SUSTAINABLE CONSTRUCTION – THE ROLE OF ENVIRONMENTAL ASSESSMENT TOOLS

Grace K C Ding
School of the Built Environment
Faculty of Design, Architecture & Building
University of Technology, Sydney
P. O. Box 123, Broadway, N.S.W. 2007, Australia
Email: grace.ding@uts.edu.au
Telephone: +61 2 9514 8659
Fax: +61 2 9514 8051

ABSTRACT

Construction has been accused of causing environmental problems ranging from excessive consumption of global resources both in terms of construction and building operation to the pollution of the surrounding environment, and research on green building design and using building materials to minimise environmental impact is already 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 than at the design stage of a project 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. The main objectives of this paper are to examine the development, role and limitations of current environmental building assessment methods in ascertaining building sustainability used in different countries which leads to discuss the concept of developing a. sustainability model for project appraisal based on a multi-dimensional approach, that will allow alternatives to be ranked is discussed in detail in the paper.

Keywords
Sustainable development, sustainable construction, environmental assessment, building performance

SUSTAINABLE CONSTRUCTION – THE ROLE OF ENVIRONMENTAL ASSESSMENT TOOLS

1. Introduction

There is concern about how to improve construction practices in order to minimise their detrimental affects on the natural environment (Cole, 1999; 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, 1998; Crawley & Aho, 1999; Rees, 1999). 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 (Cole, 1998; Cooper, 1999; Holmes & Hudson, 2000).

According to Cole (1998), 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. Using a single method to assess a building's environmental performance and to satisfy all needs of users is no easy task. Therefore, an ideal environmental building assessment will include all the requirements of the different parties involved in the development.

The objective of this paper is to overview and analyse the current environmental building assessment methods used in different countries in terms of their characteristics and limitations in assessing building sustainability. Some of these assessment methods are single-dimensional when the multifaceted building sustainability needs a multi-dimensional approach. This paper presents the development of a sustainability index using a multi-criteria approach in assessing and ranking projects. It concludes by setting out a conceptual framework of a multi-criteria model for appraising projects at the feasibility stage to include environmental issues in the decision making process.

2. An overview of environmental building assessment methods

Building designers and occupants have long been concerned about building performance (Cooper, 1999; Kohler, 1999; Finnveden & Moberg, 2005). Considerable work has gone into developing systems to measure a building's environmental performance over its life. They have been developed to evaluate how successful any development is with regards to balancing energy, environment and ecology, taking into account both the social and technology aspects of projects (Clements-Croome, 2004).

Separate indicators, or benchmarks based on a single criterion, have been developed to monitor specific aspects of environmental building performance such as air quality and indoor comfort. However, these benchmarks serve to emphasise the need for a comprehensive assessment tool to provide a thorough evaluation of building performance against a broad spectrum of environmental criteria. The Building Research Establishment Environmental Assessment Method (BREEAM) in 1990 was the first such comprehensive building performance assessment method.

BREEAM was the first environmental building assessment method and it 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 assessment can be carried out as early as at the initial stages of a project. The results of the investigation can be 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 made an impact worldwide, with

Canada, Australia, Hong Kong and other countries using the BREEAM methodology in developing their own environmental building assessment methods.

Following the launch of BREEAM in the UK many other assessment methods have been developed around the world to undertake environmental building assessment. Table 1 summarised the old and new environmental building assessment methods used in different countries. Most of the environmental building assessment tools cover the building level and based on some form of life cycle assessment database (Seo *et al*., 2006). Tools are basically in two categories: assessment and rating tools. Assessment tools provide quantitative performance indicators for design alternatives whilst rating tools determine the performance level of a building in stars.

Table 1 – Summary of environmental building performance assessment methods

Assessment Methods		**Origin**	**Characteristics**	**References**
ABGR	Australian Building Greenhouse Rating	Department of Commence, NSW, 2005	- a performance based accredited assessment tool - using star rating on a scale of one to five star - provide a national approach to benchmarking greenhouse performance of buildings and tenancies - based on 12 months of energy consumption	Seo *et al* 2006
AccuRate		CSIRO, 2006	- the new version of NatHERs - addresses problems associated with rating homes in tropical and sub-tropical environment through the inclusion of a ventilation model - it includes an extensive database of materials - allows users to modify construction elements	Seo *et al* 2006
BASIX	Building Sustainability Index	Department of Infrastructure, Planning and Natural Resources, 2004	- web-based planning tool for residential development - to assess the water and energy efficiency of new residential developments - NatHERS and AccuRate are simulation packages used to assess energy performance - it is mandatory for all new residential development and a BASIX certificate is required for development approval	Seo *et al* 2006
BEPAC	Building Environmental Performance Assessment Criteria	Canada, 1993	- developed by the University of British Columbia - similar to BREEAM but a more detailed & comprehensive assessment method - limited to new & existing office - uses a point system for rating - a voluntary tool	Cole 1994 &1998 Crawley & Aho 1999
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency	Japan, 2004	- a co-operative project between industry and government - applicable in accordance with the stages of a development in pre-design, new construction, existing building and renovation - it is based on the concept of closed ecosystems to determine the environmental capacities - consideration for regional character	Cole 2005 Yau *et al* 2006 Seo *et al* 2006
CEPAS	Comprehensive Environmental Performance Assessment Scheme	HK, 2001	- developed by the Building Department - for all types of existing and new buildings - to serve as a unified yardstick for a common, comprehensive assessment scheme for buildings - 8 performance categories - employing an additive/weighting approach	Cole 2005

CPA	Comprehensive Project Evaluation	UK, 2001	- developed by the Royal Institution of Chartered Surveyors and the Environment Agency - different from a building performance method as it is used to assess projects during the development process using a combination of financial & economic approach - a multi-criteria analysis approach to assess environmental and social impacts of a project - a checklist type evaluation framework that requires an independent assessor to undertake the assessment - a voluntary tool	Woolley *et al* 1999 RICS 2001
DQI	Design Quality Indicator	UK	- supported by the UK Construction Industry Council - a toolkit used throughout the development process to capture the opinions of all stakeholders - aims at improving the design of buildings by providing feedback & capturing perceptions of design quality embodied in buildings - assess buildings in three main categories: functionality, build quality & impact - aim at assisting clients in defining their aspirations to which project's success will be measured against	Clements-Croome 2004 Cole 2005
Eco-Quantum		Netherlands	- the only method that is explicitly & comprehensively based on life cycle assessment - assess the environmental burden of a complete building on the basis of LCA - easy to use & has extensive database of the most commonly used materials & products - not a comprehensive assessment method - only applicable to single residential buildings	Yau *et al* 2006 Seo *et al* 2006
EMGB	Evaluation Manual for Green Buildings	Taiwan, 1998	- operated and implemented by the Ministry of Interior - consists of 9 environmental criteria - a single tool for all types of buildings - not able to reflect regional differences - only assess the quantifiable criteria and non-quantifiable issues are omitted - assess the least number of performance criteria	Cheung 2004 Yau *et al* 2006 ABRI 2003
EPGB	Environmental Performance Guide for Building	Department of Public Works & Services, NSW	- assess buildings using a framework of environmental performance into 5 categories - useful to consider resource consumption & loadings - buildings are rated and a single indicator for the total performance	Seo *et al* 2006
GBTool	Green Building Challenge	International, 1995	- the most comprehensive framework - international collaboration of over 20 countries - absolute performance indicators to complement the relative scores - more than 90 individual performance assessment - 4 levels of weighting - a comprehensive evaluation method that can be used by different regions with the adjustment of regional variations	Cole 1998 Larsson 1998 Kohler 1999 Larsson & Cole 2001 Rohracher 2001 Todd *et al* 2001 Yau *et al* 2006 Seo *et al* 2006
GHEM	Green Home Evaluation Manual	China, 2001	- introduced by the Science & Technology Development Promoting Centre & Ministry of Construction - the first environmental standards and design guidelines related to performance standards - only relates to residential projects - simple rating that without explicit weighting system to address resources allocation and indoor environmental quality - no clear definition for the degree of severeness for unsatisfied pre-requisite requirements	Liu *et al* 2005 Yau *et al* 2006
GreenStar		Green Building Council	- Australia's first comprehensive method for evaluating environmental building performance - for commercial buildings only	Seo *et al* 2006

			- rating system on a scale from 0 to 6 stars	
HKBEAM	Hong Kong Building Environmental Assessment Method	Hong Kong, 1996	- has separate assessment methods for new & existing office buildings - similar to BREEAM - it has been criticised as assessing the quantifiable criteria but the non-quantifiable social and environmental issues have been deliberately ignored - assessing new building 'as built' rather than 'as designed' - assessment process not transparent - assessment categorised under the global, local & indoor scales - emphasis on life-cycle impacts of environmental issues - assessing building performance in grades ranging from fair to excellent	Davies 2001 Todd *et al* 2001 Lee *et al*. 2002 Yau *et al* 2006
LEED	Leadership in Energy & Environmental Design	USA, 2000	- developed by the US Green Building Council - a certification process developed to create an industrial standard - self-assessing system awards rating of certified, silver, gold & platinum - use simple checklist format to rate building performance - for new and existing commercial, institutional, high-rise residential & major renovation - comprises 5 areas of sustainability - a voluntary tool	Crawley & Aho 1999 Larsson 1999 Yau *et al*. 2006 Seo *et al*. 2006
NABERS	National Australian Building Environmental Rating System	Department of Environment and Heritage, 2001	- a performance-based rating system that measures an existing building's overall environmental performance during operation - for existing commercial buildings and houses - self assessment & accredited ratings score out of 10 with 10 the best - a voluntary tool	Yau *et al*. 2006 Seo *et al*. 2006
NatHERS		CSIRO	- computer-based house energy rating system - to give houses an energy efficiency rating from 0 to 5 stars - 0 star being inefficient whilst 5 star indicates high level of energy efficiency - considers detail design, construction, orientation, insulation, etc. - links to locational climate information	Seo *et al* 2006
SBAT	Sustainable Building Assessment Tool	South Africa	- performance criteria that acknowledge social and economic issues - divide15 performance areas into 5 performance criteria - integral part of building process based on the typical life cycle of a building	Gilberd 2005 Cole 2005
SPeAR	Sustainable Project Appraisal Routine		- a project assessment methodology within Ove Arup's consulting projects - to enable a rapid review of project sustainability - use a graphical format to present sustainable design - to identify opportunities to optimise performance - rated on a scale of +3 to -3 - in 4 main elements: environment, social, economic & natural resources	Clement-Croome 2004 Cole 2005 Yau *et al* 2006

EMGB, NABERS and BASIX are operated by the government while the others have a private, voluntary and contractual origin and are guidance type only. They essentially aim at showing those involved in the building process the potential for improvement. 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, more comprehensive building assessment methods are 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 subsequent construction work on site. The primary role of an environmental building assessment method is to provide a comprehensive assessment of the environmental characteristics of a building (Cole, 1999) using a common and verifiable set of criteria and targets for building owners and designers to achieve higher environmental standards. It also enhances the environmental awareness of building practices and lays down the fundamental direction for the building industry to move towards environmental protection and achieving the goal of sustainability. It provides a way of structuring environmental information, an objective assessment of building performance, and a measure of progress towards sustainability.

3. Critique on the environmental building assessment methods

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

3.1 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 can be assessed and incorporated at design development. Environmental issues can be incorporated 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, 1999).

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 is usually carried out when the design of the project is almost finalised (Crawley & Aho, 1999; Soebarto & Williamson, 2001). Therefore, the use of environmental assessment methods as design guidelines cannot be sufficient. Consequently, in order for environmental building assessment methods to be useful as a design tool, they must be introduced as early as possible to allow for early collaboration between the design and assessment teams. They also need to be reconfigured so that they do not rely on detailed design information before that has been generated by the designer.

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, replacing an existing ventilation system by installing more windows to allow for natural ventilation and daylight may be impracticable, difficult or expensive to facilitate. The environmental assessment methods have predominantly been applied to new construction, but refurbishment and maintenance of existing buildings are also an important part of a sustainable future.

3.2 Optimum project selection process

Environmental building assessment methods are less useful for selecting the optimum project options 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 while different development options or locations of development are decided at the feasibility stage (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. Environmental issues should be considered as early as possible in the selection phase in order to minimise environmental damage, maximise the return to natural resources and reduce remedial costs. According to Crookes and de Wit (2002), environmental assessment is most efficient during the identification and preparation stages of a proposed project. 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. Although, by this stage it may be too late to consider many environmental issues.

3.3 Financial aspects

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 aspects 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. As in the revised GBC model includes economic issues in the evaluation framework (Larsson, 1999). This is particularly important at the feasibility stage where alternative options for a development are assessed. Both environmental and financial aspects must be considered when assessing environmental concerns.

3.4 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, BEPAC and GreenStar, BASIX, AccuRate 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, for instance, using geographically adapted database (Reijnders & Roekel, 1999).

The Green Building Challenge (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 to allow for regional variations in the evaluation. 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.

3.5 Complexity

Environmental issues are broad and difficult to capture. Consequently, environmental building assessment methods tend to be too comprehensive with respect to incorporating environmental criteria as well as inclusive of other factors such as financial and social aspects. For example, the BEPAC comprises 30 criteria and GBTool comprises 120 criteria (Cole, 1999, Larsson, 1999). The comprehensive 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 is one of the challenges in developing an effective and efficient environmental building assessment tool.

3.6 Evaluation of quantitative and qualitative data

The assessment of environmental performance of buildings includes both quantitative and qualitative performance criteria. Quantitative criteria comprise annual energy use, water consumption, greenhouse gas emissions etc., whereas qualitative criteria include impact on ecological value of the site, impact on local wind patterns, 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. Environmental issues can only be evaluated on a 'feature-specific' basis where points are awarded for the presence or absence of desirable features (Cole, 1998). The use of market-based approaches 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.

3.7 Weighting

Weighting is inherent to the systems and when not explicitly, all criteria are given equal weights (Todd *et al*., 2001). According to Lee *et al*. (2002) weighting is the heart of all assessment schemes since it will dominate the overall performance score of the building being assessed. However, there is at present neither a consensus-based approach nor a satisfactory method to guide the assignment of weightings. 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, it may be manipulated the results to improve the overall scores in order to satisfy specific purposes (Larsson, 1999; Todd *et al*., 2001). In CASBEE the weighting coefficients play an important part in the assessment process. The weighting coefficients were determined by questionnaire survey to obtain opinions from the users of the system such as designers, building owners and operators, and related officials. The weighting coefficients may be modified to suit local conditions such as climate or to reflect the prioritised policies (IBEC, 2004). The weighting coefficients may need to be updated regularly which can be a time consuming activity.

Cole (1998) states that the main concern is the absence of an agreed theoretical and non-subjective basis for deriving weighting factors. There is not enough 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. It demands 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, the weighting of the criteria should be derived on a project-by-project basis and reflect the objective of a development. The absence of any readily used methodological framework has hampered existing environmental assessment methods in achieving sustainability goals.

3.8 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 (Forsberg & von Malmborg, 2004). 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. 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 (Nijkamp *et al*., 1990). Decision-makers often employ 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. Single criterion evaluation techniques have dominated project appraisal since World War II and they were mainly concerned with economic efficiency (Nijkamp *et al*., 1990; Tisdell, 1993; van Pelt, 1994; 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 (Tisdell, 1993; 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; 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 the usefulness of CBA.

Other single criterion evaluation techniques focus on energy efficiency such as energy rating. Energy analysis methods focus on the inputs in physical measures and they may be used as evaluation techniques for different types of objects (Finnveden & Moberg, 2005). 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; Pullen, 2000; 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 the need 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 by development, and the importance of distributional issues in economic development (Nijkamp *et al*., 1990) has fostered this new perspective. Thus single dimensional appraisal techniques are increasingly controversial (Nijkamp *et al*., 1990; van Pelt, 1994; 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 (Powell, 1996; Popp *et al*., 2001). Multi-criteria analysis (MCA) provides the required methodology to evaluate multiple criteria and objectives in project appraisal (Nijkamp *et al*., 1990; Janssen, 1992; van Pelt, 1994).

The multi-criteria 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, minimise the negative environmental impacts resulting from its activities, and 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. 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.

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 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 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).

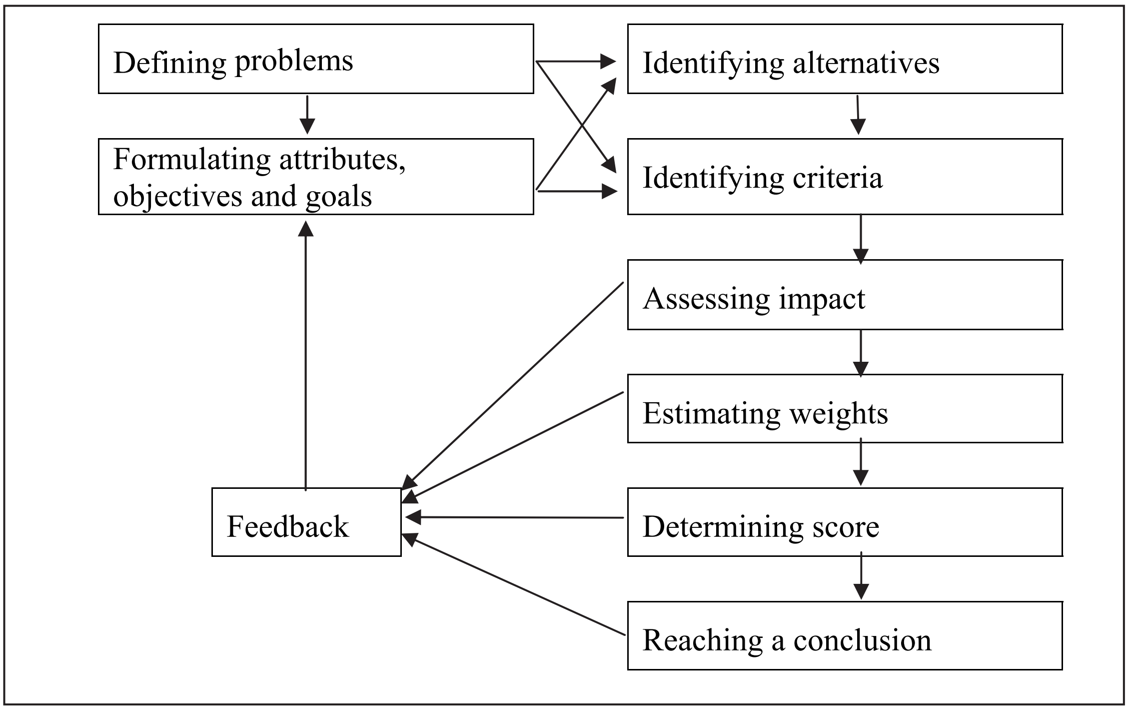
Giarni and Stahel developed another concept, the 'service economy' which seeks more cyclical industrial and economic processes, rather than the current linear process of production, consumption and waste (Bentivegna *et al*., 2002). Reusing, refurbishing and recycling materials and components form a 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 environmental building assessment is multi-dimensional and the aspects, as described in the PICABUE and others, have summarised the essential components to be assessed in a development. The single dimensional approach and the credit award system of the existing environmental building assessment methods are insufficient to evaluate the complex nature of sustainability in buildings. This is particularly seriously as existing assessment approaches mainly evaluate buildings during the pre-design stage and it will be a more effective way of considering environmental issues as early as the conceptual design phase of a building.

5. A way forward - A multiple dimensional model of project appraisal

Given the previous discussion of a trend towards multiple criteria in environmental project appraisal, it is necessary to develop a model to facilitate multiple dimensional assessment of criteria to aid decision-making. 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, 1994; Hobbs & Meier, 2000; RICS, 2001). Figure.1 shows the model adopted in the research of a multi-dimensional decision model. 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, 2002). Each stage can supply additional information and 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, 2002).

Figure 1 Multiple Dimensional Decision Model of Project Appraisal



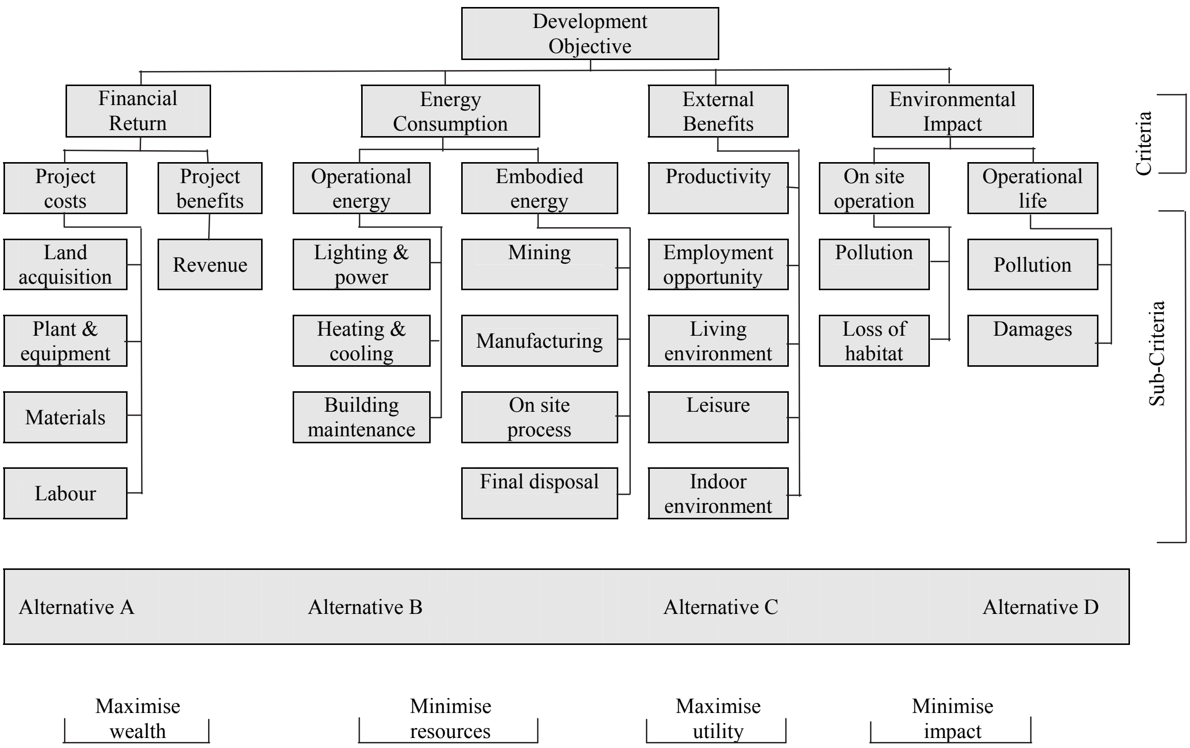
Source: Adopted from Nijkamp *et al*., 1990

Based on the principle of multiple dimensional decision model Ding and Langston (2002) developed a multi-dimensional model for the measurement of sustainability that has the advantage of relative simplicity and the inclusion of CBA calculation. The model determines a sustainability index, and can be used not only to compare options for a given problem but also to benchmark projects against each other. The model applies to both new design and refurbishment situations, and can be used to measure facility performance.

The sustainability index has four main criteria (see Figure 2)

- Maximize wealth. Profitability is considered part of the sustainability equation. The objective is to maximise investment return. Investment return is measured as benefit-cost ratio (BCR) and therefore includes all aspects of maintenance and durability.
- Maximize utility. External benefits, including social benefit, are another clear imperative. Designers, constructors and users all want to maximize utility. Utility can relate to wider community goals. A weighted score can be used to measure utility.
- Minimize 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 minimized as much as possible. Energy usage can be measured as annualised Gj/m^2.
- Minimize impact. Loss of habitat encompasses all environmental and heritage issues. The aim is to minimize impact. Assessment scorecards are a useful method to quantify impact. Impact can be expressed as a risk probability factor.

Figure 2 – The Sustainability Index concept



These criteria can be assembled together to illustrate the performance of new projects and changes to existing facilities using a multi-criteria approach (Ding, 2005). This investigation is a design tool to predict the extent to which sustainability ideals are realised, but is also an aid in ongoing facility management. Criteria can be individually weighted to reflect particular client motives.

When all four criteria are combined, an indexing algorithm is created that can rank 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.

The sustainability index (SI) model can be expressed as follows:

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

$$e_{ji} = f\{ BCR, EC, EB, EI \} \tag{2}$$

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.

A sustainability index for environmental building assessment 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 sustainability index includes the quantification of both objective and subjective measures that gives a full life-cycle analysis of buildings. The model 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 and 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, HK-BEAM, LEED and GBTool 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. The sustainability index can assist in decision-making for a project from as early as the feasibility stage. 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 impact on 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.

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 (1999) 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 (1999) 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.

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 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.

6. Conclusion

Ecologically sustainable development is a major concern, and embodies both environmental protection and management. The concept of sustainable development is broad. Generally, sustainable development concerns attitudes and judgment to help insure long-term ecological, social and economic growth in society. Applied to project development, it involves the efficient allocation of resources, minimum energy consumption, low embodied energy intensity in building materials, reuse and recycling, and other mechanisms to achieve effective and efficient short- and long-term use of natural resources. Current environment assessment methods do not adequately and readily consider environmental effects in a single tool and therefore do not assist in the overall assessment of sustainable development.

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 paper 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 a weighting system are still major obstacles to the acceptance of environmental building assessment methods. In the sustainability index stakeholders will have the opportunity to participate in identifying the criteria and sub-criteria that concern them most in the evaluate framework. Additionally, stakeholders will also be participated to derive weights to reflect the level of importance of criteria and sub-criteria during the feasibility stage of a project.

Building developments involve complex decisions and the increased significance of environmental issues has further complicated the situation. Society is not just concerned with economic growth and development, but also the long-term effects 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 to aid decision-making is no longer adequate. A much more sophisticated model needs to be used 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. Use of a sustainability index will greatly simplify the measurement of sustainable development, and thereby make a positive contribution to the identification of optimum design solutions and facility operation.

References

Abelson, P.W., 1996. Project appraisal and valuation of the environment: general principles and six case studies in developing countries. MacMillan, New York.

ABRI, 2003. Evaluation manual for green building in Taiwan, Ministry of Interior, 3rd Edition. Architecture & Building Research Institute, Taiwan.

Bentivegna, V., Curwell, S., Deakin, M., Lombardi, P., Mitchell, G., Nijkamp, P., 2002. A vision and methodology for integrated sustainable urban development: BEQUEST. Building Research and Information, 30 (2), 83–94.

Burke, R., 1999. Project management planning and control techniques. John Wiley &.Sons, Chichester.

IBEC, 2004. CASBEE for new construction. Institute for Building Environment and Energy Conservation, Japan.

Chambers, N., Simmons, C., Wackernagel, M., 2000. Sharing nature's: ecological footprints as an indicator of sustainability. Earthscan, London.

Cheng, C.L., 2004. Water environment issues and sustainable strategy in Taiwan. Proceedings of The International Workshop, Tokyo, September.

Clements-Croome, D., 2004. Intelligent buildings design, management and operation. Thomas Telford, London.

Cole, R.J., 1994. Assessing the environmental performance of office buildings. Proceedings of CIB Congress, Watford, UK.

Cole, R.J., 1998. Emerging trends in building environmental assessment methods. Building Research and Information, 26 (1), 3–16.

Cole, R.J., 1999. Building environmental assessment methods: clarifying intentions. Building Research and Information, 27 (4/5), 230–246.

Cole, R.J., 2005. Building environmental assessment methods: redefining intentions and roles. Building Research & Information, 35(5), 455-467.

Cooper, I., 1999. Which focus for building assessment methods–environmental performance or sustainability? Building Research and Information, 27 (4/5), 321–331.

Cooper, I., 2002. Transgressing discipline boundaries: is BEQUEST an example of the new production of knowledge? Building Research and Information, 30 (2), 116–129.

Crawley, D. & Aho, I., 1999. Building environmental assessment methods: application and development trends. Building Research and Information, 27 (4/5), 300–308.

Crookes, D. & de Wit, M., 2002. Environmental economic valuation and its application in environmental assessment: an evaluation of the status quo with reference to South Africa. Impact Assessment and Project Appraisal, June, 127–134.

Curwell, S., 1996. Specifying for greener buildings. The Architects' Journal, January, 38–40.

Curwell S. & Cooper, I., 1998. The implications of urban sustainability. Building Research and Information, 26 (1), 17–28.

Curwell, S., Hamilton, A. & Cooper, I., 1998. The BEQUEST network: towards sustainable urban development. Building Research and Information, 26 (1), 56–65.

Curwell, S., Yates, A., Howard, N., Bordass, B. & Doggart, J., 1999. The Green Building Challenge in the UK. Building Research and Information, 27 (4/5), 286–293.

Davies, H., 2001. Environmental benchmarking of Hong Kong buildings. Structural Survey, 19 (1), 38–45.

Ding, G.K.C., 2002. Multi-criteria analysis, in: Langston, C. & Lauge-Kristensen, R. (Eds.), Strategic management of built facilities. Butterworth Heinemann, London, 196–207.

Ding, G.K.C., 2005. Developing a multicriteria approach for the measurement of sustainable performance. Building Research & Information, 33 (1), 3-16.

Ding, G.K.C. & Langston, C., 2002. A methodology for assessing the sustainability of construction projects and facilities. Proceedings of Environmental & Economic Sustainability–Cost Engineering Down Under, ICEC Melbourne 2002, Melbourne, April.

Elkington, J., 1997. Cannibals with forks: the triple bottom line of 21st century business. Capstone, Oxford.

Finnveden, G. & Moberg, A., 2005. Environmental systems analysis tools–An overview. Journal of Cleaner Production, 13, 1165-1193

Forsberg, A. & von Malmborg, F., 2004. Tools for environmental assessment of the built environment. Building and Environment, 30, 223–228.

Gibberd, J., 2005. Assessing sustainable buildings in developing countries – the sustainable building assessment tool (SBAT) and the sustainable building lifecycle (SBL). Proceedings The 2005 World Sustainable Building Conference, Tokyo, 27-29 September 2005, 1605-1612.

Hanley, N. & Spash, C.L., 1993. Cost benefit analysis and the environment, Edward Elgar, Hants.

Herendeen, R.A., 1998. Ecological numeracy: quantitative analysis of environmental issues, John Wiley, New York.

Holmes, J. & Hudson, G., 2000. An evaluation of the objectives of the BREEAM scheme for offices: a local case study. Proceedings of Cutting Edge 2000, RICS Research Foundation, RICS, London.

Hobbs, B.F. & Meier, P., 2000. Energy decision and the environment: a guide to the use of multicriteria methods, Kluwer Academic Publishers, Boston.

Janikowski, R., Kucharski, R. & Sas-Nowosielska, A., 2000. Multi-criteria and multi-perspective analysis of contaminated land management methods. Environmental Monitoring and Assessment, 60, 89–102.

Janssen, R., 1992. Multiobjective decision for environmental management, Kluwer Academic, Dordrecht.

Johnson, S., 1993. Greener buildings: environmental impact of property, MacMillan, Basingstoke.

Joubert, A.R., Leiman, A., de Klerk, H.M., Katau, S. & Aggenbach, J.C., 1997. Fynbos (fine ash) vegetation and the supply of water: a comparison of multi-criteria decision analysis and cost-benefit analysis. Ecological Economics, 22 (2), 123–140.

Kohler, N., 1999. The relevance of Green Building Challenge: an observer's perspective. Building Research and Information, 27 (4/5), 309–320.

Larsson, N., 1998. Green Building challenge '98: international strategic considerations. Building Research and Information, 26 (2), 118–121.

Larsson, N.K., 1999. Development of a building performance rating and labelling system in Canada. Building Research and Information, 27 (4/5), 332–341.

Larsson, N.K. & Cole, R.J., 2001. Green Building Challenge: the development of an idea. Building Research and Information, 29 (5), 336–345.

Lee, W.L., Chau, C.K., Yik, F.W.H., Burnett, J. & Tse, M.S., 2002. On the study of the credit-weighting scale in a building environmental assessment scheme. Building and Environment, 37, 1385–1396.

Liu, Y., Prasad, D., Li, J., Fu, Y. & Liu, J., 2005. A holistic approach to developing regionally specific framework for green building assessment tools in China. Proceedings of The 2005 World Sustainable Building Conference, Tokyo, 27-29 September 2005, 1634-1641.

Lord, D., 1994. Modelling energy and material flow in building design and consumption using an electronic spreadsheet. Proceedings of First International Conference, CIB TG16, Sustainable Construction, Florida, USA, November.

Lowton, R.M., 1997. Construction and the natural environment. Butterworth Heinemann, Oxford.

Mitchell, G., May, A.& MacDonald, A., 1995. PICABUE: a methodological framework for the development of indicators of sustainable development. International Journal of Sustainable Development and World Ecology, 2, 104–123.

Nijkamp, P., Rietveld, P. & Voogd, H., 1990. Multicriteria evaluation in physical planning. North-Holland, New York.

Popp, J., Hoag, D. & Hyatt, D.E., 2001. Sustainability indices with multiple objectives. Ecological Indicators, 1, 37–47.

Powell, J.C., 1996. The evaluation of waste management options. Waste Management and Research, 14, 515–526.

Pullen, S., 2000. Energy used in the construction and operation of houses. Architectural Science Review, 43 (2), June, 87–94.

Rees, W., 1999. The built environment and the ecosphere: a global perspective. Building Research and Information, 27 (4), 206–220.

Reijnders, L. & van Roekel, A., 1999. Comprehensive and adequacy of tools for the environmental improvement of buildings. Journal of Cleaner Production, 7, 221-225.

RICS, 2001. Comprehensive project appraisal: towards sustainability. RICS Policy Unit, Royal Institution of Chartered Surveyors, London.

Roar, J., 2002. Environmental initiatives: towards triple-bottom line reporting. Corporate Communications: An International Journal, 7 (3), 169–183.

Rogers, M. & Ryan, R., 2001. The triple bottom line for sustainable community development. Local Environment, 6 (3), 279–289.

Rohracher, H., 2001. Managing the technological transition to sustainable construction of buildings: a socio-technical perspective. Technology Analysis and Strategic Management, 13 (1), 137–150.

Seo, S., Tucker, S., Ambrose, M., Mitchell, P. & Wang, C.H., 2006. Technical evaluation of environmental assessment rating tools, Research & Development Corporation, Project No. PN05.1019.

Soebarto, V.I. & Williamson, T.J., 2001. Multi-criteria assessment of building performance: theory and implementation. Building and Environment, 36, 681–690.

Tisdell, C., 1993. Project appraisal, the environment and sustainability for small islands. World Development, 21 (2), 213–219.

Todd, J.A., Crawley, D., Geissler, S. & Lindsey, G., 2001. Comparative assessment of environmental performance tools and the role of the Green Building Challenge. Building Research and Information, 29 (5), 324–335.

Uher, T.E., 1999. Absolute indicator of sustainable construction. Proceedings of COBRA 1999, RICS Research Foundation, Royal Institution of Chartered Surveyors, London, 243–253.

van Pelt, M.J.F., 1994. Environment and project appraisal: lessons from two cases. The Annals of Regional Science, 28 (1), 55–76.

Woolley, N., Footitt, A. & Hickman, M., 1999. Comprehensive project evaluation. Proceedings of ROOTS' 99, RICS Research Foundation, Royal Institution of Chartered Surveyors, London.

Yates, R. & Baldwin, R., 1994. Assessing the environmental impact of buildings in the UK. Proceedings of the CIB Congress, Watford, UK.

Yau, R., Cheng, V. & Yin, R., 2006. Building performance assessment in China. Proceedings of The 2nd International Conference on Intelligent Green and Energy Efficient Building & Technologies and Products expo, Beijing, 28-30 March 2006.

Young, J.W.S., 1997. A framework for the ultimate environment index–putting atmospheric change into context with sustainability. Environmental Monitoring and Assessment, 46, 135–149.