainability index has international applications and international co-operation in testing the model using projects from different countries will enable more interesting comparisons to be made and to consolidate the robustness of the methodology. This area of research can further be acknowledged if the concept and principle of sustainability index is taken to the international arena.

Based on the literature review, sustainable development determinants were identified for project appraisal. This research ranked and summarised sustainable development determinants into four criteria using a questionnaire of construction industry professionals in New South Wales. The opinions and rankings received from the survey may be confined to these particular practitioners and the opinions in ranking these determinants from other states of Australia deserve further investigation. Other survey methods such as personal interview and telephone surveys may also be used to increase the coverage and to strengthen the survey results.

The sustainability index is a composite index that consists of four criteria. As indicated in the research (see Chapter Eight), the four criteria were highly correlated. Further research can be carried out to explore the possibility of reducing the number of variables so that the evaluation process can be simplified. The sustainability index can be further studied using a bigger sample and other statistical processes such as curvilinear models, two-way analysis of variance, and logistic regression.

Besides reducing the number of variables in the sustainability index, further research can be undertaken to explore different combinations of variables that may be applied to deal with different development objectives. Project appraisal often starts with a definition of a problem and the formulation of project objectives. Therefore, different combination may be required to deal with different requirements at different time. To capture the impact of a project on the environment there is an initial requirement to examine the data of sustainable development determinants for different types of construction. Such an examination, while acknowledging the constraints of being unable to consider all the factors, is nevertheless the best measure of building performance characteristics and may be able to provide a platform for project evaluation.

This research was based on government projects. Further research can be carried out by applying the sustainability index to private development as well as large-scale infrastructure projects such as roads, dams and bridges. The nature, construction methods, specifications and impacts on the environment will be different from government projects and further research on studying the sustainability index may provide new insights. This is particularly important for infrastructure projects which are usually large scale and more likely to cause environmental degradation.

SINDEX, as developed in the research, was based on the concept and principles of the sustainability index to be a benchmarking tool to rank projects. Benchmarks, as discussed in Chapter Nine, have been used by other industries and have gained significant attention in the construction industry. The benefits of setting benchmarks for assessment, and searching for best practice in construction, are so obvious that research needs to be undertaken. This is particularly important for environmental issues, as progress or rate of deterioration need to be measured and monitored. Benchmarks may form the standard and against which project performance can be compared and evaluated.

The benefits of environmental benchmarking in construction for promoting best practice deserve further investigation. The four criteria in the sustainability index can form the platform and allow benchmarks to be set to assess environmental building performance. Data for the four criteria can be collected and measured in accordance with the methodology established in this research. Results from the analysis can be used to benchmark project performance in terms of weak, medium and strong sustainability. Eventually, indicative sustainability index ranges can be determined for different project classes.

Another central and important issue for further study is to examine the energy use from a financial viewpoint. This study has discovered that energy consumption is positively correlated with building cost. An increase in building cost also increases the energy usage. Further research is required to investigate this relationship in greater details and to explore the reasons for such a phenomenon. Besides, the embodied energy intensity of materials and components are insufficient to provide a more comprehensive evaluation of energy usage during construction and subsequent usage. This is particularly important if energy analysis of a project is carried out on a life cycle approach. The energy incurred during site operation and demolition is largely unknown at the time of this research. Therefore, the research of energy analysis of buildings is still in its infancy and further research needs to be undertaken in order to provide a more accurate analysis with cost implications of demolishing a building.

The research in the development of a sustainability index was the prime objective and the model has been successfully applied in ranking building projects to provide the best solution for a development. The research, whilst completed at this stage, has opened up opportunities for further research in many other areas including an international application. The findings in this research can be further extended and modified to accomplish the ultimate goal of promoting and improving sustainable practices in construction.

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Faculty of Design, Architecture and Building

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PROJECT APPRAISAL
AND
ENVIRONMENTAL AWARENESS
SURVEY

To be completed by respondent (optional)

Organisation: ____

Name: ____

Position in the Organisation: __________________________________

Contact Phone: ______________________ Fax: ___________________________

Email: ____

Date: ____

<u>To Complete</u>:

✓	Place a tick in the space adjacent to your response to multiple choice questions and Yes/No questions.
①	Where asked to rank write a number in the space provided to each item.
✍	Where asked to specify or give details, write a short response in the space provided.

PART I - GENERAL DETAILS

1.1 About Yourself

a. Please indicate the position you hold in the industry

☐ Architect
☐ Private Developer
☐ Project Manager
☐ Real Estate Agent
☐ Quantity Surveyor
☐ Lawyer
☐ Engineer
☐ Property Consultant
☐ Building Owner
☐ Contractor/Builder
☐ Government Agency Employee
☐ Others (please specify) ____

b. Gender ☐ M ☐ F

c. Age Range

☐ ≤ 25
☐ 26 - 35
☐ 36 - 45
☐ 46 - 55
☐ 56 - 65
☐ Over 65

d. Please indicate your highest educational qualification

☐ Postgraduate degree
☐ Postgraduate diploma
☐ Undergraduate degree
☐ Diploma or Certificate
☐ Secondary School Matriculation
☐ Other (please specify) ____

1.2 About Your Organisation

a. What type of organisation do you work for?

☐ Architectural
☐ Engineering
☐ Quantity Surveying
☐ Project Management
☐ Government Agency
☐ Environmental Assessment
☐ Development/Investment
☐ Education
☐ Real Estate
☐ Supplier
☐ Sub-Contracting
☐ Head Contracting
☐ Legal Practice
☐ Others (please specify) ______________________________

b. The organisation that you are working is an

☐ Independent practice

☐ Affiliated with other offices in Australia (Location of head office ______________________________)

☐ Affiliated with other offices overseas (Location of head office ______________________________)

☐ Government Department (Which department ______________________________)

☐ Educational institution

☐ Tertiary ☐ Secondary ☐ Primary

c. How long have you been working for this organisation? __________ Years

d. Number of people in the organisation

Management __________ No Technical & Support Staff __________ No

Professional Staff __________ No Others (please specify) ______________________________ No.

e. Organisation annual turnover

☐ Below $250,000 ☐ $250,001 - 500,000 ☐ $500,001 - 1,000,000

☐ $1,000,001 - 2,500,000 ☐ $2,500,001 - 5,000,000 ☐ Over $5,000,000

f. Age of Business

☐ Below 5 years ☐ 11 - 20 years ☐ 31 - 40 years

☐ 6 - 10 years ☐ 21 - 30 years ☐ Over 40 years

PART II - ENVIRONMENTAL AWARENESS

2.1 Do you consider environmental assessment an important issue for building development?

☐ Yes ☐ No Why ____

2.2 Do you agree that the impacts of environmental effects need to be incorporated in project development decisions?

☐ Yes ☐ No Why ____

2.3 Within the context of environmental impact please rate the following items according to their importance for the construction industry (Importance: Least = 1 & Most = 5):

		Importance				
		Least=1	**2**	**3**	**4**	**Most=55**
a	Biodiversity	☐	☐	☐	☐	☐
b	Noise pollution	☐	☐	☐	☐	☐
c	Air pollution	☐	☐	☐	☐	☐
d	Water pollution	☐	☐	☐	☐	☐
e	Ozone depletion	☐	☐	☐	☐	☐
f	Acid rain	☐	☐	☐	☐	☐
g	Depletion of renewable resources	☐	☐	☐	☐	☐
h	Depletion of non-renewable resources	☐	☐	☐	☐	☐
i	Desertification	☐	☐	☐	☐	☐
j	Destruction of historical buildings	☐	☐	☐	☐	☐
k	Global warming	☐	☐	☐	☐	☐
l	Salination	☐	☐	☐	☐	☐
m	Population growth	☐	☐	☐	☐	☐
n	Deforestation	☐	☐	☐	☐	☐

o	Other ______________________________	☐	☐	☐	☐	☐

2.4 How would you rate the importance of each of the following items to project design? (please ✓)

		Importance				
		Least=1	**2**	**3**	**4**	**Most=5**
a	Low embodied energy materials	☐	☐	☐	☐	☐
b	Minimise heat gain or loss	☐	☐	☐	☐	☐
c	Use recycled building materials	☐	☐	☐	☐	☐
d	Standardise building components	☐	☐	☐	☐	☐
e	Use natural lighting & ventilation	☐	☐	☐	☐	☐
f	Minimise waste/pollution	☐	☐	☐	☐	☐
g	Use control systems (eg BMS, etc.)	☐	☐	☐	☐	☐
h	Avoid environmentally-harmful materials	☐	☐	☐	☐	☐
I	Other ______________________________	☐	☐	☐	☐	☐

2.5 How would you rate the importance of the following variables during project selection? (please ✓)

		Importance				
		Least=1	**2**	**3**	**4**	**Most=5**
a	Aesthetics/visual impact (project image)	☐	☐	☐	☐	☐
b	Energy consumption/conservation (capital & operational energy)	☐	☐	☐	☐	☐
c	Environmental impact (negative externalities, eg pollution)	☐	☐	☐	☐	☐
d	Functional layout (planning efficiency & flexibility)	☐	☐	☐	☐	☐
e	Heritage preservation (preservation of existing requirements)	☐	☐	☐	☐	☐
f	Maintenance/durability (low ongoing maintenance requirements)	☐	☐	☐	☐	☐
g	Overall financial return (return on investments)	☐	☐	☐	☐	☐
h	Project life span (projects that are long lasting)	☐	☐	☐	☐	☐
i	Recycling/refurbishment potential (reuse of building materials)	☐	☐	☐	☐	☐

j	Social benefits (positive externalities eg marketing, tourism)	☐	☐	☐	☐	☐
k	User productivity gains (efficiency of project users)	☐	☐	☐	☐	☐

2.6 In the following evaluation matrix eleven attributes are identified as being important in the selection of a project for development. Please follow the steps below and choose between two attributes to demonstrate that one is more important than the other in the selection process:

Step 1: Compare attribute a with b, and place the letter indicating the more important attribute in the corresponding cell.
Step 2: Repeat for each combination of attributes similar to the example. Equal rankings can be shown as a/b, etc.
Step 3: Check all cells in the table have been completed.

a	Aesthetics/visual impact (project image)
b	Energy consumption/conservation (embodied & operational energy)
c	Environmental impact (negative externalities e.g. pollution)
d	Functional layout (planning efficiency & flexibility)
e	Heritage preservation (preservation of existing buildings)
f	Maintenance/durability (low ongoing maintenance requirements)
g	Overall financial return (return on investment)
h	Project life span (projects that are long lasting)
i	Recycling/refurbishment potential (reuse of building materials)
j	Social benefits (positive externalities e.g. marketing, tourism)
k	User productivity gains (efficiency of project users)

2.7 Please list any additional aspects of project selection that you consider important.

____

____

____

____

2.8 Please rank the following list to indicate the most suitable stage of project development to incorporate environmental issues (1 = Least Important, 4 = Most Important):

☐ Feasibility Study Stage ☐ Design Development Stage

☐ Construction Stage ☐ Post Occupancy Stage

2.9 As a practising professional in the construction industry how often do you use the following techniques in project appraisal/selection? (please ✓)

		Never	**Rarely**	**Often**	**Frequently**	**Very Frequently**
a	Simple Payback or Accounting Rate of Return	☐	☐	☐	☐	☐
b	Discounted Cash Flow Method (including Cost-Benefit Analysis, etc.)	☐	☐	☐	☐	☐
c	Feasibility Studies (non-discounted)	☐	☐	☐	☐	☐
d	Multiple Criteria Analysis (MCA)	☐	☐	☐	☐	☐
e	Risk Analysis	☐	☐	☐	☐	☐
f	Energy Analysis	☐	☐	☐	☐	☐
g	Environmental Impact Assessment (EIA)	☐	☐	☐	☐	☐

h	Other (please specify)__________________	☐	☐	☐	☐	☐

2.10 Are you familiar with the following building performance assessment techniques? (please ✓)

☐ BREEAM

☐ BES

☐ BQA

☐ EVE

☐ EPM

☐ VIKKI

☐ LCA

PART III - ENVIRONMENTALLY-CONNECTED PROJECTS

3.1 Have you ever been involved in the design or assessment of any projects with significant environmental impact?

☐ Yes (Please goto Q3.2) ☐ No (Please turn to P 11)

3.2 If you answered YES to the previous question please provide details of these:

Number of environmentally-connected projects you have worked on over the last 5 years

Completed projects ________ No On-going projects ________ No

3.3 Please indicate the approximate percentage allocation of the type of environmentally-connected projects with which you have been involved over the last 5 years (based on total numbers):

☐ Residential ____________ %

☐ Office ____________ %

☐ Industrial ____________ %

☐ Educational ____________ %

☐ Hospital, Health ____________ %

☐ Recreational ____________ %

☐ Retail ____________ %

☐ Hotel ____________ %

☐ Religious ____________ %

☐ Infrastructure ____________ % ☐ Other (please specify) ____ %

3.4 Based on the information that you have provided in Question 3.2 and 3.3, please select <u>TWO</u> most important projects from the list and provide details by completing the following tables. This information will be kept anonymous and will only be used for this research.

<u>Project No 1</u>

Type of Project eg office, residential	
Location of Project eg Sydney, Singapore	
Project completion eg 1996	
Total construction cost (including professional fees) in Aus$ (tick one):	☐ < 1 million ☐ 1-5 million ☐ 6-10 million ☐ 11-20 million ☐ > 20 million
Design & Construction period (tick one):	☐ < 1 year ☐ 1-2 years ☐ 3-5 years ☐ > 5 years
Your role in this project eg Architect, Engineer	
Client (tick one) : ☐ Public ☐ Private	

Details of your contribution to the environmental aspects of the project (please list and give an indicative value of each of these aspects):	
Who initiated the consideration of these environmental issues? eg Client	

Any distinctive design, procurement or other special features (please list):	Any unusual external factors, limitations or other constraints (please list):

Project No 2

Type of Project eg office, residential	
Location of Project eg Sydney, Singapore	
Project completion eg 1996	
Total construction cost (including professional fees) in Aus$ (tick one):	☐ < 1 million ☐ 1-5 million ☐ 6-10 million ☐ 11-20 million ☐ > 20 million
Design & Construction period (tick one):	☐ < 1 year ☐ 1-2 years ☐ 3-5 years ☐ > 5
Your role in this project eg Architect, Engineer	
Client (tick one) : ☐ Public ☐ Private	

Details of your contribution to the environmental aspects of the project (please list and give an indicative value of each of these aspects):	
Who initiated the consideration of these environmental issues? eg Client	

Any distinctive design, procurement or other special features (please list):	Any unusual external factors, limitations or other constraints (please list):

3.5 How many years have you been working with environmentally-connected projects? (please ✓)

☐ Less than 1 year ☐ 1 - 2 years ☐ 3 - 5 years
☐ 6 - 10 years ☐ 11 - 20 years ☐ Over 20 years

3.6 Have you undertaken any specialised training in order to perform the work required in these projects?

☐ Yes (please specify type of training ____) ☐ No

3.7 Is your organisation specialised in work related to environmental issues?

☐ Yes ☐ No

3.8 If you answered YES to Question 3.7 please give details of area of specialisation

____

____

____

____

****

Thank you for your kind assistance. Copy of the compiled results of the survey will be made available. If you want to receive a copy of the survey result, please tick this box ☐ and if you would like to participate further in an in-depth interview, please tick this box ☐
(please make sure that you have your name and telephone written on the front page).

Please be advised that this survey is being conducted privately and it is agreed that individual survey documents will not be forwarded for any other purposes other than for this research and the information in them will not be available to other people apart from presentation in a summary form.

Thank you once again for your participation in this survey.
Please return as soon as possible, by 30 November 1999, in the envelope provided to:

Grace K C Ding
Faculty of Design, Architecture & Building
University of Technology, Sydney

OR

Fax to 9514 8051 (Att. Grace Ding).

P O Box 123, Broadway, NSW 2007	

Survey summary

Part II - Environmental Awareness

Profession	Arch	Cont	Eng	Env	Plan	PM	Bldg Dev	QS	Other	Total
Response	20	18	33	16	10	18	7	27	3	152

2.1 Do you consider environmental assessment an important issue for building development?

Yes	19	18	32	16	10	16	7	25	3	146
No						2		1		3
Total										149

2.2 Do you agree that the impacts of environmental effects need to be incorporated in project development decisions?

Yes	19	18	33	16	10	17	7	25	3	148
No						1		1		2
Total										150

2.3 Rate the importance of environmental impacts for the construction industry

Biodiversity	75	60	104	71	38	59	19	90	9	525
Noise pollution	83	79	138	67	43	69	28	107	14	628
Air pollution	91	81	142	69	41	76	30	116	13	659
Water pollution	95	83	145	75	42	79	33	118	14	684
Ozone depletion	87	71	122	58	34	70	29	104	13	588
Acid rain	87	64	116	54	32	67	28	99	9	556
Renewable resources	70	64	108	59	35	63	25	97	12	533
Non-renewable res	88	74	123	67	36	70	32	109	14	613
Desertification	77	45	109	50	32	54	22	94	9	492
Historical bldg	78	69	132	64	36	66	28	96	14	583
Global warming	84	69	120	62	36	67	26	102	12	578
Salination	82	56	121	59	35	66	27	100	11	557
Population growth	81	62	108	57	40	69	27	99	14	557
Deforestation	87	67	125	63	36	67	27	110	12	594
Others	14	9	14	10		4	9		4	64

2.4 How would you rate the importance of each of the following items to project design?

Low embodied energy mt'ls	72	61	111	61	39	56	25	92	13	530
Minimise heat gain/loss	91	70	128	67	41	67	30	109	14	617
Use recycled bldg mt'ls	71	66	112	62	36	64	23	97	12	543
Stand bldg components	66	65	112	53	31	66	23	94	10	520
Use natural lighting & vent	89	77	131	66	39	72	28	109	13	624
Minimise waste/pollution	87	84	137	71	41	75	32	117	14	658
Use control systems	76	66	115	52	36	67	28	104	11	555
Avoid env-lly harmful mt'ls	84	77	141	73	42	77	32	116	13	655
Others	4	4	14	5		7				34

2.5 How would you rate the importance of the following variables during project selection?

Aesthetics/visual impact	85	73	130	62	42	71	31	106	15	615
Energy consump/conserv	80	76	133	68	39	71	29	110	13	619
Environmental impact	79	79	133	75	44	74	31	113	14	642
Functional layout	90	77	132	66	41	74	30	105	14	629
Heritage preservation	80	70	125	64	40	66	29	95	13	582
Maintenance/durability	79	77	130	66	39	75	28	109	13	616
O/a financial return	81	80	138	61	39	74	33	109	12	627
Project life span	76	68	128	62	39	70	26	98	11	578
Recycling/ref potential	67	71	113	61	37	66	24	98	13	550
Social benefits	76	66	105	62	41	70	26	85	12	543
User productivity gains	79	72	106	59	35	71	26	98	12	558

2.6 Evaluation matrix

Aesthetics/visual impact	67.5	49	28.5	35	34	13	29.5	84	11	351.5
Energy consump/conserv	50.5	80	90	51.5	37.5	29.5	25	113.5	14	491.5
Environmental impact	62.5	151.5	322	204	68.5	125.5	24.5	181.5	33	1173.0
Functional layout	112	50	172	56	43.5	47.5	25	168	10	684.0
Heritage preservation	141	34	114	74.5	44.5	46.5	23	49	5	531.5
Maintenance/durability	25	60	93.5	63	24	67.5	19.5	56.5	5	414.0
O/a financial return	178.5	156.5	511.5	73.5	47	214	82	356	55	1674.0
Project life span	56	55	49	34	28	42.5	11.5	91	3	370.0
Recycling/ref potential	28.5	34	58	59.5	19	23	6.5	58	18	304.5
Social benefits	80	24	101	76	43	43.5	16.0	57	11	451.5
User productivity gains	33.5	18	50.5	25	15	38	12.5	96.5	0	289.0

2.7 Please list any additional aspects of project selection that you consider important.

No additional information from participants.

2.8 Rank the most suitable stage to incorporate environmental issues

Feasibility study stage	21	25	44	18	10	22	7	39	3	189
Design development stage	32	31	60	30	13	27	10	39	6	248
Construction stage	49	55	89	46	21	40	16	70	9	395
Post occupancy stage	64	69	127	61	28	55	19	95	12	530

2.9 How often do you use the following techniques in project appraisal/selection?

Simple pay back	32	40	68	35	11	34	18	50	3	291
DCF	38	34	67	40	13	46	20	52	3	313
Feasibility studies	44	40	76	43	15	47	19	65	3	352
MCA	33	25	52	30	13	31	10	36	3	233
Risk analysis	36	45	80	43	13	52	20	54	6	349
Energy analysis	48	29	63	29	14	34	14	36	6	273
EIA	58	36	81	56	24	50	17	36	7	365
others	7	4	7	0	6	7	0	2	0	33

2.10 Are you familiar with the following building performance assessment techniques?

BREEAM				1		1	1	1		4
BES			1	1		1		1		4
BQA	1	3				1	1	4		10
EVE	1		1	1						3
EPM		2	2	2		1		2	1	10
VIKKI										0
LCA		1	2	4	1	1	1	2		12

Survey on the Total Energy Consumption of Public High Schools in NSW

This is a research project undertaken by the University of Technology, Sydney and this research aims to examine total energy consumption of public high schools. Total energy consumption includes embodied energy of building materials and components and operational energy consumed during the effective life of a building.

We aimed to study about thirty public high schools in New South Wales and your school has been selected as case studies for this research project. Embodied energy of building materials and components has been assessed for your school. In order to finalise the total energy consumption assessment we need co-operation from your school. We need to know the total energy consumed by your school last year. Your help will be greatly appreciated if you can complete the following survey and fax back to us at your earliest convenience.

All response will be kept anonymous and all the information provided in this survey will only be used for research purposes.

Please **FAX** your reply to:

Grace K C Ding
University of Technology, Sydney
Fax No.: 9514 8051

Survey completed by:

Name: ______________ Telephone: ______________
Position: ______________ Fax: ______________
School: ______________ Email: ______________
______________ ______________

1. Total number of students in the school for year 2001: ____________________ No

2. No of staff for year 2001 (please fill in the space):

   Full Time: ______________________ No.
   Part Time: ______________________ No.
   Causal: ______________________ No.

3. Please obtain information from your energy bills and complete the following table for operational energy consumption of your school last year (2001). If you can provide information for the whole year it will allow us to have a more accurate calculation. However, if it is too difficult or too time-consuming to retrieve your electricity, gas and water bills please complete the table as much as you can. Thanks in advance for your help.

Type	**Total Consumption (per annum)**			
	Jan - March	**April - June**	**July - Sept**	**Oct - Dec**
Electricity	kWh	kWh	kWh	kWh
Gas	MJ	MJ	MJ	MJ
Water	Kilolitre	Kilolitre	Kilolitre	Kilolitre

If you would like to have a report of this research please tick the box. ☐

Thank you once again for your co-operation in this survey.

The appraisal of social and environmental matters for public high schools in New South Wales

The Project Management and Economics Program at the University of Technology, Sydney is undertaking a research project on the evaluation of social and environmental impacts for public high school projects in NSW. All responses will be kept anonymous and a report of this research will be sent to you as a contributor.

This evaluation process is divided into three parts. Part A involves the rating of a list of social and environmental benefits (or positive effects) identified as being important for a public high school development. All criteria are rated based on their level of benefit on the project from a five-point scale (ranging from 1 to 5). A score of 1 represents the lowest level of benefit whilst a score of 5 indicates the highest level of benefit.

Part B involves the assessment of the social and environmental impact (or negative effects) for a public high school development. All criteria to be assessed are based on the likelihood of environmental damage being incurred over the economic life of the project. The level of impact is divided into five levels ranging from 1 to 5, 1 being the lowest level of impact and 5 being the highest level of impact. This rating will later be converted into a percentage of impact associated with each development.

Part C involves the weighting of all the social and environmental criteria to reflect their level of importance in a public high school development. Each criterion is compared against another and the most important one of the pair circled. This approach of pairwise comparison is used to derive relative weight for each criterion. The resulting weightings will be used to multiply with the scores obtained in Part A and B.

Name of Project : ______________________________

Project completion : ______________________________

Evaluation completed by : ______________________________

Position : ______________________________

Part A - Social and Environmental Benefits

Taking account of the contribution of positive effects of development to society, please rate the following criteria in accordance with their level of benefits on a scale of 1 to 5 by ticking the appropriate boxes (1=lowest level, 5=highest level).

For the nominated project, to what extent do the following criteria generate benefits to society?

		Criteria	Low 1	2	3	4	High 5
A		**Aesthetics/visual impact** (evaluate the image of a development to the community)					
	a	Project social image – improvement on the local community perception of education					
	b	Appearance – project exterior in harmony with local buildings					
B		**Functional layout** (evaluate the overall layout of a development)					
	a	Layout flexibility – ease of rearranging layout to suit requirements					
	b	Groupings of functions – functions are put together without long communication lines					
	c	Space utilisation – generous arrangements of rooms and other facilities					
	d	Provisions for disabled facilities					
	e	Level of adaptability – the possibility of changes to suit other future use					
C		**Heritage preservation** (evaluate the heritage implication of a development)					
	a	National heritage – implications of national historical events/features within the area					
	b	Local heritage – implications of local historical events/features within the area					
D		**Recycling/refurbishment potential** (evaluate the recycling potential of a development)					
	a	Design for deconstruction – building components designed for recovery and reuse					
E		**Social benefits** (evaluate the social contribution of a development to the community)					
	a	Employment opportunity – provision of employment opportunities to local community					
	b	Improvement of living environment – usage of vacant land to improve local living environment					
	c	Education services – provision of education opportunity to local children					
	d	Local transportation system – improvement of existing transportation network					
F		**Environment** (evaluate the positive effects of a development to the surrounding area)					
	a	Improvement on the beauty of the natural landscape					
	b	Improvement on the ecological value of the natural landscape					
	c	Protection of local flora and fauna					
	d	Provision of an environment that supports natural habitat					
G		**Recreation** (evaluate the provision of additional facilities to the community)					
	a	Recreational facilities – provision of sport centres, playgrounds, etc					
	l	Leisure – provision of additional functional venues					

Part B - Social and Environmental Impact

Taking account of the generation of negative effects of development to society, please rate the following criteria in accordance with their level of impact on a scale of 1 to 5 by ticking the appropriate boxes (1=lowest level, 5=highest level).

For the nominated project, to what extent do the following criteria generate impact to society?						
	Criteria	**Low 1**	**2**	**3**	**4**	**High 5**
H	**Manufacture** (evaluate these aspects for the manufacturing of building materials or components)					
	a Virgin source of materials – involvement of virgin materials in the manufacturing of building materials					
	b Recycled materials – involvement of recycled materials in the manufacturing of product components					
	c Origin of materials – raw materials or components are obtained locally					
	d Hazardous materials – involvement of hazardous materials in the manufacturing process of building materials					
	e Greenhouse gas – emission of greenhouse gas during the manufacturing of building materials					
	f Pollution – generation of untreated pollution during the manufacturing process					
	g Manufacturing waste – recycling of manufacturing waste					
	h Packaging – involvement of packaging in products					
I	**Design** (evaluate these aspects at the design stage of a development)					
	a Design objective – consideration of environmental performance					
	b Evaluation of products – consideration of a life-cost approach in the evaluation of products					
	c Energy consumption – consideration of embodied energy in the decision process					
	d Energy-efficient – decision on products selection					
J	**Disposal** (evaluate these aspects for the demolition of an existing building)					
	a Demolished materials - collection and recycling of demolished materials on site					
	b Demolished waste – inclusion of hazardous materials in the demolished waste					
	c Non-recyclable waste – delivery to landfill					
K	**Construction** (evaluate these aspects at the construction stage of a development)					
	a Air pollution – generation of pollutants to the air during the construction process					
	b Noise pollution – generation of noise during the construction process					
	c Water run off – generation of pollutants to natural and municipal watercourses					
	d Monitoring of environmental impact during the construction process					
	e Construction waste – recycling of construction waste on site					

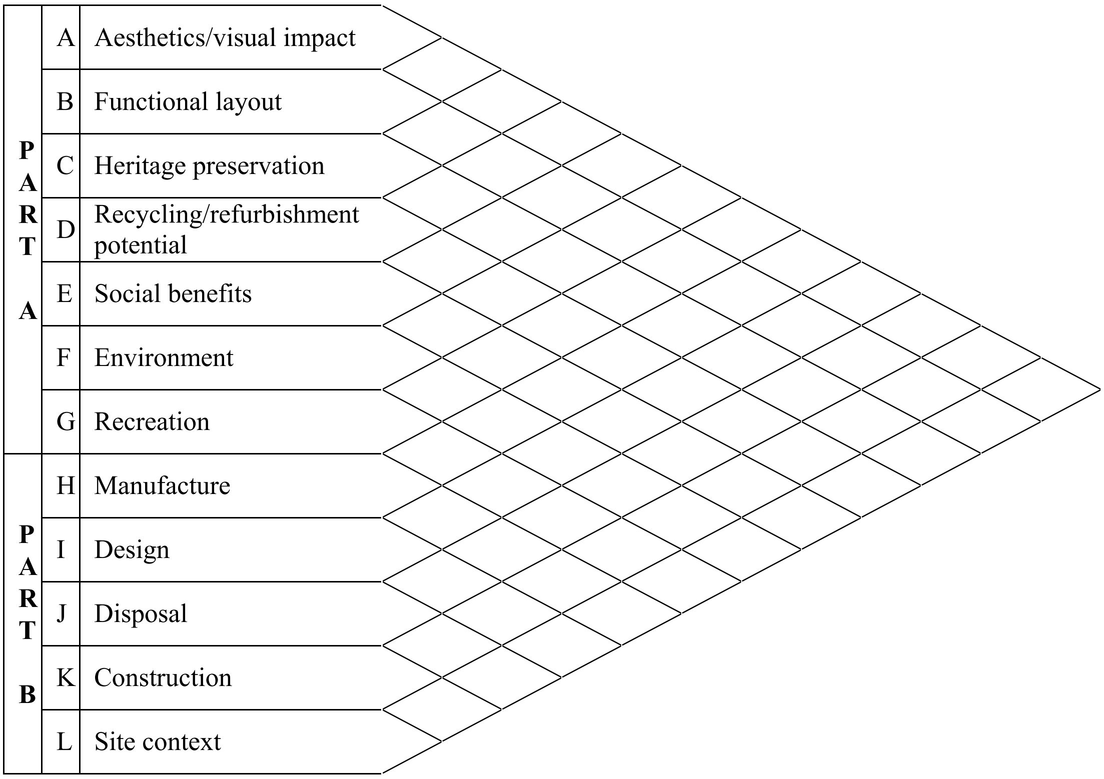
		Criteria	Low 1	2	3	4	High 5
I	**Site context** (evaluate these aspects in the general context of the site and the development)						
	a	Ease of access to site from public transport					
	b	Existence of rare or endangered species on or near the site					
	c	Disruption of natural features of the site by the project					
	d	Interference of the quality of the surface and/or groundwater by the project					
	e	Disturbance of the existing transport system on completion of the project (e.g. traffic congestion)					
	f	Traffic noise – generation of traffic noise on completion of the project to the nearby area					

Part C - Weighted Scoring Evaluation Matrix

This part involves the weighting of all the social and environmental criteria in Part A and B to reflect their relative importance in relation to the nominated project. A pairwise comparison is used to derive the weighting for each group as identified above.

In the following evaluation matrix please follow the steps below and choose between two attributes to demonstrate that one is more important than the other in the selection process:

Step 1: Compare attribute A with B, and place the letter indicating the more important attribute in the corresponding cell.
Step 2: Repeat for each combination of attributes similar to the example. Equal rankings can be shown as A/B, etc.
Step 3: Check all cells in the table have been completed.



PART A	A	Aesthetics/visual impact
	B	Functional layout
	C	Heritage preservation
	D	Recycling/refurbishment potential
	E	Social benefits
	F	Environment
	G	Recreation
PART B	H	Manufacture
	I	Design
	J	Disposal
	K	Construction
	L	Site context

Public High School **Building Life Span = 60 Years**

PR	Preliminaries	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Security provision											
2	Insurance (imputed vandalism cost)											
3	Garage collection											
4	Miscellaneous maintenance work											
5	Preliminaries				1,730,600.00							
	Total				**1,730,600.00**							

SB	Substructure	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	150 r.c. slab gnd placed on fill, incl. sand binding and damp proof membrane	m2	90	2,134	192,060.00	482.23	1,029,078.82					
2	400 dia. concrete bored piers	m	50	476	23,800.00	6058.32	363,499.20					
3	900 dia. concrete bored piers	m	180	248	44,640.00	6058.32	957,214.56					
4	"Termi-mesh" or termite barrier	m	25	1,348	33,700.00	Incl	-					
5	Termi-mesh termite barrier at slab penetrations	Item	400	2	800.00	Incl	-					
6	100 conc. paving slab to attach covered ways	m2	36	1,458	52,488.00	319.93	466,457.94					
7	110 r.c. stiffened slab on gnd, incl. basecourse, sand blinding and damp proof membrane	m2	62	808	50,096.00	408.70	330,229.60					
8	300 x 500 deep r.c. edge beam	m	68	173	11,764.00	5485.17	142,614.42					
9	300 x 500 deep r.c. secondary beams	m	45	230	10,350.00	5485.17	191,980.95					
10	600 x 350 deep r.c. strip footing to brick wall	m	85	463	39,355.00	5485.17	532,061.49					
11	270 cavity brick wall	m2	135	520	70,200.00	2076.36	1,079,707.20					
12	Termi-mesh termite barrier at slab penetrations	Item	500	5	2,500.00	Incl	-					
13	110 r.c. stiffened slab on gnd, incl. basecourse, sand blinding and damp proof membrane	m2	92	623	57,316.00	408.70	254,620.10					
14	120 r.c. stiffened slab on gnd, incl. basecourse, sand blinding and damp proof membrane	m2	62	46	2,852.00	445.85	20,509.10					
15	120 r.c. stiffened slab with beams on gnd, incl. basecourse, sand blinding and damp proof membrane (Undercroft)	m2	96	79	7,584.00	445.85	35,222.15					

16	120 r.c. stiffened slab with beams on gnd, incl. basecourse, sand blinding and damp proof membrane	m2	96	646	62,016.00	445.85	288,019.10					
17	Termi-mesh termite barrier at slab penetrations	Item	600	1	600.00	Incl	-					
18	150 r.c. slab and bored piers on filled gnd, incl. sand blinding and damp proof membrane	m2	130	1,216	158,080.00	482.23	586,391.68					
19	Termi-mesh termite barrier at slab penetrations	Item	300	2	600.00	Incl	-					
20	120 r.c. stiffened slab with beams on gnd, incl. basecourse, sand blinding and damp proof membrane	m2	95	1,312	124,640.00	445.85	584,955.20					
21	Termi-mesh termite barrier at slab penetrations	Item	800	1	800.00	Incl	-					
22	Drainage to subfloor	Item	5000	1	5,000.00	Incl	-					
23	120 r.c. stiffened raft slab with beams, incl. sand blinding and damp proof membrane	m2	105	78	8,190.00	445.85	34,776.30					
24	Walls below Ground Floor level	Item	3000	1	3,000.00	Incl	-					
	Total				**962,431.00**		**6,897,337.81**					

UP	**Upper Floors**	**Unit**	**Rate**	**Qties**	**Total Cost**	**EE Value**	**Initial EE**	**Recurrent EE**	**Descript**	**Qties**	**Life Span**	**Cyc**
1	225 suspended r.c. slab	m2	178	1,302	231,756.00	704.83	917,688.66					
2	400 x 600 deep r.c. edge beam	m	175	349	61,075.00	5485.17	460,754.28					
3	1200 x 450 deep r.c. beam	m	350	72	25,200.00	5485.17	213,921.63					
4	225 suspended r.c. slab	m2	180	937	168,660.00	704.83	660,425.71					
5	1800 x 450 deep r.c. beam	m	505	91	45,955.00	5485.17	405,902.58					
6	225 suspended r.c. slab, incl. beam and drop panels	m2	245	363	88,935.00	704.83	255,853.29					
7	225 suspended r.c. slab, incl. beam and drop slabs	m2	235	770	180,950.00	704.83	542,719.10					
	Total				**802,531.00**		**3,457,265.25**					

SC	Staircase	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cycle
1	2100 wide r.c. stair, wide rising 3.50m, w/ 2 flights and 1 intermediate landg, incl. finishes	m	2500	22	55,000.00	4080.00	73,440.00					
2	Additional flight of steps to gnd floor	m	800	2	1,600.00	Incl	-					
3	Reo	t		2.07	Incl	34000.00	70,380.00					
4	Fwk	m2		258	Incl	57.20	14,757.60					
5	Metal balustrade	m		5	Incl	695.53	3,477.65	6,955.30	replace	5	30	2
						11.85	-	592.50	repaint	5	6	10
6	Metal handrail	m		9	Incl	59.28	533.52	1,067.04	replace	9	30	2
						11.85	-	167.44	repaint	9	6	10
7	Grano topping to stair t, r, ldg & string	m2		11	Incl	4080.00	44,880.00	134,640.00	replace	11	20	3
8	Repaint stair flight and landing soffit	m2				10.60	-	445.20	repaint	7	10	6
	Total				**56,600.00**		**207,468.77**	**143,867.48**				

CL	Column	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Concrete columns	m2	35	1,302	45,570.00	6058.32	2,368,803.12					
2	Steel columns	m2	30	5,183	155,490.00	483.23	2,504,581.09					
3	114 CHS column to attached covered way	m2	70	12	840.00	34000.00	5,780.00					
4	Steel columns	m2	35	2,409	84,315.00	483.23	1,164,101.07					
5	100 dia. CHS columns to covered ways	m	70	78	5,460.00	34000.00	31,620.00					
6	R.c. columns	m2	35	1,787	62,545.00	6058.32	3,247,259.52					
7	Steel column to attached covered way 1st floor	Item	1000	1	1,000.00	Incl	-					
8	Steel columns	m2	32	1,518	48,576.00	483.23	733,543.14					
	Total				**403,796.00**		**10,055,687.94**					

RF	Roof	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Steel roof framing to main roof, incl.purlins and roof bracing	m2	75	7,653	573,975.00	163.10	1,248,204.30					
2	Steel roof framing over external stair	m2	70	282	19,740.00	163.10	45,994.20					
3	300 x 150 x 2 galv. steel wire safety mesh	m2	5	7,504	37,520.00	24.32	182,497.28					
4	Painting exposed steelwork	Item	2700	1	2,700.00	11.85	1,066.50	6,399.00	repaint	1	10	6
5	0.48 BMT colorbond finished steel corrugated roofing to main roof and clerestory roof, incl. vapour barrier and insulation (Building)	m2	42	6,377	267,834.00	294.40	1,877,388.80	3,754,777.60	replace	6,377	30	2
6	0.48 BMT colorbond finished steel corrugated roofing to attach way, incl. vapour barrier	m2	33	2,617	86,361.00	259.04	677,907.68	1,355,815.36	replace	2,617	30	2
7	Colorbond steel barge capping	m	25	693	17,325.00	38000	169,480.00	338,960.00	replace	693	30	2
8	Colorbond steel ridge capping	m	40	477	19,080.00	38000	116,660.00	233,320.00	replace	477	30	2
9	Steel roofing for 300 wide translucent strips	m	15	318	4,770.00	246.09	23,378.55	93,514.20	replace	318	15	4
10	200 dia.half-round colorbond finished steel eaves gutter , incl. leaf guard	m	30	739	22,170.00	97.24	71,860.36	143,720.72	replace	739	30	2
11	114 dia. galv. CHS downpipe, incl. painting	m	75	269	20,182.50	11.85	1,149.45	6,896.70	repaint	269	10	6
11a	Ditto	t		3.91	Incl	38000.00	148,580.00	297,160.00	replace	269	30	2
12	75 dia.colorbond finished steel downpipe, incl. plastic coated balloon type leaf guard	m	25	305	7,625.00	72.92	22,240.60	44,481.20	replace	305	30	2
13	Precast concrete downpipe pit	No.	80	116	9,280.00	Incl	-					
14	Steel roof framing over outdoor workshop	m2	75	222	16,650.00	163.10	36,208.20					
15	Painting exposed steelwork	Item	2000	1	2,000.00	11.85	829.50	4,977.00	repaint	1	10	6
16	700 dia. aluminium turbo roof vent, with base, painted matching colorbond roofing (type RV1)	No.	2000	34	68,000.00	Incl	-	-				
17	600 x 600 anodised aluminium ceiling vents	No.	150	94	14,100.00	Incl	-	-				
18	Painting exposed steelwork	Item	3000	1	3,000.00	11.85	1,185.00	7,110.00	repaint	1	10	6
19	Painting exposed steelwork	Item	2500	2	5,000.00	11.85	1,896.00	11,376.00	repaint	1	10	6
20	450 dia. aluminium turbo roof vent, with base, painted matching colorbond roofing (type RV3)	No.	1000	3	3,000.00	Incl	-	-				
21	Painting exposed steelwork	Item	2300	2	4,600.00	11.85	1,777.50	10,665.00	repaint	2	10	6
22	600 x 600 ventilated skylight	No.	800	4	3,200.00	Incl	-	-				
23	Steel roof framing incl. Purlins and roof bracing	m2	72	522	37,584.00	163.10	85,138.20					
24	700 dia. aluminium turbo roof vent, with base, painted matching colorbond roofing (type RV2)	No.	2300	10	23,000.00	Incl	-	-				
25	Steel roof framing incl. Purlins and roof bracing	m2	76	1,138	86,488.00	163.10	185,607.80					
26	Painting exposed steelwork	Item	2800	1	2,800.00	11.85	1,125.75	6,754.50	repaint	1	10	6

27	Painting exposed steelwork	Item	5000	1	5,000.00	11.85	1,896.00	11,376.00	repaint	1	10	6
28	0.48 BMT colorbond finished steel corrugated roofing incl. vapour barrier and foil backed "Anticon" thermal insulation	m2	45	1,378	62,010.00	294.40	405,683.20	811,366.40	replace	1,378	30	2
29	600 dia. aluminium turbo roof vent, with base, painted matching colorbond roofing (type RV4)	No.	1600	10	16,000.00	Incl	-	-				
30	250 dia.half-round colorbond finished steel eaves gutter , incl. leaf guard	m	35	222	7,770.00	121.55	26,984.10	53,968.20	replace	222	30	2
31	Spreaders	Item	300	1	300.00	Incl	-	-				
32	Steel roof framing incl. Purlins and roof bracing	m2	73	622	45,406.00	163.10	101,448.20					
33	500 dia. acrylic domed skylight	No.	600	2	1,200.00	Incl	-	-				
34	Steel roof framing incl. Purlins and roof bracing	m2	80	239	19,120.00	163.10	38,980.90					
	Total				**1,514,790.50**		**5,475,168.07**	**7,192,637.88**				

EW	External Wall	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	230 faced brick wall to external stair	m2	135	103	13,905.00	2036.84	209,794.52					
2	230 faced brick balustrade wall	m2	135	58	7,830.00	2036.84	118,136.72					
3	Steel stud wall framing with 110 faced brick veneer, incl. vapour barrier & thermal insulation	m2	126	2,993	377,153.28	1312.49	3,928,650.07					
4	Soldier course	Item	2000	5	10,000.00	Incl	-	-				
5	Extra over brick veneered walls for cant brick window sills	m	35	659	23,065.00	1018.42	58,049.94					
6	Steel stud wall framing with vertical metal cladding, incl. vb & thermal insulation	m2	80	2,125	170,000.00	481.38	1,022,932.50	2,045,865.00	replace	2125	30	2
7	Steel stud wall framing with 9 vitrepanel lining, incl. vapour barrier & thermal insulation	m2	220	276	60,720.00	428.05	118,141.80	236,283.60	replace	276	30	2
8	Perforated metal mesh walls to stair	m2	200	336	67,200.00	198.90	66,830.40	133,660.80	replace	336	30	2
9	Wall beams and bracing	Item	8800	2	17,600.00	Incl	-	-				
10	Steel Lintels	Item	3000	5	15,000.00	Incl	-	-				
11	Perforated mesh infilled wall	m2	250	40	10,000.00	198.90	7,956.00	15,912.00	replace	40	30	2
12	Wall beams and bracing	Item	8000	1	8,000.00	Incl	-	-				
13	Steel Lintels	Item	3100	1	3,100.00	Incl	-	-				

14	Extra over metal clad walls for perforated metal cladding	m2	30	3	90.00	198.90	596.70	1,193.40	replace	3	30	2
15	Wall beams and bracing	Item	7500	1	7,500.00	Incl	-	-				
16	Soldier course to brick veneered walls	Item	4000	1	4,000.00	Incl	-	-				
17	Wall beams and bracing	Item	9500	1	9,500.00	Incl	-	-				
18	270 cavity brick wall	m2	135	331	44,685.00	2076.36	687,275.16					
19	Soldier course in brick walls	Item	1600	1	1,600.00	Incl	-	-				
20	Extra over metal clad walls for perforated metal lining	m2	150	3	450.00	198.90	596.70	1,193.40	replace	3	30	2
21	Wall beams and bracing	Item	7600	1	7,600.00	Incl	-	-				
22	Steel Lintels	Item	2500	1	2,500.00	Incl	-	-				
23	Wall beams and bracing	Item	8600	2	17,200.00	Incl	-	-				
24	Steel Lintels	Item	2600	1	2,600.00	Incl	-	-				
25	Soldier course in brick veneered walls	Item	1800	1	1,800.00	Incl	-	-				
26	Steel Lintels	Item	2800	1	2,800.00	Incl	-	-				
27	Soldier course in cavity & veneered brick walls	Item	5100	1	5,100.00	Incl	-	-				
28	Wall beams and bracing	Item	10000	1	10,000.00	Incl	-	-				
29	Soldier course to brick veneered walls	Item	1300	1	1,300.00	Incl	-	-				
30	Glazed wall with 10 laminated safety glass	m2	550	13	7,150.00	904.11	11,753.43	11,753.43	replace	13	40	1
						317.50		2,476.50	repair 5%	0.65	5	12
31	Wall beams and bracing	Item	4000	1	4,000.00	Incl	-	-				
32	Steel Lintels	Item	2000	1	2,000.00	Incl	-	-				
33	Extra over brick veneered walls for soldier course	m	35	31	1,085.00	Incl	-	-				
34	Steel beams and wall bracing	Item	3500	1	3,500.00	Incl	-	-				
35	Steel Lintels	Item	1200	1	1,200.00	Incl	-	-				
36	Wall beams and bracing (5776.28m2)	t		22.87	Incl	38000	869,060.00					
37	Lintel	t		5.02	Incl	38000	190,760.00					
	Total				**921,233.28**		**7,290,533.94**	**2,448,338.13**				

NW	Internal Wall	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Steel stud wall framing	m2	30	6,504	195,120.00	107.53	699,375.12	1,398,750.24	replace	6504	25	2
2	Insulation in steel framed walls	m2	8	1,067	8,536.00	35.36	37,729.12	75,458.24	replace	1067	25	2
3	Steel stud wall framing with 110 common brick veneer, incl.vapour barrier & thermal insulation	m2	126	40	5,040.00	1312.49	52,499.60	8,602.40	replace	40	25	2
4	110 common brick wall	m2	60	35	2,100.00	1018.42	35,644.70					
5	Insulation infill to steel framed walls	m2	8	752	6,016.00	35.36	26,590.72	53,181.44	replace	752	25	2
6	230 common brick wall	m2	120	32	3,840.00	2036.84	65,178.88					
	Total				**220,652.00**		**917,018.14**	**1,535,992.32**				

WW	Windows	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Aluminium windows glazed with 6.38 clear float laminated safety glass	m2	320	1,039	332,480.00	1733.67	1,801,283.13	1,801,283.13	replace	1039	40	1
						317.50		197,739.00	repair 5%	52	5	12
2	Perforated metal sunscreens	m2	250	145	36,250.00	751.65	108,989.25	217,978.50	replace	145	30	2
3	Insect screens	m2	100	69	6,900.00	1677.98	115,780.62	231,561.24	replace	69	30	2
4	Aluminium windows glazed with 6.38 obscure glass	m2	350	8	2,800.00	1733.67	13,869.36	13,869.36	replace	8	40	1
						317.50		1,524.00	repair 5%	0.40	5	12
5	Fixed metal louvres	m2	280	64	17,920.00	305.86	19,575.04	39,150.08	replace	64	30	2
6	Adjustable metal louvres equal to "Korab"	m2	300	69	20,700.00	305.86	21,104.34	42,208.68	replace	69	30	2
7	galv. steel framed horizontal flat bar security grille behind steel louvres, incl. painting	m2	150	25	3,750.00	185.03	4,625.75	1,777.50	repaint	25	10	6
	Total				**420,800.00**		**2,085,227.49**	**2,547,091.49**				

NS	Internal Screens & Borrowed Lights	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Internal aluminium windows glazed with 6.38 clear float laminated safety glass	m2	320	457	146,240.00	1733.67	792,287.19	792,287.19	replace	457	40	1
						317.50		87,058.50	repair 5%	22.85	5	12
2	Operable wall	m2	600	179	107,400.00	851.80	152,472.20	304,944.40	replace	179	25	2
3	Internal alum windows with double glazing	m2	550	23	12,650.00	1733.67	39,874.41	39,874.41	replace	23	40	1
						317.50		4,381.50	repair 5%	1	5	12
4	Accordion door	m2	350	36	12,600.00	262.43	9,447.48	9,447.48	replace	36	40	1
5	38 terrazzo toilet partit incl Anti-graffiti finish	m2	300	189	56,700.00	4080.00	771,120.00	1,542,240.00	replace	189	30	2
	Total				**335,590.00**		**1,765,201.28**	**2,780,233.48**				

ED	External Doors	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Pair of solid core doors 1200 x 2100 high	No.	900	9	8,100.00	769.91	6,929.19	6,929.19	replace	9	40	1
2	Pair of solid core doors 1800 x 2400 high	No.	1600	13	20,800.00	1366.13	17,759.69	17,759.69	replace	13	40	1
3	Pair of solid core doors 1800 x 2400 high with glazed upper panel to each other	No.	1800	5	9,000.00	1366.13	6,830.65	6,830.65	replace	5	40	1
4	Concrete threshold	m	40	108	4,320.00	4080.00	8,160.00					
5	900 x 2100 high solid core door	No.	750	44	33,000.00	597.68	26,297.92	26,297.92	replace	44	40	1
6	900 x 2100 high solid core door with 600 x 800 high glazed viewing panel	No.	850	6	5,100.00	597.68	3,586.08	3,586.08	replace	6	40	1
7	Pair of solid core doors 1600 x 2400 high	No.	1400	2	2,800.00	1214.33	2,428.66	2,428.66	replace	2	40	1
8	3000 x 2100 high electrically operated roller shutter	No.	1000	2	2,000.00	198.90	2,585.70	5,171.40	replace	2	30	2
						11.85		924.30	repaint	13	10	6
9	900x2100 high solid dr w/ glazed upper panel	No.	850	14	11,900.00	597.68	8,367.52	8,367.52	replace	14	40	1
10	Pair of solid core doors 1600 x 2100 high	No.	1300	1	1,300.00	1062.54	1,062.54	1,062.54	replace	1	40	1
11	Al framed glazed fanlights to solid core doors	m2	350	7	2,450.00	1733.67	12,135.69	12,135.69	replace	7	40	1
12	Insect screen to 900 x 2100 high doors	No.	350	6	2,100.00	1677.98	18,457.78	18,457.78	replace	6	40	1
13	Pair of solid core doors 1500 x 2100 high	No.	1200	3	3,600.00	996.13	2,988.39	2,988.39	replace	3	40	1
14	Pair of solid core doors 1800 x 2100 high	No.	1500	15	22,500.00	1195.36	17,930.40	17,930.40	replace	15	40	1
15	Aluminium framed fanlights, glazed with 6.38 clear float laminated safety glass	m2	350	4	1,400.00	1733.67	6,934.68	6,934.68	replace	4	40	1

16	Solid core doors 1200 x 2100 high	No.	900	1	900.00	769.91	769.91	769.91	replace	1	40	1
17	2100 x 2100 high roller shutter	No.	1000	1	1,000.00	198.90	795.60	1,591.20	replace	1	30	2
						11.85		355.50	repaint	5	10	6
18	1800 x 2100 high galv. steel framed & vertical SHS infilled gate	No.	1700	1	1,700.00	107.21	428.84	857.68	replace	1	30	2
19	Panic bolts to double-leafed entry doors	No.	900	10	9,000.00	Incl	-	-				
20	Fixed metal louvres to fanlights	m2	300	8	2,400.00	305.86	2,446.88	4,893.76	replace	8	30	2
21	Pair of aluminium framed glazed entry doors, overall 1800 x 2100 high	No.	2500	1	2,500.00	1733.67	6,934.68	6,934.68	replace	1	40	1
22	Pair of solid core doors 1600 x 2100 high	No.	900	3	2,700.00	1062.54	3,187.62	3,187.62	replace	3	40	1
23	900 x 2100 high flyscreen door	No.	350	1	350.00	1677.98	3,355.96	10,067.88	replace	1	20	3
24	Ptg to timber doors	m2		626	Incl	8.44	5,283.44	31,700.64	repaint	626	10	6
25	Hardware	t		0.27	Incl	229310	61,913.70	61,913.70	replace		40	1
	Total				**150,920.00**		**227,571.52**	**260,077.46**				

ND	Internal Doors	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	900 x 2100 high solid core door	No.	730	83	60,590.00	597.68	49,607.44	0.00	replace	83	80	0
2	900 x 2100 high solid core door with glazed upper panel	No.	850	53	45,050.00	597.68	31,677.04	0.00	replace	53	80	0
3	Aluminium framed glazed fanlights	m2	350	20	7,000.00	1,733.67	34,673.40	0.00	replace	20	80	0
4	Pair of solid core doors, 1800 x 2100 high each leaf with glazed upper panel	No.	1500	2	3,000.00	1,195.36	2,390.72	0.00	replace	2	80	0
5	1200 x 2100 roller shutter	No.	500	2	1,000.00	198.90	994.50	0.00	replace	2	80	0
6	2000 x 2100 high roller shutter	No.	800	1	800.00	198.90	795.60	0.00	replace	1	80	0
						11.85		711.00	repaint	10	10	6
7	900 x 1200 high timber slat type roller shutter	No.	500	2	1,000.00	198.90	397.80	795.60	replace	2	30	2
						8.44		151.92	repaint	3	10	6
8	1-hr fire rated door 900 x 2100 high, with 100 x 600 high observation panel incl. painting	No.	1200	3	3,600.00	597.68	1,793.04	0.00	replace	3	80	0
9	Pair of solid core doors, 1800 x 2100 high	No.	2000	7	14,000.00	1,195.36	8,367.52	0.00	replace	7	80	0
10	600 x 1500 high toilet doors	No.	400	24	9,600.00	236.19	5,668.56	11,337.12	replace	24	30	2
11	900 x 2100 high solid core sliding door	No.	730	1	730.00	597.68	597.68	0.00	replace	1	80	0
12	Pair of solid core doors, 1200 x 2100 high	No.	900	3	2,700.00	796.91	2,390.73	0.00	replace	3	80	0
13	600 x 1800 high toilet doors	No.	400	29	11,600.00	283.42	8,219.18	16,438.36	replace	29	30	2

14	Aluminium framed glazed fanlights	m2	320	8	2,560.00	1,733.67	13,869.36	0.00	replace	8	80	0
15	Pair of solid core doors, 1500 x 2100 high	No.	1200	1	1,200.00	996.13	996.13	0.00	replace	1	80	0
16	Ptg to timber doors	m2		725	Incl	8.44	6,114.78	36,688.68	repaint	725	10	6
17	Hardware	t		0.37	Incl	229,310.00	84,844.70	0.00	replace		80	0
	Total				**164,430.00**		**253,398.18**	**66,122.68**				

WF	Wall Finishes	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	13 painted plasterboard wall lining	m2	30	12,863	385,890.00	52.71	678,021.59	497,026.32	repaint	12,863	10	6
2	Extra over plasterboard for pinboard wall lining	m2	55	5,475	301,125.00	4.49	24,582.75	73,748.25	replace	5,475	20	3
3	9 painted fibre cement wall lining	m2	48	4,360	209,280.00	161.1	702,396.00	277,296.00	repaint	4,360	10	6
4	Ceramic wall tiling to splashbacks	m2	95	131	12,445.00	222.63	29,164.53	58,329.06	replace	131	25	2
5	Cement render & paint on brick wall	m2	30	224	6,720.00	40.62	9,098.88	14,246.40	repaint	224	10	6
6	Corrosion treatment of acid bay	Item	500	1	500.00	Incl	-	-				
7	Ceramic wall tiling	m2	80	69	5,520.00	222.63	15,361.47	30,722.94	replace	69	25	2
8	9 plywood wall lining incl.painting	m2	55	322	17,710.00	65.64	21,136.08	16,306.08	repaint	322	10	6
9	9 plywood wall lining fixed to steel stud wall framing, incl.painting	m2	55	899	49,445.00	65.64	59,010.36	45,525.36	repaint	899	10	6
10	9 plywood wall lining on timber battens, fixed to brick walls, incl.painting	m2	90	115	10,350.00	65.64	7,548.60	5,823.60	repaint	115	10	6
	Total				**998,985.00**		**1,546,320.26**	**1,019,024.01**				

FF	Floor Finishes	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Steel trowelled finish to concrete slab	m2	4	2,401	9,604.00		-					
2	Carpet & underlay	m2	42	5,386	226,212.00	220.82	1,189,336.52	4,757,346.08	replace	5,386	15	4
						220.82	-	713,601.91	repair 5%	269.30	5	12
3	Non-foam backed vinyl sheet flooring	m2	40	1,269	50,760.00	98.5	124,996.50	374,989.50	replace	1,269	20	3
4	Skirtings	Item	7600	2	15,200.00	Incl	-	-				
5	Industrial vinyl sheet flooring	m2	65	690	44,850.00	98.5	67,965.00	203,895.00	replace	690	20	3
6	Skirtings	Item	4800	1	4,800.00	Incl	-	-				
7	Ceramic floor tiling	m2	75	611	45,825.00	233.76	142,827.36	285,654.72	replace	611	25	2
8	Skirtings	Item	5800	1	5,800.00	Incl	-	-				
9	Steel trowelled finish for chem-resistant finish	m2	25	12	300.00	Incl	-	-	repaint	12	20	3
10	Foam-backed vinyl sheet flooring	m2	48	105	5,040.00	98.5	10,342.50	31,027.50	replace	105	20	3
11	Skirtings	Item	9200	1	9,200.00	Incl	-	-				
12	Carpet for impact absorptive underlay	m2	15	210	3,150.00	220.82	46,372.20	231,861.00	replace	210	12	5
						220.82		556,466.40	repair 5%	210	5	12
13	Skirtings	Item	3600	2	7,200.00	Incl	-	-				
14	Skirtings	Item	9300	1	9,300.00	Incl	-	-				
15	Anti-static vinyl sheet flooring	m2	65	13	845.00	98.5	1,280.50	3,841.50	replace	13	20	3
16	Skirtings	Item	5600	1	5,600.00	Incl	-	-				
17	Carpet & underlay to risers	m2	50	15	750.00	220.82	3,312.30	13,249.20	replace	15	15	4
						220.82		1,987.38	repair 5%	0.75	5	12
18	Sprung timber flooring	m2	140	757	105,980.00	155.44	117,668.08	117,668.08	replace	757	35	1
18a	Ptg to timber flooring	m2		757	Incl	8.44	6,389.08	38,334.48	repaint	757	10	6
19	Tiered timber platform	m2	100	33	3,300.00	155.44	5,129.52	5,129.52	replace	33	35	1
19b	Ptg to tiered timber platform	m2		33	Incl	8.44	278.52	1,671.12	repaint	33	10	6
20	Skirtings	Item	21000	1	21,000.00	Incl	-	-				
21	100 high vinyl skirting	m	25	42	1,050.00	Incl	-	-	replace	42	20	3
	Total				**575,766.00**		**1,715,898.08**	**7,336,723.39**				

CF	Ceiling Finishes	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	13 rakg plasterboard ceiling lining, incl.painted	m2	50	3,977	198,850.00	52.71	209,627.67	76,835.64	repaint	3,977	20	3
2	Suspended 13 plasterboard ceiling, incl.painted	m2	55	1,234	67,870.00	52.71	65,044.14	23,840.88	repaint	1,234	20	3
3	Raking 6 f.c. ceiling over stair, incl.painting	m2	60	646	38,760.00	161.10	104,070.60	12,480.72	repaint	646	20	3
4	Suspended perforated metal acoustic ceiling	m2	70	1,126	78,820.00	70.50	79,383.00	317,532.00	replace	1,126	15	4
5	Raking perforated metal acoustic ceiling	m2	70	2,799	195,930.00	70.50	197,329.50	789,318.00	replace	2,799	15	4
6	Insulation to clgs, excl.perforated acoustic clg	m2	8	6,528	52,224.00	35.36	230,830.08	-				
7	Rakg F/R clg in 2 layers of 16 plb'd, painted	m2	80	10	800.00	98.98	989.80	193.20	repaint	10	20	3
8	Suspended 6 fibre cement ceiling, incl.painting	m2	60	356	21,360.00	309.83	110,299.48	11,320.80	repaint	356	20	3
9	Raking fibre cement ceiling over stair, incl.ptg	m2	60	63	3,780.00	309.83	19,519.29	2,003.40	repaint	63	20	3
10	Ext'l rakg fibre cement clg to balcony,painted	m2	60	76	4,560.00	309.83	23,547.08	2,416.80	repaint	76	20	3
11	Suspended fire-rated ceiling, incl.painting	m2	80	13	1,040.00	251.61	3,270.93	251.16	repaint	13	20	3
12	Suspended 9 fibre cement ceiling, incl.painting	m2	70	21	1,470.00	309.83	6,506.43	667.80	repaint	21	20	3
13	Suspended 6 fibre cement ceiling, incl.painting	m2	55	12	660.00	309.83	3,717.96	381.60	repaint	12	20	3
14	13 raking flush jointed plb'd ceiling, painted	m2	50	38	1,900.00	251.61	9,561.18	734.16	repaint	38	20	3
15	9 raking fibre cement ceiling, incl.painting	m2	70	152	10,640.00	309.83	47,094.16	4,833.60	repaint	152	20	3
	Total				**678,664.00**		**1,110,791.30**	**1,242,809.76**				

FT	Fitments	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	FIX ONLY loose furniture, equipment & fittings	Item	5000	5	25,000.00							
2	Bracket for monitor	No.	100	53	5,300.00							
3	Projection screen	No.	500	51	25,500.00							
4	Mobile shelving system type MSS 400-300 (5 bays 400 deep & 4 bays 300 deep), 1245 wide x 2179 high	No.	8000	6	48,000.00							
5	900 wide x 400 deep x 2175 high adjustable steel shelving unit (Type SA400)	No.	250	61	15,250.00							
6	900 long timber rack with 6 pegs	No.	150	10	1,500.00							
7	Glass mirror	m2	150	20	3,000.00							
8	CP brass hat & coat hook	No.	10	20	200.00							
9	Vertical blinds	m2	75	1,472	110,400.00							
10	Door signage, incl. door no. & name plate	No.	80	266	21,280.00							
11	Miscellaneous signage, incl. block sign	Item	1000	7	7,000.00							
12	Roller blind type projection screen	No.	500	4	2,000.00							
13	Plan cabinet with 5 drawers for A0 size dwgs	No.	1000	2	2,000.00							
14	1.20 long stainless steel art trough	No.	250	2	500.00							
15	Stainless steel double laundry tub with cupboard	No.	700	1	700.00							
16	Hanging lines for art works	No.	50	3	150.00							
17	900 wide x 600 deep x 2175 high adjustable steel shelving unit (Type SA600)	No.	350	52	18,200.00							
18	Mobile shelving system type MSS-400B	No.	6000	1	6,000.00							
19	Rack module for sheets	No.	1000	2	2,000.00							
20	Cupboard for flammable liquids, 100 litres	No.	800	2	1,600.00							
21	1.8 high cupboard with shelving	No.	500	5	2,500.00							
22	Electro-static doormat	No.	300	1	300.00							
23	Rack for timber stack	No.	1000	1	1,000.00							
24	Rack module for wooden lengths	No.	1200	5	6,000.00							
25	Rack module for wooden sheets	No.	1000	1	1,000.00							
26	Rack module for metal sheets	No.	1000	1	1,000.00							
27	Cabinet for flammable liquids, 250 litres	No.	500	1	500.00							
28	Non-flammable spray booth type curtain	No.	800	2	1,600.00							
29	900 wide x 900 deep x 2175 high adjustable steel shelving unit (Type SA900)	No.	600	7	4,200.00							
30	Rack module for metal lengths	No.	1000	5	5,000.00							
31	Non-flammable welding curtain & track	m	150	8	1,200.00							

32	Shelving for pottery	No.	200	2	400.00							
33	900 L timb rack with 6 pegs for mops & brooms	No.	150	2	300.00							
34	Cabinet for flammable liquids, 100 litre	No.	800	1	800.00							
35	Miscellaneous signage, incl. block sign	Item	900	1	900.00							
36	4-burner electric stove	No.	1000	8	8,000.00							
37	4-burner gas stove	No.	1000	9	9,000.00							
38	4-burner gas cook top	No.	800	2	1,600.00							
39	2-burner gas cook top	No.	400	2	800.00							
40	Domestic dishwasher	No.	1500	4	6,000.00							
41	Towel rail	No.	150	2	300.00							
42	3300 x 900 high demonstration mirror	No.	500	2	1,000.00							
43	Range hood	No.	500	1	500.00							
44	400 deep timber shelving	m	65	22	1,430.00							
45	2300 x 1500 high demonstration mirror	No.	600	6	3,600.00							
46	Safety showers	No.	1200	2	2,400.00							
47	Rack for draining	No.	1000	4	4,000.00							
48	Infill for bench cupboards	No.	100	2	200.00							
49	600 wide shelving for animals & plants	m	65	6	390.00							
50	400 wide stainless steel plant socking shelf	m	500	2	1,000.00							
51	10m long x 12 dia. hose with fittings & hook	No.	30	1	30.00							
52	1800 long plastic coated wire-type tray for glass tubing	No.	200	1	200.00							
53	Mobile shelving system type MSS-300B	No.	6000	2	12,000.00							
54	900 x 450 x 2100 high adjustable timber shelving unit (Type AS-T450)	No.	500	8	4,000.00							
55	Corrosion resistant acid bay	No.	1000	1	1,000.00							
56	Cabinet for flammable liquids, 250 litres	No.	1000	2	2,000.00							
57	5m long x 12mm dia. hose	No.	15	1	15.00							
58	Mobile storage system type MSS 400B	No.	500	2	1,000.00							
59	600 deep x 900 high bench cupboard unit	m	700	6	4,200.00							
60	300 deep x 600 high overhead cupboard	m	350	6	2,100.00							
61	Microwave convection oven	No.	1000	2	2,000.00							
62	5 litre boiling water unit	No.	1500	5	7,500.00							
63	Dishwasher for cups & glasses	No.	1200	2	2,400.00							
64	Mobile shelving system type MSS-400B	No.	5000	2	10,000.00							
65	Paper towel dispenser	No.	80	20	1,600.00							
66	1750 x 900 cork mat	No.	60	2	120.00							
67	38 dia. x 850 satin finish stainless steel grab rail	No.	100	5	500.00							
68	38 dia. x 2000 long L-shaped satin finish stainless steel grab rail	No.	150	6	900.00							

69	1.80m (H) shower curtain & track	m	165	29	4,785.00							
70	600 x 150 wide particleboard shelf	No.	50	5	250.00							
71	Toilet roll holder	No.	30	28	840.00							
72	Brown out curtains	m2	75	48	3,600.00							
73	FIX ONLY loose furniture, equipment & fittings	Item	3000	2	6,000.00							
74	6.0 (L) x 1.8 (H) mirror	No.	3000	3	9,000.00							
75	6.0 (L) exercise bar	No.	900	3	2,700.00							
76	Curtain sets over mirrors	No.	4000	2	8,000.00							
77	2m (L) clothes rack for customers	No.	600	1	600.00							
78	900 x 1800 (H) mirror	No.	400	1	400.00							
79	Miscellaneous signage, incl. block sign	Item	800	1	800.00							
80	FIX ONLY loose furniture, equipment & fittings	Item	4000	2	8,000.00							
81	shelving for fitness store	m	40	7	280.00							
82	250 wide aluminium seating bench	m	150	100	15,000.00							
83	Rack with hooks for clothes	m	150	18	2,700.00							
84	1200 x 900 high mirror	No.	200	2	400.00							
85	700 (L) towel rail	No.	100	1	100.00							
86	Mobile change table	No.	3000	1	3,000.00							
87	Electrical gate	No.	20000	1	20,000.00							
88	Mobile shelving system type MSS 2400A	No.	10000	1	10,000.00							
89	38 dia. x 850 satin finish stainless steel grab rail	No.	80	1	80.00							
90	Paper towel dispenser	No.	150	2	300.00							
91	FIX ONLY loose furniture, equipment & fittings	Item	6000	1	6,000.00							
92	Basketball assembly complete with hoops & moveable backboards	No.	2000	2	4,000.00							
93	Floor plates & net posts	No.	300	6	1,800.00							
94	Telescopic work platform	No.	10000	1	10,000.00							
95	Moveable timber stairs	No.	300	2	600.00							
96	12 (L) lighting bar & cable tray support	No.	1500	4	6,000.00							
97	Track for stage curtain	m	150	52	7,800.00							
98	8.0 x 1.8 (H) mirror	No.	3600	1	3,600.00							
99	Exercise bar	m	150	16	2,400.00							
100	2.4 (L) rack for bats	No.	500	1	500.00							
101	0.9 (L) rack for javelins	No.	100	1	100.00							
102	1.35 (L) rack for discus	No.	1200	1	1,200.00							
103	1.35 (L) rack for shot putt	No.	1200	1	1,200.00							
104	Rack for high jump bars	No.	100	6	600.00							
105	3m (L) x 50mm (W) x 25mm (H) fl batten	No.	100	1	100.00							
106	Hose hooks	No.	5	2	10.00							
107	Steel pipe frame	No.	200	7	1,400.00							

108	38 dia. x 2000 long L-shaped satin finish stainless steel grab rail	No.	200	2	400.00							
109	250 wide shower seat	m	150	6	900.00							
110	Rack with hooks for clothes	m	50	31	1,550.00							
111	Miscellaneous signage, incl. block sign	Item	1200	1	1,200.00							
112	Mobile shelving system type MSS-300B	No.	5000	1	5,000.00							
113	Microwave oven	No.	800	1	800.00							
114	5 litre boiling water unit	No.	1200	1	1,200.00							
115	Mobile shelving system type MSS-400B	No.	6000	1	6,000.00							
116	FIX ONLY loose furniture, equipment & fittings	Item	2000	1	2,000.00							
117	600 x 900 (H) bench cupboard/severy bench, L-shaped on plan, incl. Drawers for $ & cutlery	m	750	12	9,000.00							
118	500 x 900 (H) severy bench	m	700	9	6,300.00							
119	700 x 900 (H) preparation bench	m	750	5	3,750.00							
120	300 x 600 (H) bench overhead bench	m	350	6	2,100.00							
121	Food slicer	No.	2000	1	2,000.00							
122	Miscellaneous signage, incl. block sign	Item	500	1	500.00							
123	Vending machine, complete with brick enclosure	No.	3500	1	3,500.00							
	Total				**604,410.00**							

SF	Sanitary Fixtures	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Pipework to sanitary fixtures	Item	6000	4	24,000.00							
2	Floor waste	No.	80	52	4,160.00							
3	Stainless steel bucket sink incl. stainless steel splashback	No.	800	6	4,800.00							
4	Electric hot water unit	No.	1000	17	17,000.00							
5	Pipework to sanitary fixtures	Item	8000	1	8,000.00							
6	Stainless steel bucket sink incl. 300 high stainless steel splashback	No.	800	7	5,600.00							
7	Pipework to sanitary fixtures	Item	12000	1	12,000.00							
8	Hand basin	No.	350	20	7,000.00							
9	Stainless steel laundry tub	No.	600	2	1,200.00							
10	Pipework to sanitary fixtures	Item	17000	2	34,000.00							
11	WC suite	No.	400	61	24,400.00							

12	Shower rose	No.	600	2	1,200.00							
13	1200 x 1200 shower tray	No.	500	1	500.00							
14	Stainless steel sink with single bowl & drainer	No.	500	3	1,500.00							
15	Pipework to sanitary fixtures	Item	15000	2	30,000.00							
16	2400 long stainless steel urinal	No.	3000	2	6,000.00							
17	1600 long stainless steel wash trough	No.	2000	14	28,000.00							
18	2000 long stainless steel wash trough	No.	2500	1	2,500.00							
19	4500 long stainless steel urinal	No.	5800	1	5,800.00							
20	3200 long stainless steel wash trough	No.	4000	2	8,000.00							
21	1200 x 1200 shower base	No.	500	1	500.00							
22	900 long stainless steel wash trough to showers	No.	1500	2	3,000.00							
23	6300 long stainless steel urinal	No.	8000	1	8,000.00							
24	Shower rose	No.	500	10	5,000.00							
25	1200 x 1200 shower base	No.	300	10	3,000.00							
26	Hot water inline circulating pumps	No.	800	1	800.00							
27	Pipework to sanitary fixtures	Item	3500	1	3,500.00							
	Total				**249,460.00**							

SH	**Space Heating**	**Unit**	**Rate**	**Qties**	**Total Cost**	**EE Value**	**Initial EE**	**Recurrent EE**	**Descript**	**Qties**	**Life Span**	**Cyc**
1	Gas heater	No.	650	73	47,450.00							
2	Gas supply to heaters, incl. Mixing valve	Item	8000	2	16,000.00							
3	Electric fan heater with remote thermostatic ctrl	No.	600	45	27,000.00							
4	Gas supply to heaters, incl. Mixing valve	Item	7000	5	35,000.00							
5	Electric radiant strip heater	No.	300	19	5,700.00							
6	Impact resistant ceiling mounted radiant heaters	No.	850	12	10,200.00							
7	Gas supply to heaters, incl. Mixing valve	Item	6000	1	6,000.00							
	Total				**147,350.00**							

VE	Ventilation	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Mechanically assisted natural ventilation	Item	10500	6	63,000.00							
2	Builder's work in connection with mechanical service installation	Item	1100	1	1,100.00							
3	Kiln ventilation	Item	8000	1	8,000.00							
4	Welding ventilation	Item	13500	1	13,500.00							
5	Dust extraction unit	Item	25000	1	25,000.00							
6	Dark room ventilation	Item	10000	1	10,000.00							
7	LMR ventilation	Item	2500	1	2,500.00							
8	Builder's work in connection with mechanical service installation	Item	3000	1	3,000.00							
9	Builder's work in connection with mechanical service installation	Item	1000	1	1,000.00							
10	Mechanically assisted natural ventilation	Item	18500	1	18,500.00							
11	Fume cupboards	No.	15000	4	60,000.00							
12	Chemical Store ventilation	Item	6500	1	6,500.00							
13	Botany/Zoology ventilation	Item	1000	1	1,000.00							
14	Mechanically assisted natural ventilation	Item	1400	1	1,400.00							
15	Mechanically assisted natural ventilation	Item	1000	1	1,000.00							
16	Mechanical exhaust	Item	7500	1	7,500.00							
17	Mechanical ventilation to access toilet	Item	1000	1	1,000.00							
18	Builder's work in connection with mechanical service installation	Item	5500	1	5,500.00							
19	Mechanical ventilation to toilet	Item	10000	1	10,000.00							
20	Builder's work in connection with mechanical service installation	Item	1000	1	1,000.00							
21	Mechanical ventilation to toilet	Item	7000	1	7,000.00							
22	Builder's work in connection with mechanical service installation	Item	1000	1	1,000.00							
23	Mechanical ventilation to access toilet	Item	2000	1	2,000.00							
24	Mechanically assisted natural ventilation	Item	2000	2	4,000.00							
25	Mechanically assisted natural ventilation	Item	1500	3	4,500.00							
26	Mechanically assisted natural ventilation	Item	500	1	500.00							
27	Mechanically assisted natural ventilation	Item	1000	1	1,000.00							
28	Air conditioning	Item	10000	1	10,000.00							
29	Builder's work in connection with mechanical service installation	Item	2000	1	2,000.00							

30	Mechanical ventilation to staff toilet	Item	1000	1	1,000.00							
31	Builder's work in connection with mechanical service installation	Item	100	1	100.00							
	Total				**273,600.00**							

FP	**Fire Protection**	**Unit**	**Rate**	**Qties**	**Total Cost**	**EE Value**	**Initial EE**	**Recurrent EE**	**Descript**	**Qties**	**Life Span**	**Cyc**
1	Fire extinguisher	No.	350	33	11,550.00							
2	1200 x 1200 fire blanket	No.	80	28	2,240.00							
3	Fire hose reel, incl. cabinet	No.	2600	1	2,600.00							
	Total				**16,390.00**							

GS	**Gas Services**	**Unit**	**Rate**	**Qties**	**Total Cost**	**EE Value**	**Initial EE**	**Recurrent EE**	**Descript**	**Qties**	**Life Span**	**Cyc**
	Total											

LE	Electric Light and Power	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Electrical services installation	m2	85	9,061	770,185.00							
2	Electric lighting to attached covered ways	m2	30	1,709	51,270.00							
3	Electric lighting to attached stair well	m2	40	177	7,080.00							
4	CCTV installation	Item	10000	1	10,000.00							
5	Sound reinforcement system	Item	15000	1	15,000.00							
6	Electrical services installation	m2	82	388	31,816.00							
7	Security surveillance system incl. CCTV install	Item	8000	1	8,000.00							
8	Electrical services installation	Item	80	68	5,440.00							
	Total				**898,791.00**							

CM	Communications	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Communications (structured cabling)	m2	10	7,858	78,580.00							
2	Telephone installation	Item	3000	1	3,000.00							
3	Telephone installation	Item	600	1	600.00							
	Total				**82,180.00**							

SP	Site Preparation	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Clear site of vegetation	m2	1.2	42,627	51,152.40							
2	Removal of trees	Item	10000	1	10,000.00							
3	Demolish existing concrete footpath	m2	12	232	2,784.00							
4	Demolish blisters	Item	800	1	800.00							
5	Make good adjoining surface of roadway	Item	1000	1	1,000.00							
6	Excavate to reduced levels	m3	10	7,500	75,000.00							
7	Excavation in rock	m3	150	80	12,000.00							

8	Filling with selected excavated material to make up levels	m3	10	5,000	50,000.00							
9	Imported fill to make up levels	m3	35	5,110	178,850.00							
10	Level, grade & compact bldg & paving platforms	m2	2.5	23,748	59,370.00							
11	Spread & deposit unused excavated material elsewhere on site	m3	15	2,700	40,500.00							
12	Forming embankments	Item	10000	1	10,000.00							
	Total				**491,456.40**							

XR	Roads, footpaths & paved areas	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	30 asphaltic concrete, incl. sub-base & base course	m2	45	3,215	144,675.00	240.44	773,014.60	231,904.38	resurface	3215	40	1
2	Concrete kerb & gutter	m	40	563	22,520.00	4080	53,040.00					
3	Crossover	No.	3000	2	6,000.00	Incl	-	-				
4	Car parking lines	m	5	513	2,565.00	10.6	271.89	815.67	repaint	513	20	3
5	Disabled parking sign painted on road surface	No.	30	4	120.00	Incl	-	-				
6	Car parking lot nos painted on road surface	No.	5	100	500.00	Incl	-	-				
7	100 plain concrete paving & footpaths with steel trowelled finish	m2	38	4,002	152,076.00	572.3	2,290,344.60					
8	Steel angle inserts in paved areas	m	30	500	15,000.00	Incl	-	-				
9	Extra over concrete paving for colored concrete	m2	28	1,017	28,476.00	Incl	-	-				
10	Extra over concrete paving for ramps	m2	50	92	4,600.00	Incl	-	-				
11	Extra over concrete paving for stairs	m2	120	198	23,760.00	Incl	-	-				
12	300 x 100 thick conc. Mowing strip	m	20	732	14,640.00	4080	89,760.00					
13	300 wide concrete dish drain	m	35	225	7,875.00	4080	40,800.00					
14	25 asphaltic concrete on basecourse	m2	30	2,584	77,520.00	200.37	517,756.08	155,326.82	resurface	2584	40	1
15	Netball post & rings	No.	350	8	2,800.00	Incl	-	-				
16	Basketball posts, backboards & rings	No.	2400	8	19,200.00	Incl	-	-				
17	Tennis net post	No.	280	16	4,480.00	Incl	-	-				
18	Volleyball net post	No.	300	16	4,800.00	Incl	-	-				
19	Netball court line marking	No.	400	4	1,600.00	Incl	-	-				
20	Tennis court line marking	No.	400	4	1,600.00	Incl	-	-				
21	Volleyball line marking	No.	400	4	1,600.00	Incl	-	-				
22	Basketball court line marking	No.	600	4	2,400.00	Incl	-	-				

23	230 brick wall	m2	135	58	7,830.00	2036.84	118,136.72					
24	Strip footing to above	m	75	24	1,800.00	714	17,136.00					
25	Concrete footpath	m2	38	232	8,816.00	572.3	132,773.60					
	Total				**557,253.00**		**4,033,033.49**	**388,046.87**				

XN	Boundary walls, fencing & gates	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	1800 high boundary security fence equal to Smorgon "Diplomat" fence (Type 1)	m	240	218	52,320.00	107.21	42,026.32	42,026.32	replace	218	40	1
2	2100 high boundary security fence equal to Smorgon "Diplomat" fence	m	260	252	65,520.00	107.21	56,714.09	56,714.09	replace	252	40	1
3	1000 x 1800 high security gate equal to Smorgon "Diplomat"	No.	600	3	1,800.00	107.21	536.05	536.05	replace	3	40	1
4	1000 x 2100 high security gate equal to Smorgon "Diplomat"	No.	900	3	2,700.00	107.21	643.26	643.26	replace	3	40	1
5	5000 wide x 1800 high double-leafed security gate equal to Smorgon "Diplomat"	No.	2500	2	5,000.00	107.21	1,929.78	1,929.78	replace	2	40	1
6	2400 high galv. M.s. weld mesh infilled fence	m	45	140	6,300.00	107.21	36,022.56	36,022.56	replace	140	40	1
7	2000 x 2400 high galv. M.s. framed & mesh infilled gate	No.	500	2	1,000.00	107.21	1,072.10	1,072.10	replace	2	40	1
8	900 high roll-top fence around protected trees	m	36	77	2,772.00	107.21	7,504.70	7,504.70	replace	77	40	1
9	3000 x 300 deep r.c. footing, incl. 300 x 600 deep beam to r.c. retaining wall	m	315	175	55,125.00	6563.7	1,148,647.50					
10	200 r.c. retaining wall	m2	250	370	92,500.00	1648.53	609,956.10					
11	300 r.c. retaining wall	m2	270	167	45,090.00	2472.8	412,957.60					
12	Concrete retaining walls for coloring pigment	m2	20	537	10,740.00	1648.53	885,260.61					
13	50 x 50 triangular timber fillet to create pattern on exposed face of concrete	m	8	502	4,016.00	Incl	-					
14	200 reinforced core-filled concrete block wall	m2	155	125	19,375.00	1089	136,125.00					
15	Cement render concrete block retaining wall incl.painting	m2	30	125	3,750.00	51.22	6,402.50	7,950.00	repaint	125	10	6
16	Agricultural pipe behind retaining walls	m	20	211	4,220.00	Incl	-					
17	600 x 400 r.c. strip footing to brick walls	m	90	84	7,560.00	1142.4	95,961.60					
18	230 faced brick walls	m2	135	91	12,285.00	2036.84	185,352.44					

19	Galv.m.s. pipe hand rails to stairs, incl.painting	m	100	111	11,100.00	59.28	6,580.08	13,160.16	replace	111	30	2
				111	Incl	11.85	206.51	2,065.10	repaint	111	6	10
20	Galv.m.s. pipe hand rails to ramps, incl.painting	m	100	51	5,100.00	59.28	3,023.28	6,046.56	replace	51	30	2
				51	Incl	11.85	94.88	948.83	repaint	51	6	10
21	900 high galv.m.s. pipe balustrade to stairs, incl.painting	m	200	56	11,200.00	695.53	38,949.68	77,899.36	replace	56	30	2
				56	Incl	11.85	597.24	5,972.40	repaint	56	6	10
22	900 high galv.m.s. pipe balustrade to ramps, incl.painting	m	200	51	10,200.00	695.53	35,472.03	70,944.06	replace	51	30	2
				51	Incl	11.85	543.92	5,439.15	repaint	51	6	10
23	900 high balustrade with perforated metal infill to ramps	m	350	57	19,950.00	695.53	39,645.21	79,290.42	replace	57	30	2
				57	Incl	11.85	607.91	6,079.05	repaint	57	6	10
24	230 faced brick screen wall	m2	135	51	6,885.00	2036.84	103,878.84					
25	Signage & letter box on screen wall	Item	3000	1	3,000.00	Incl	-		replace	1	30	2
	Total				**459,508.00**		**3,856,711.78**	**422,243.95**				

XB	Outbuildings & covered ways	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	outdoor learning spaces	m2	530	270	143,100.00	1294.48	349,509.60	127,051.20	replace	270	30	2
2	detached coverways	m2	601.6	1,493	898,188.80	1294.48	1,932,658.64	702,546.08	replace	1493	30	2
	Total				**1,041,288.80**		**2,282,168.24**	**829,597.28**				

XL	Landscaping & Improvements	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Excavate to desired subgrade levels	m3	30	681	20,430.00							
2	Cultivate subgrade	m2	1	18,667	18,667.00							
3	Imported topsoil mixture 200mm deep	m3	26	379	9,854.00							
4	Organic mulch 50mm deep	m2	4	1,894	7,576.00							
5	Cells	No.	2	17,749	35,498.00							

6	150mm tree	No.	8.5	1,923	16,345.50							
7	75mm tree	No.	15	843	12,645.00							
8	35L tree in planted areas	No.	60	19	1,140.00							
9	35L tree in turfed areas	No.	75	90	6,750.00							
10	5L tree	No.	5	171	855.00							
11	Steel edging	m	25	128	3,200.00							
12	Subsoil drainage	m	35	300	10,500.00							
13	Spray existing grass surface	m2	0.3	7,850	2,355.00							
14	Site topsoil 75mm deep	m3	26	393	10,218.00							
15	Seed understorey	m2	0.85	7,850	6,672.50							
16	Spade edging	m	4	391	1,564.00							
17	Site topsoil 75mm deep	m3	15	839	12,585.00							
18	Soft-leafed buffalo turfing	m2	5	24,389	121,945.00							
19	Mulch around Angophora floribunda	m2	6	412	2,472.00							
20	Maintenance - 10%	Item	26319	1	26,319.00							
21	Aluminium flagpoles	No.	1200	2	2,400.00							
22	Aluminium seats	m	150	272	40,800.00							
	Total				**370,791.00**							

XK	**External Stormwater Drainage**	**Unit**	**Rate**	**Qties**	**Total Cost**	**EE Value**	**Initial EE**	**Recurrent EE**	**Descript**	**Qties**	**Life Span**	**Cyc**
1	150 dia. UPVC stormwater drain	m	75	550	41,250.00							
2	225 dia. UPVC stormwater drain	m	105	1,060	111,300.00							
3	300 dia. FRC stormwater drain	m	120	280	33,600.00							
4	375 dia. FRC stormwater drain	m	145	60	8,700.00							
5	400 dia. FRC stormwater drain	m	180	110	19,800.00							
6	Stormwater pits	No.	1500	54	81,000.00							
7	Excavating trenches in rock	m3	150	50	7,500.00							
	Total				**303,150.00**							

XD	External Sewer Drainage	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	100 dia. sewer drain	m	65	800	52,000.00							
2	150 dia. sewer drain	m	75	170	12,750.00							
3	225 dia. sewer drain	m	105	120	12,600.00							
4	Manhole	No.	2500	10	25,000.00							
5	Dilution pit	No.	5500	2	11,000.00							
6	Excavating trenches in rock	m3	150	30	4,500.00							
	remove blockage in pit											
	Total				**117,850.00**							

XW	External Water Supply	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	20 dia. copper pipes	m	30	300	9,000.00							
2	25 dia. copper pipes	m	35	1,120	39,200.00							
3	32 dia. copper pipes	m	40	30	1,200.00							
4	40 dia. copper pipes	m	45	60	2,700.00							
5	50 dia. copper pipes	m	60	90	5,400.00							
6	Blackflow prevention device	No.	2200	1	2,200.00							
7	Sprinkler heads, valves, etc	No.	1500	4	6,000.00							
	Total				**65,700.00**							

XG	External Gas	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	20 dia. copper gas pipe	m	40	200	8,000.00							
2	25 dia. copper gas pipe	m	45	80	3,600.00							
3	32 dia. copper gas pipe	m	48	150	7,200.00							
4	Gas meter & regulator	No.	1200	1	1,200.00							
	Total				**20,000.00**							

XF	External Fire Protection	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	100 dia.ct lined ductile iron fire hydrant pipe	m	110	300	33,000.00							
2	150 dia.ct lined ductile iron fire hydrant pipe	m	140	120	16,800.00							
3	Hydrant landing valves	m	650	8	5,200.00							
	Total				**55,000.00**							

XE	External Electrical Light and Power	Unit	Rate	Qties	Total Cost	EE Value	Initial EE	Recurrent EE	Descript	Qties	Life Span	Cyc
1	Consumer & submains	Item	150000	1	150,000.00							
2	Communications cabling	Item	80000	1	80,000.00							
3	Electronic security	Item	60000	1	60,000.00							
4	External lighting	Item	90000	1	90,000.00							
5	Main switchboard	Item	30000	1	30,000.00							
6	External control cabling	Item	20000	1	20,000.00							
7	AVMRS	Item	35000	1	35,000.00							
8	PABX	Item	30000	1	30,000.00							
	Total				**495,000.00**							

APPENDIX F

Testing assumptions of multiple regression analysis

The proper use of multiple regression analysis requires that assumptions of regression are tested.

Multicollinearity between independent variables

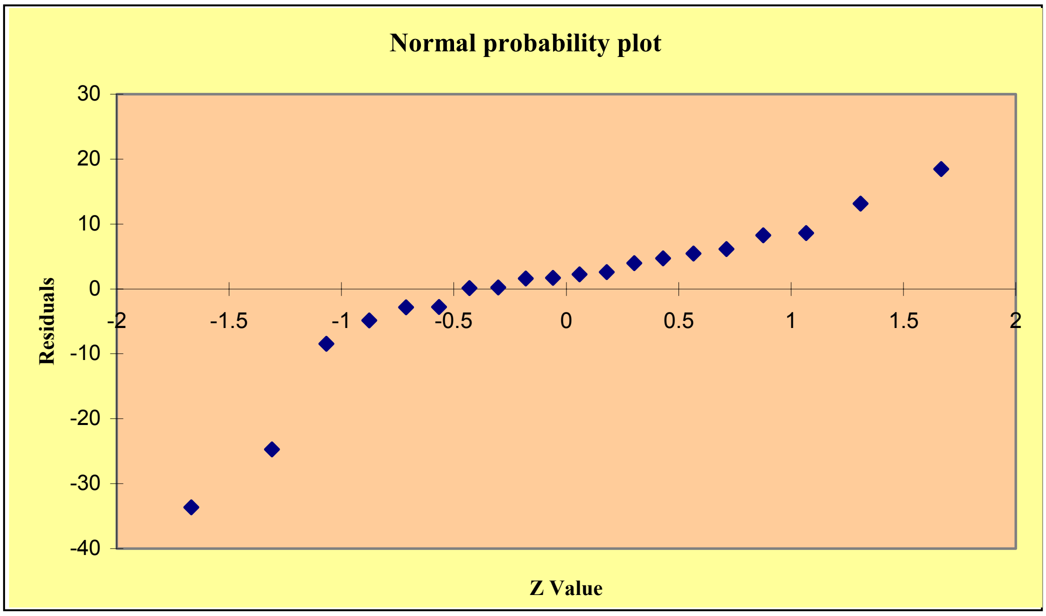
In order to test the assumption that there is no multicollearity between independent variables, variance inflation factors (VIF) were calculated and the results were shown in the following table:

Regression Statistics	**R/m^2 and all other x**	**B/m^2 and all other x**	**\$/m^2 and all other x**
Multiple R	0.763	0.926	0.891
R Square	0.582	0.858	0.794
Adjusted R Square	0.533	0.842	0.770
Standard Error	428.745	0.011	0.024
Observations	20	20	20
VIF	2.394	7.053	4.853

The VIF for the three independent variables of 2.394, 7.053 and 4.853 are all less than 10. It implies that there is no reason to suspect any multicollearity between independent variables.

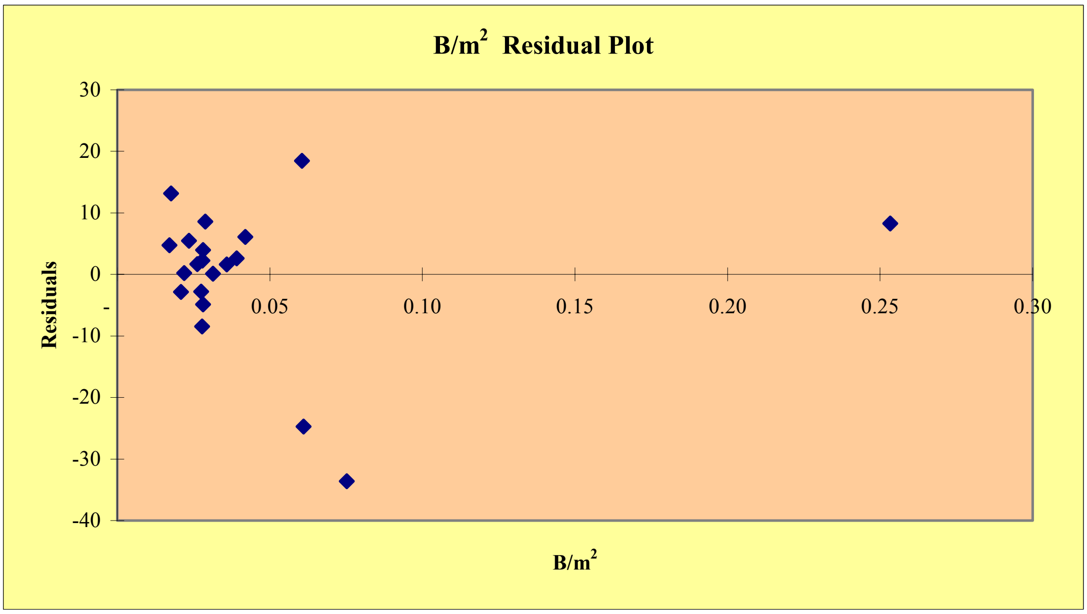
Normality of error terms

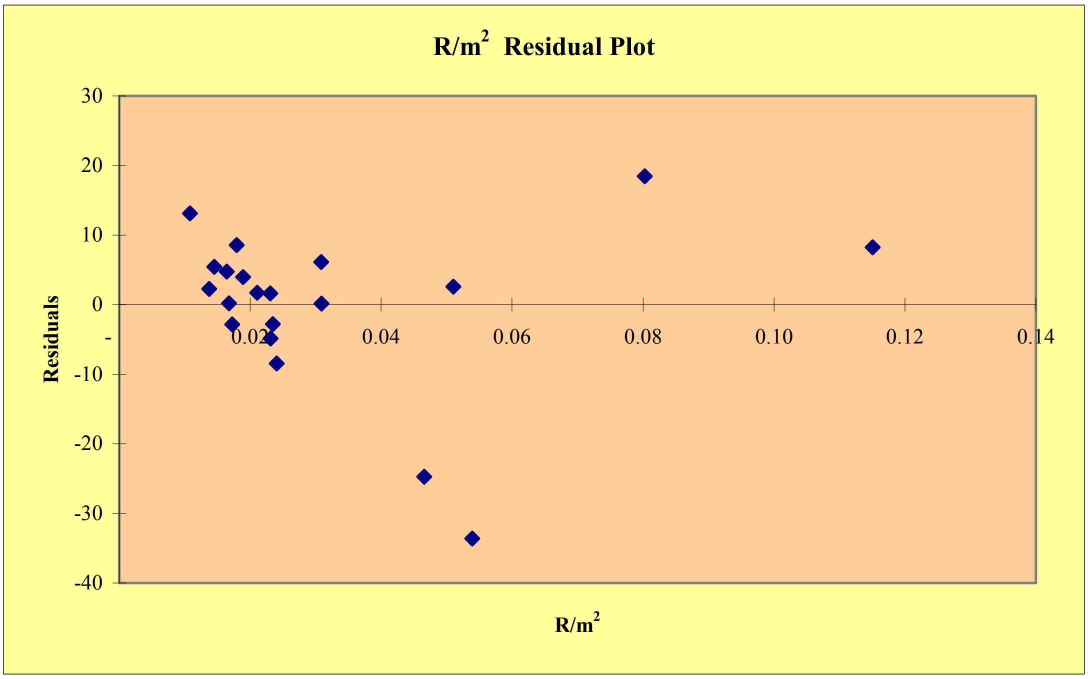
Normal probability plot was used to check the assumption of normality with mean equal to zero. The graphs shows that the points fall reasonably close to a straight line indicating that the normality assumption is most likely satisfied.

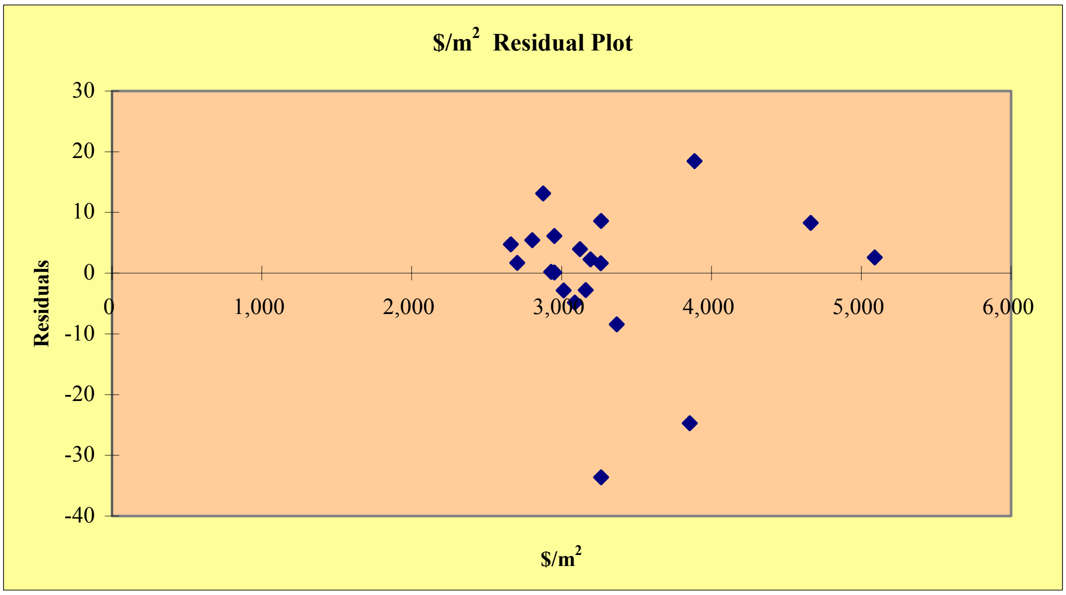


Homoscedasticity of error terms

The assumption of homoscedasticity can be evaluated from a plot of the residuals with X_i. The following graphs of residual plots do not show any trends and there is no apparent violation in the assumption of equal variance at each level of X.







Serial correlation between the error terms

The independence of the error terms was evaluated using Durbin-Watson statistic. The following table shows the computation of the Durbin-Watson statistic:

Sum of Squared Difference of Residuals	5029.197
Sum of Squared Residuals	2631.553
Durbin-Watson Statistic (*D*)	1.911

The lower and upper critical value of Durbin-Watson statistic at a 5% level of significance with sample size of 20 and three independent variable are $d_L = 1.00$ and $d_U = 1.68$. Since $D = 1.911 > d_U$, it is concluded that there is no evidence of serial correlation between the error terms.