Assessment of sustainable construction practices

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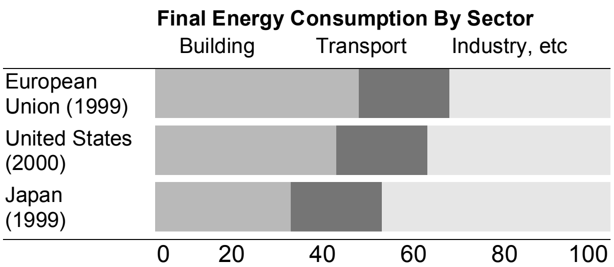
ABSTRACT: There is a lack of assessment for environmental impacts of building during construction process. The paper examines criteria for assessment of the sustainability of the construction process of building. Buildings can be assessed at four stages of their lifecycle to evaluate the environmental impact of the construction process - pre-construction, during construction, post-construction and after demolition. Existing methods and systems to evaluate the environmental impact of building projects are focused predominantly on the pre and post-construction stages, rather than the construction stage. This is despite the fact that environmental impact is considerable during the construction process. For example construction of building is responsible for 2-10% of building impacts, Building and transport (that is, during building construction) account for 50 - 65 per cent of total final energy consumption (UNEP, Industry and environment, 2003, p. 5).
This paper investigates methods of assessment of the building during construction process. It proposes a series of criteria, which can be used to assess the sustainability of various building practices during the construction stage. (These criteria are to be developed into a formal checklist in a later paper - this would enable designers and other interested parties to identify the most appropriate sustainable practices for their projects).
Following a discussion of existing construction practices, three methods for assessment of sustainable construction practice are critically reviewed (the Lawson method, the Twin model, and the LEED model). Finally there is proposal of criteria that can be considered in assessment of environmental impact during the building construction process.

INTRODUCTION

It is commonly accepted that present building construction practices are not sustainable. This may be illustrated by reference to figure 1. The post-construction energy consumption of a building (industrial use etc) accounts for around half of total building energy consumption. Building and transport (that is, during building construction) account for 50 - 65 per cent of total final energy consumption (UNEP, Industry and environment, 2003, p. 5). Total final energy consumption may be taken as an approximate measure of the total environmental impact of a building. Given this, it may be appreciated that environmental impact is greatest while the building is being constructed – and so this is the area that needs addressing if environmental impact is to be reduced.



NB Building sector data represent building operations only; energy use in manufacture and transport of building materials, etc. is excluded

Source: European Commission, US Department of Energy, Japanese Resource and Energy Agency, in Environmentally Sustainable Buildings: Challenges and Policies, OECD, 2003

Figure 1: Energy Consumption

The United Nations Environment Program (UNEP, 2003) has announced that, if existing practices do not change, expansion of the built environment will destroy or disturb natural habitats and wildlife on over 70 per cent of the land surface of the Earth by 2030. This process is driven mainly by increases in population, economic activity and urbanization. Construction uses around half of all resources humans take from nature. Production and transport of building materials consumes 25 - 50 per cent of all energy used (depending on the country considered). And estimates of the contribution of industry to global anthropogenic carbon dioxide emission range from 5 - 7 per cent.

Hendriks (2002) argues that “existing construction practice has various negative effects on health, both human and plants and animals in the ecosystem”. He believes that optimising technical on-site performance will minimize negative impacts.

Yencken and Wilkinson (2000) argue that “there is little likelihood that current environmental policies and programs will on their own prevent continuing environmental degradation.” They give two reasons for this. Firstly, existing policies do not deal comprehensively with the identified environmental problems in construction practices. Secondly, there is a lack of appropriate tools and methods to evaluate the environmental impact of construction processes. This makes it difficult to identify and deal with problems in this area successfully.

Industry groups are taking this problem in hand (2004).Fore example; Green Globe is a unique global environmental benchmarking and certification program for the Travel and Tourism industry. A study by this group provides evidence that existing construction practices are not sustainable (Green Globe Design & Construct handbook, 2004, p. 26).

There is general agreement that even though sustainability has been found to be possible at different stages of construction, implementing sustainability has

received little attention, especially in relation to construction processes. Buildings have considerable impact on the environment during their lifecycles. This may be at the pre-construction stage (material production); during the construction process; or in the post-construction stage (use, repair, maintenance, refurbishment, and finally demolition).
The environmental impacts of construction processes are considerable, and can have variable impact on the environment. Three methods for assessment of environmental impact in the construction industry, and the degree to which they take environmental impact of construction processes into account, are reviewed in the next section.

1. CRITERIA ASSESSMENT OF ENVIRONMENTAL IMPACT OF CONSTRUCTION PRACTICE

The question to be considered in this section is to what extent existing assessment methodologies evaluate the environmental impact of construction practices. There are several methods available, each evaluating a particular stage of the building lifecycle or a special type of building. Three assessment methods are considered in this paper - the 'Lawson' method, (from Australia), the 'Twins' model and the 'LEED' model. These are chosen as representative examples of assessment practice particularly pertinent to the question above (these methods are considered to review because they examine construction process).
Other well-known methods not reviewed here include the NIBE Environmental Classification of Construction Materials (Haas, 1993); the Handbook for Sustainable Renovation and Sustainable Residential Building (1995); the Four-variant method, BOOM (Stofberg et al, 1994); National Measures for Sustainable House Building (New Housing, Ministry of VROM, 1996); BREEAM 1998 (Baldwin, Yates, Howard & Rao, 1998).

1.1. Lawson method

This method is comprehensive, and designed for the Australian context. Lawson's methodology is also easily understood, and materials, buildings and systems are all included in the environmental impact evaluation. The Lawson method is performed in two stages - materials assessment of the industry process of individual material and whole building assessment, combinations of materials that are used in a building.

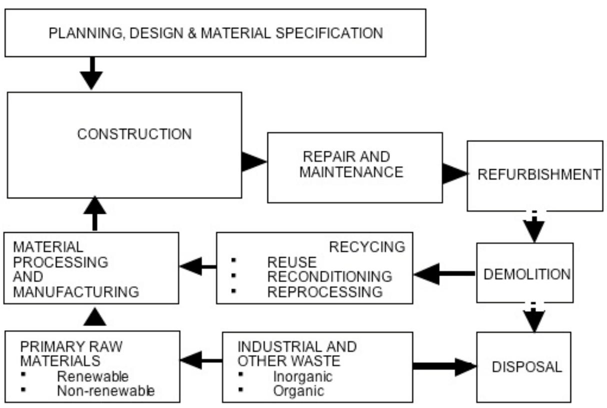


Figure 2: General model of the life cycle of materials (from Lawson 1999, p. 63). *(Broken arrows signify less strength in relationships)*

1.1.1 WHOLE BUILDING ASSESSMENT

The second phase of the Lawson method provides an environmental performance summary of the whole building based on seven criteria - one relates to the site of the building; five relate to the choice, use, maintenance and disposability of materials and final criteria provides an estimate of the *operational energy performance*. (Lawson calls these criteria *site sensitivity; use of low ecological impact materials; use of renewable material;, use of embodied energy materials; operational energy performance; freedom from maintenance; potential for deconstruction*). Like phase 1, rating is against a five-point scale from excellent to poor. These criteria were developed after review of a number of experienced building designers and company's projects with known low energy usage (Lawson, 1999, p. 22).
Aims The Lawson method aims to increase the awareness and understanding of architects and others in respect to the environmental implications of their work. It is also intended to provide practical and useful information to assist in the development and implementation of a methodology for ecological sustainability in relation to building design and construction.
Scope The Lawson method is used to study manufacturing processes and their environmental impact, and then to provide embodied energy ratings of typical Australian building materials and assemblies. These can be useful to architects and others. Lawson also presents a method for assessing the relative embodied energy of construction materials as they are used in contemporary Australian building. Environmental performance summaries, which focus on energy issues as well as other environmental aspects of buildings, are also provided.
Life Cycle Assessment of building (LCA)
From the above, it can be seen that the Lawson method can be used to assess the environmental impact of a building during several stages of its life cycle (see figure 3). It takes into account the manufacturing process and the embodied energy of construction materials (materials assessment - LCA stage 1); and the embodied energy of construction as a whole (whole building assessment - LCA stage 3). However, the evaluation of the environmental impact of a building during the construction process (LCA stage 2) receives little attention in the Lawson method.
The Lawson method for evaluation of the environmental impact of buildings forms part of the RAIA (Royal Australian Institute of Architecture) environmental policy. It was first described by Lawson (1996) in his book '*Building Materials Energy and The Environment'* which examines the environmental impacts of most common built materials. Lawson has created a life cycle model for materials to help with the assessment.

1.2. TWIN MODEL

This method was first described by Haas, 1997).
The Twin model is a method for analysing the life cycle of building products. The main criteria considered are 'eco-toxicity' and 'human toxicity' during the life cycle of the building, with particular focus on related health issues in these areas. Those likely to use the Twin model are designers and property developers.
The Twin model also adds to the LCA evaluation by using a number of weighting factors to compare the environmental effects of various building components. The final result is given as a score for a particular building construction material or product.

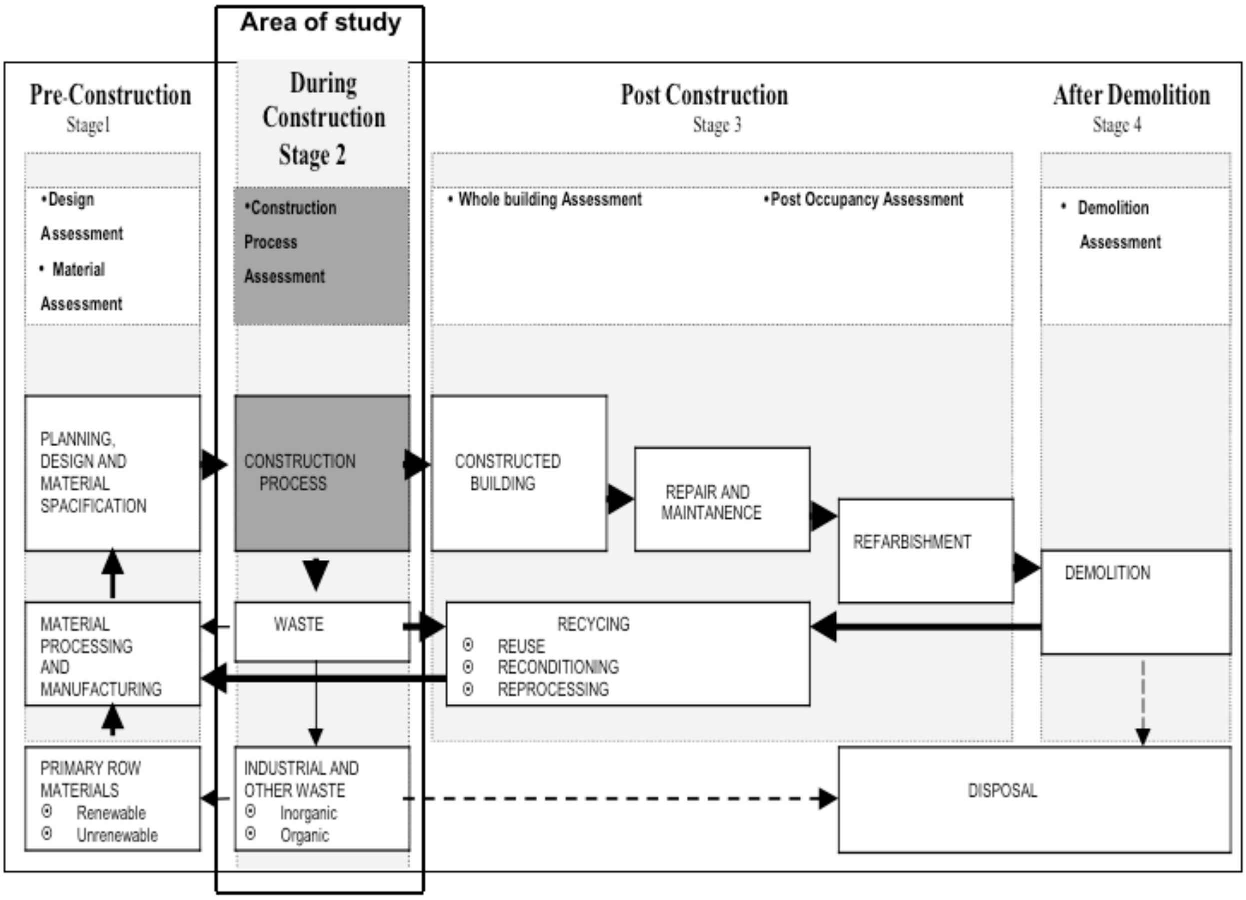


Figure 3: Life cycle model (adapted from Lawson 1999, p.63)

The main criteria above are subdivided into various categories, with numerical scores given for each. Analysis of the various scores easily identifies which materials or products are the most environmentally friendly. This quantitative data is supplemented with qualitative data in the form of two matrices, one focusing on environmental assessment and the other on health assessment. It should be noted that the Twin model applies to building products, not the construction process (Hendrinks, 2001, p. 55).

Aims The Twin model is a method for analyzing the life cycle of building products.

Scope The Twin model focus is on eco-toxicity and human toxicity, both of which are set against life-cycle criteria. Data can be used to assess the potential impact of building materials on human health and the environment. Financial costs for implementing environmental and health safety measures can also be estimated. The main target users for Twin model are designers and property developers.

LCA The Twin model assesses buildings in the design stage (LCA stage 1) and the post-construction stage (LCA stage 3) of the building life cycle (see figure 3), with particular focus on health aspects and deterioration of materials.

1.3. LEED (leadership in energy & environmental design)

This assessment method – the Green Building Rating System - was developed by the Green Building Council in the United States (LEED 2002).

Aims The LEED Green Building Rating System represents the attempt of the Green Building Council to provide a national assessment standard for a construction to qualify as an environmentally-friendly 'green building'. The rating system is based on established and innovative practices, standards and technologies. Through its use as a design guide and third-party certification tool, it aims to improve occupant well being, environmental performance, and economic returns.

Scope This method covers three areas - building monitoring and evaluation; building energy analysis; and building inspections and energy audits. (LEED, 2002, p. i)

LCA The LEED green building method rates buildings in the design (LCA stage 1) and post-construction stage (LCA stage 3) of the building life cycle. It is for use in assessment of new commercial constructions, major renovations, and high rise residential buildings.

The sections of the LEED document that deal with construction are titled 'Material and Resources' (p. 24) and 'Indoor Environmental Quality' (p. 52). Some sub-sections also investigate issues related to the construction processes (for example, see 'water use reduction in construction processes', p.19). However, the document does not study the main issues of construction processes (LEED, 2002, p. IV).

1.4. Strengths & weaknesses of assessment methods

The three methods reviewed above focus on assessment of the environmental impact of the construction process at various aspects of the building life cycle. As can be seen in figure 3, these methods variously cover the pre and post construction stages of the building life cycle (LCA stages 1 and 3). However, the environmental impact during the construction process itself (LCA stage-2) receives relatively little attention in these methods.

In the remaining section of this paper, items that need to be considered in evaluation of the environmental impact during the construction process (LCA stage-2) are proposed. This could be a useful tool for building designers and others to use for determining sustainable construction practices.

2. CONSTRUCTION PROCESS ASSESSMENT

2.1. Stages and categories of assessment

Buildings can be evaluated at four stages of their lifecycle (see figure 3 for LCA stages) – pre-construction (raw material, design processes); during the construction process; post-construction (use, repair, maintenance and refurbishment); and post-demolition. Table-1 shows these stages, the various categories of assessment applicable in each stage, and the methods available to evaluate the environmental impact of construction practices in each stage.

Table 1: Building Life Cycle stages and Assessment methods

Life Cycle Stages of Building	Assessment Categories	Assessment Methods
Pre-construction (Stage One)	Strategies and design assessment	Twin, LEED
	Material and product assessment	Lawson, LEED
During construction (Stage Two)	*Construction process assessment*	*No model (Studied in this paper)*
Post-construction (Stage Three)	Whole building assessment	Lawson, Twin, LEED
	Post occupancy assessment	Twin, LEED
Post-demolition (Stage Four)	After demolition assessment	LEED

The building life cycle has four stages and each stage has a boundary. The boundary of LCA stage-2 (Construction Process Assessment) starts with reception of raw materials at the site and ends with the constructed building being available for use. Construction process assessment must include all workshop activities (prefabrication) or onsite construction activity to provide construction elements; procurement and transport of raw materials or elements to the site; all other onsite activities during the construction process; and movement of all people working on the site and using local facilities, services or available infrastructure. (Hyde, 2000, p.47).
Table-2 shows lists the main areas that need consideration when evaluating the environmental impact of building construction practices. As indicated in the table, the Lawson method does consider some of these areas in assessment of environmental impact in stages 1 and 3 of the building life cycle, but does not apply them in stage 2. The following section of this paper discusses and group items that should be considered in development of a building environmental checklist during construction process.

2.2. Construction process assessment

Construction process assessment is the second stage of the building life cycle assessment (figure 3). It has not been an area of particular interest in recent studies of sustainability or assessment of construction practices, despite the fact that the environmental impact of construction processes can be considerable.
Some aspects of building performance may vary during the construction process, and this makes it difficult to factor these into the design stage. Post-construction assessment of environmental impact can also be problematic. For example, the written policy on sustainability and environmental impact may not have been fully or properly implemented – this would depend, at least in part, on the experience and interest of the person(s) responsible for this area of the construction process. Indeed, exactly who should bear the responsibility for implementing sustainability and environmental impact policy may at times be unclear. Such areas need ongoing evaluation during the construction process itself.

Table 2: Indicators considered to study and studied by Lawson in stages of building life cycle

Indicators considered to evaluate environmental impacts of building during construction process in this study	Stage 1 Material assessment Lawson	Stage 2 Process assessment Lawson	Stage 3 Whole building assessment Lawson
Policy (effective control)	-		
Site sensitivity	-		+
Use of low ecological impact materials	+		+
Recyclability, potential for reuse	+		+
Embodied energy efficient	+		+
System life span	+		+
Operational energy performance	-		+
Resource of labour, human forces, facilities and materials			
Water consumption and water waste			
Raw material availability	+		+
Material waste in work and rework			
Freedom from maintenance	+		+
Effect on health, site security, safety and noise control			

Problematic areas in construction process assessment can be the source and suppliers of materials; or the distance that site personnel will need to travel to reach or move around on the site. There is also the question of how such issues can be measured.
Table 3 summarises the main areas to be considered in developing a checklist to assess the environmental impact of the construction process. These areas are proposed after reference to a number of sources (Degeer, 2003, p.13; Edwards, 1999, p. xv; European Commission, 1999, p. 1; Green Globe, 2002, p.16; Hendrinks, 2001, p.130; Lawson, 1999, p.21; LEED, 2002, p.10).

Table 3: Areas of interest in evaluation of the construction processes

- Policy (effective control)
- Site sensitivity
- Use of low ecological impact materials in process
- Use of recyclable, reusable onsite facilities
- Operational energy performance
- Equipment and type of machinery needed to perform
- Resource types (labour, human resources, facilities and materials)
- Water consumption and water waste; wet trades,
- Material waste in work and rework, daily inventory
- Effect on health, site security, safety and noise control

The checklist to be developed in a later paper aims to assess the environmental impact of building construction processes. It will include all aspects of the building process (preliminary, excavation, external works and landscaping); and also all measurable items that arise or occur during the construction process (e.g. percentage of wet trade; duration of trades; number of personnel; percentage of prefabrication; use of local facilities; effective control of environmental policies). The proposed checklist is partly based on Lawson's indicators and definitions, but using numerical scales (1, 2, 3, 4 and 5).

A trial of this checklist will be conducted by assessing the construction process of the 'Research Station on Heron Island', Australia, 'Lark Quarry' Trackways Building and Shelter on Lark Quarry conservation Park, Australia. (Data for this assessment is available, and will allow retrospective analysis of the environmental impact of the station construction process.) The checklist and the results of this trial will be presented in a later paper in this series.

SUMMARY & CONCLUSION

This paper reviews the building lifecycle and existing methodologies for assessing sustainable construction practices. From this review, it appears that the evaluation of the environmental impact of construction processes (stage 2) is a neglected area of study. Several criteria are therefore proposed that need consideration in evaluation of the environmental impacts of building during construction process.

A later paper will develop and trial a building construction process checklist. This tool would be of value to designers and others interested in evaluation of the environmental impact of building during construction process, and with a wish to identify the optimum sustainable construction system for their project with regard 'ecological value' and 'location'. Ultimately this tool might be useful to establish benchmarks for sustainable construction practices during construction process.

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