CRC Construction Innovation
BUILDING OUR FUTURE

Environmental assessment for commercial buildings: Stakeholder requirements and tool characteristics

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PREFACE

The Cooperative Research Centre for Construction Innovation (CRC CI) is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, the CRC CI is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. The CRC CI is a seven year project funded by a Commonwealth grant and industry, research and other government support. More than 150 researchers and an alliance of 19 leading partner organisations are involved in and support the activities of the CRC CI.

There are three research areas:

- Program A - *Business and Industry Development*
- Program B - *Sustainable Built Assets*
- Program C - *Delivery and Management of Built Assets*

Underpinning these research programs is an *Information Communication Technology* (ICT) Platform.

Each project involves at least two industry partners and two research partners to ensure collaboration and industry focus is optimised throughout the research and implementation phases. The complementary blend of industry partners ensures a real-life environment whereby research can be easily tested and results quickly disseminated.

The major project in the **Sustainable Built Assets** core area is an Automated Environmental Assessment System for Commercial Buildings incorporating a CAD-based tool and associated material-performance databases. These are being combined to facilitate real-time environmental appraisal of commercial building design from concept stage to detailed specification to meet a growing need from designers and regulators for real-time appraisal of design performance of constructed assets.

In the current marketplace for the design and construction industry it is impossible for organisations to spend significant resources examining the environmental impacts of different products and evaluating the performance of different components and systems. This project will enable industry to make these types of assessments by providing a uniform level of information, and tools to access the information on environmental measures for different products and designs in real time.

This Working Paper (Report 2001-006-B-01) is part of a series of Working Papers and Progress Reports for the core area of **Sustainable Built Assets**.

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EXECUTIVE SUMMARY

This report was drafted to facilitate the development and application of LCADesign by:

- focusing on needs of the stakeholders for building environmental assessment (BEA);
- incorporating sustainable building requirements and optimal tool characteristics and
- ensuring provision of such reasoning in the Sustainable Built Assets program projects reliant on integrated life cycle assessment/computer aided design.

In 1992 the national strategy for Ecologically Sustainable Development (ESD) was introduced to reduce local, national and global depletion of natural resources/habitat. In this context sustainable building design involves enabling building industry stakeholders to address an array of environmental, social and economic criteria considering the corporate triple bottom line. The Australian built environment share of resource depletion of water, clean air, productive land and pollution detrimental to community health is significant. In addition to social, functional, economic and technical aspects, sustainable design requires consideration of community, air, land and water resource consumption and pollution of community, air, land and water sinks. Characterisation of BEA tools with respect to stakeholder applications as well as building, project, product, asset and design lifecycles found many lacked:

- support for stakeholder decision making;
- whole of life considerations integrated from earliest investment /planning;
- consideration of policy development and pre/post-occupancy assessment and
- operational service delivery functionality measures as they focus on physical metrics.

Discussion is provided on immediate and long-term development plans for LCADesign as a user-friendly BEA application with integrated features considering:

- communication in planning and strategic/tactical decision-making towards ESD and
- documentation and interactive framework, guideline and checklist applications

Recommendations for consideration include proposals for development of an interactively packaged comprehensive toolbox to enhance market penetration containing, as depicted in Figure 1.

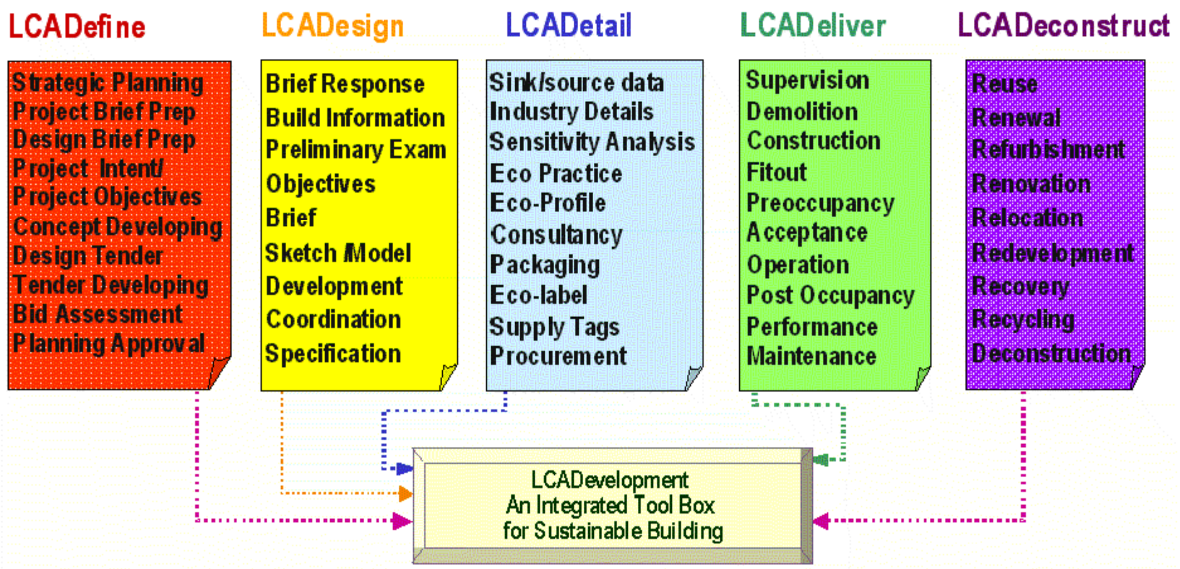

Figure 1 Proposed LCADevelop, LCADesign LCADeliver and LCADeconstruct Applications

BACKGROUND

Sustainable Development was defined as a goal in 1986 to address unsustainable patterns of consumption contributing to escalating environmental deterioration [1]. The global scale of habitat deterioration and destruction, climate change and depletion of natural resources elicited responses from the United Nations with the Montreal Protocol on Ozone Depletion in 1987 [2], the Rio Convention on Biological Diversity in 1992 [3] and the Kyoto Protocol on Climate Change in 1997 [4]. In 1992, the Council of Australian Governments' National Strategy for Ecologically Sustainable Development (ESD) defined ESD as using, conserving, and enhancing community resources so that ecological processes on which life depends are maintained and the total quality of life now and in the future can be increased [5].

In 1996 the term "triple bottom line" was introduced to describe social, environmental and economic business benefits [6]. A further commitment to a component of ESD, the National Greenhouse Response Strategy (NGRS) was endorsed in 1996 [7]. In the context of ESD and the built environment BEA Sarja [9] argues:

"Buildings, and civil and industrial infrastructures are the longest lasting and most important products of our society. The economic value contained in buildings, and civil and industrial infrastructures are, to say the least, significant, and the safe reliable and sound economic and ecological operation of these structures is greatly needed. In industrialized countries buildings and civil infrastructures represent 80% national property. Construction plays a major role in natural resource use and in development of the quality of the natural environment in our time. Consequently, building and civil engineering can make a major contribution to sustainable development of our society".

In 1997 the national "CGI-97 Directions Forum" recognised that the total buildings' share of environmental deterioration was significant as it is a major consumer of resources and generator of air, water and land pollution [8]. This Forum agreed that, in the Australian built environment, there was depletion of natural reserves of freshwater, clean air, naturally productive land and pollution of urban air to an extent that it can be detrimental to the health of both human communities and natural ecosystems [10].

Also studies, for example, commissioned by Queensland DPW in 1999, found the building sector share of greenhouse emissions (GGE) was 22% as shown in Figure 2. Figure 2 also shows residential and commercial operation dominates such emissions generation [11].

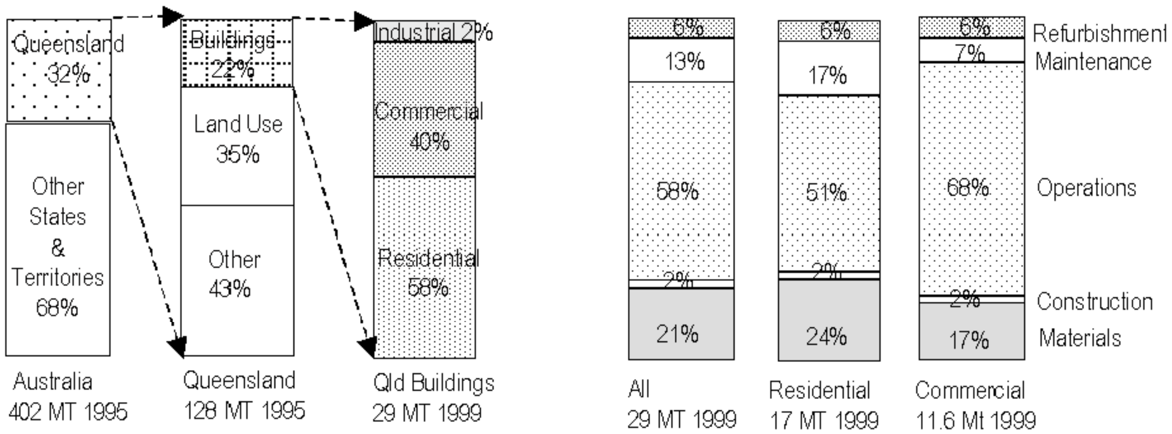

Figure 2 (a) Building National Share GGE and (b) QLD Building Phase Share GGE

INTRODUCTION

Sustainable building design involves the consideration of stakeholder relationships while addressing an array of environmental, social and economic criteria. A few building environmental assessment (BEA) methods employed are shown in Figure 3, a diagram of sustainability scope related to the triple bottom line [12]. As to the criteria involved, Sarja [9] argues that sustainable design should address:

- social aspects of welfare, health, safety, comfort;
- functional as well economic aspects of useability for changing needs;
- technical aspects of serviceability, durability, reliability and
- ecological aspects of natural resource consumption of energy, raw material and water; air, water and soil pollution, waste production and impact on biodiversity.

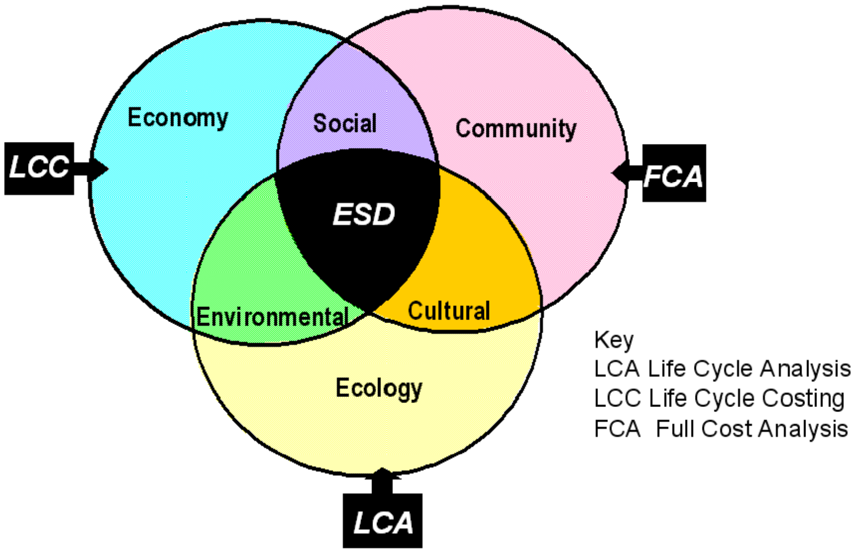

Figure 3 Sustainability Scope Considering Triple Bottom Line Accounting Method

Every living community depends on a sustainable source of supply and healthy levels of emissions [12]. Because all supply comes from community, air, land and water sources and all emissions go to community, air, land and water sinks these are essential to focus upon Sustainable supply and sinks relationships related to ecological and social aspects are shown in Table 1 [13].

Table 1 ESD Considerations for Conserving Resources and Reducing Emissions

Conserving Resources of			
Community	Energy	Materials / Land	Water
Natural heritage Cultural heritage Built heritage Access and safety	Passive solar design Efficiency in use Waste avoidance Conserve sources	Materials durability Waste avoidance Reliant on renewables Conserve sources	Efficiency in use Waste avoidance Waste management
Reducing Emissions to			
Air Indoors	Air Outdoors	Materials / Land	Water
Volatile organics Ventilation Indoor air quality	Ozone depleting gases Greenhouse gases Airborne particulates	Construction waste Recycled materials Avoid toxic waste	Effluent reduction Waste treatment Conserve sources

PROPOSED LCADESIGN BEA TOOL

The growing need for detailed design performance appraisal calls for a uniform level of information applicable to broad criteria along with tools using new methods to access environmental/and economic costings for different options [14]. To facilitate sustainable design of buildings, the CRC CI is developing LCADesign, a software tool with the aim of it being accepted by government and industry as the preferred environmental appraisal tool for Australian commercial buildings [15]. It provides:

- Environmental assessment over the development process and the building life cycle;
- Automatic take-off from CAD of quantities of all components for impact assessment;
- Assessment based on internationally recognised life cycle costing/analysis methods;
- An exclusive life cycle inventory database and various life cycle impact methods and
- Assessment based on recognised environmental and economic costing methods [16].

It is being developed to enable building design professionals to:

- Perform real time appraisal of material alternatives against environmental criteria;
- Enable users to consider impacts and report environmental life cycle costs;
- Compare impacts of product alternatives at all levels of design analysis and
- Effectively assess and appraise building design performance in a timely manner [15].

LCADesign analyses resource use in operations as depicted in Figure 4 [16]. It compiles an inventory and impact assessment of resources consumed from sources (arrow in) and emissions generated to sinks (arrow out).

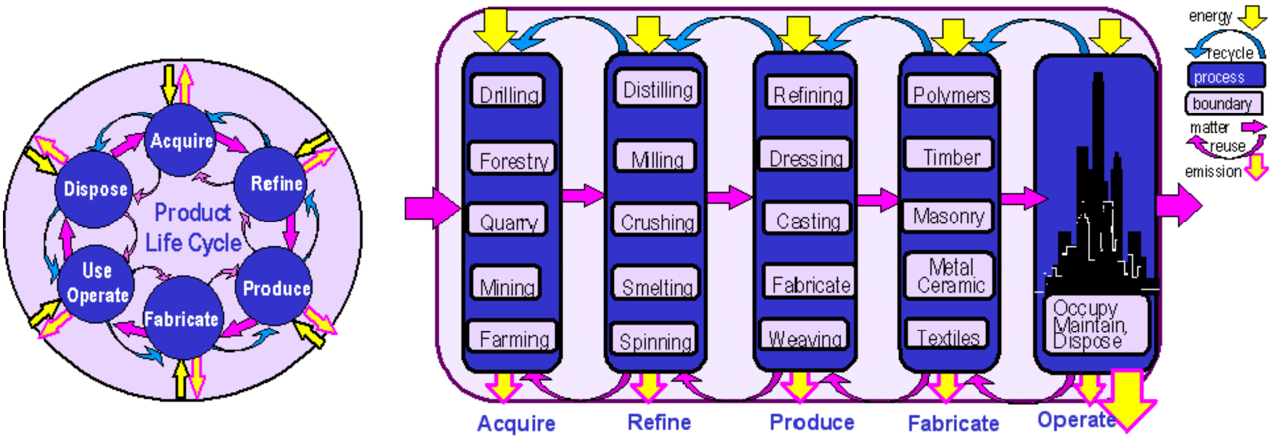

Figure 4 Operational Flows Over the (a) Product Life Cycle and (b) Built Life Cycle

The application of LCADesign can provide reports that indicate lower impact alternative building designs for:

- Enhanced user assessment of building impacts from cradle to gate/grave/cradle;
- Objective, detailed and comparative assessment and
- Automatic generation of comprehensible graphics and reports from CAD [15].

In addition CRC CI plans are also in hand to potentially integrate:

- life cycle economic costing as well as
- indoor air quality assessment across LCADesign [14 to 16].

OBJECTIVES

This report seeks to analyse criteria for LCADesign tool development to facilitate it becoming a user-friendly, interactive, flexible and comprehensive BEA tool for technical assessment that involves, for example, calculating and reporting as well as for decision-support that involves strategic planning, guidance and checking. The objectives were:

1. To review and characterise BEA tool:

- Attributes, functionality and stakeholder reach;
- Professional stakeholders and their need for such applications and
- Features and functionality required to meet such stakeholder needs.

2. To characterise BEA stakeholders needs by considering:

- Assessment and reporting tasks over the building life cycle;
- Asset, project and design processes over their temporal life cycle and
- Product, construction and building processes over their physical life cycles.

3. To determine the extent that stakeholders needs are being met considering :

- Previous reviews of BEA tools along with a further review of additional tools;
- Additional perspectives not considered in previous reviews;
- User applications over the full life cycle from cradle to cradle and
- Evaluation of deliverables by temporal and physical life cycles.

4. To review LCADesign project planning by considering:

- Stakeholder applications mapped against potential tool deliverables;
- Gaps between stakeholder needs and tool attributes/applications;
- Prospective plug-in tools needed for their work to fill such gaps;
- Further work to be undertaken on LCADesign supplements to fill these gaps;
- Comparisons of tool characteristics with that of LCADesign and
- Comparisons of stakeholder needs and the core purpose of LCADesign.

5. To facilitate development and packaging of LCADesign to integrate:

- Alignment of technical and linguistic needs with other Australian BEA tools;
- Provision of comparisons against best practice performance benchmarks;
- Appraisal of design performance against ESD criteria and end points;
- Communication of ESD principals/policy for strategic decision-making and
- Interactivity with supporting frameworks, guidelines and checklists.

METHODOLOGY

This work involved applying the following methodologies in order to assess BEA tools and their provision of technical assessment and decision-support compared to LCADesign attributes and functionality.

1. Gap analyses of stakeholder needs and applications were undertaking by:

- Reviewing professional stakeholders and classes of typical applications;
- Evaluating tool applications required over:
- asset, project and design temporal life cycles and
- product, construction and building physical life cycles;
- Characterising tools functionality in meeting such stakeholder needs

2. Characterisations were considered from previous reviews of such tools including;

- CRC CI reviews of BEA international tools and databases;
- RMIT reviews of international tools and databases as well as
- Independent reviews of BEA tools from architectural design perspectives.

3. Characterisations were put together for five recently developed BEA tools including the:

- Environmental Estimating tool (ENVEST 2);
- Guideline for Ecologically Sustainable Office Fitout (GESOF);
- Ecologically Sustainable Asset Management Rating System (ESSAM);
- Green Star Environmental Rating System For Buildings (Green Star) and
- National Australian Building Environment Rating Scheme (NABERS).

4. Comparisons of stakeholder needs and their application needs were reviewed considering:

- Product, construction, building, asset, project and design management perspectives;
- Tool features, attributes, applications and capacity to meet stakeholder needs;
- Deficiencies in coverage of stakeholder needs over the building life cycle and
- Attributes and types of gaps to be filled to fulfill potential requirements.

5. Comparative analyses were made of LCADesign attributes considering:

- Applications, features and functionality compared to those of all tools reviewed;
- Applications, features and functionality required to meet all stakeholder's needs;
- Classes of key stakeholder applications and features as potential deliverables;
- Development opportunity and provision of such deliverables to meet user needs.

6. A conceptual framework of LCADesign features was developed considering the need for:

- Alignment of communications with ESD principals, policy, planning and strategies;
- Technical and linguistic coordination with other environmental assessment tools;
- Comparative assessments against best building practice/performance benchmarks;
- Documentation/templates for briefs specification, contract and evaluation;
- Proposed plug in tools to meet user needs for operation assessment and ESD criteria;
- Interactivity with supporting frameworks, guidelines and checklists as well as
- Enhanced user assessment and LCADesign deliverables in a development timeline.

BUILDING ENVIRONMENTAL ASSESSMENT TOOLS

There are accepted attributes that are considered useful for most BEA tools. These are summarised in Table 2 and it is against these attributes that they must be compared [18,14]. For sustainable design such tools also need to address a complex array of:

- Stakeholder needs and relationships in the built environment [20 to23,];
- Different contexts in relation to the building industry [24 to 28] and
- Environmental, social and economic criteria [18 to 23, 28 to 31].

Table 2 Tool Attributes

Function of tool use	Quality of Outcome Measure
Assist in the task being undertaken,	Fitness for purpose and strength
Offer a critical connection for stakeholders	User-friendliness and comfort of fit
Keep objectives clear	Ease of control for reliable use
Provide interpretation of professional language	Appropriate range of use and common language
Bridge across different communication formats	Easy to learn/ understand for early proficiency
Bridge across different paradigms	Portability/adaptability/comprehensiveness
High level of market penetration/adoption	Recognition as quality product

In a recent substantive study Reijnders and Van Roekel [18] classed BEA tools as types of:

Checklists	Blueprints (best practice)	Building component LCA
Manuals	Scoring Systems	Eco Preference lists
Eco-labels	Computer based guidance	

To consider ESD (as shown in parenthesis) stakeholders apply such basic tools as:

- Classing systems for (sustainable), premium, superior and typical accommodation;
- Rating systems to compare (sustainable), best and typical building operations;
- (Environmental) condition assessment procurement/marketing/estate/tenant checklist;
- Acquisition selection systems to support policy direction in a corporate portfolio;
- Calculators of (sustainable), best and typical new built design and operations and
- Benchmarks/labels to establish (sustainable), best and typical building operations [13].

LCADesign does not offer such systems, checklists or benchmarks/labels to support policy development or implementation [14 to 17]. In its current form, as a tool type, LCADesign is a calculator of best and typical new built design only. In addition to generating such measures of outcomes, Watson [18] stresses the importance of creating tools to support the design process as these:

- Provide a means of assistance in undertaking a task;
- Make a job easier or more efficient where critical to the task process;
- Act as bridge between assessment and the stakeholder tasks to be undertaken plus
- Connect different professions, ideologies and paradigms essential in BEA.

Most significant for tool developers Watson [18] conceptualizes BEA as bridging two different areas:

- Sets of prerequisite skills for problem solving in science as well as design and
- Paradigms involving scientific method/knowledge and design process/knowledge.

INDUSTRY STAKEHOLDER TYPES

The construction industry's ability to assess/reduce environmental social and economic impacts/costs while complying with legislation is important [18 to 23]. Addressing such issues, requires dealing with increasing complexities that pose difficulties in commercial where resources to gather, analyse and verify such information are limited [14 to 17]. The industry stakeholders that physically deal with buildings, products and services include:

- Developers, Owners, Occupants Facility Managers, Operators, Clients, Suppliers and
- Project Managers, Designers, Builders, Contractors, and Manufacturers [8,13].

Such stakeholders need BEA tools applied to:

- Affect the physical environment of building/development [18] and
- Assess environmental credentials & sustainability issues such [13] arrayed in Table 1.

Figure 5 (adapted from AEMMA [32]) depicts Roles of Primary Stakeholders Disseminating Information on BEA as users, providers, trainers and regulators [18]. Leading providers, from a diverse group, drive, facilitate and deliver more sustainable practice while laggards must perform to minimum standards set by regulators. Those most affected are designer users, university trainers, manufacturing providers and council regulators depicted on the axis of one quadrant and at the core of all others. Influential stakeholders at the core in all quadrants include Government, Planners and Associations. From investment to occupancy all groups can affect BEA.

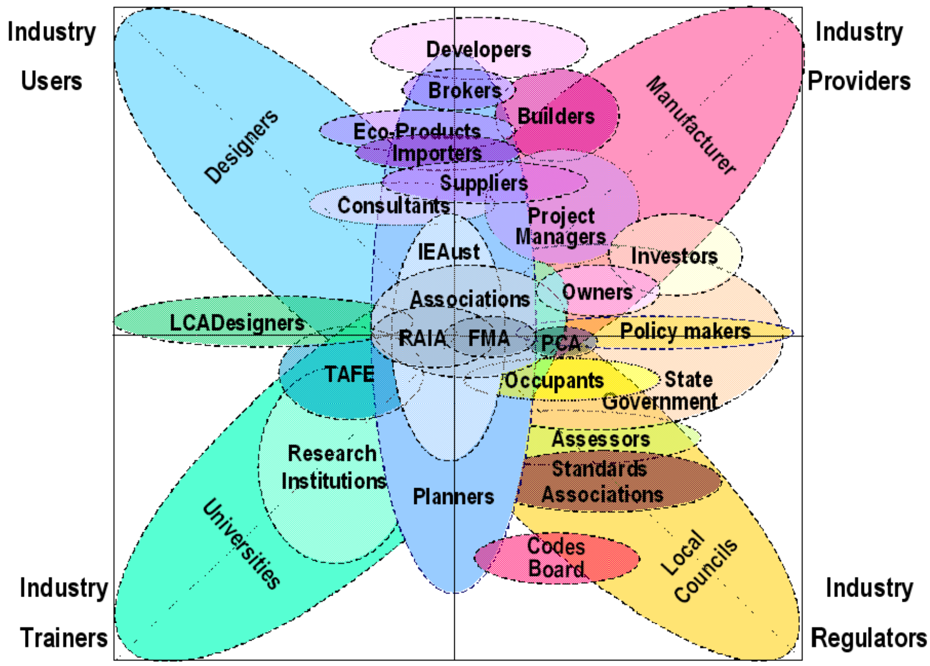

Figure 5 Role of Primary Stakeholders Disseminating Information on BEA

Also many are stakeholders who may never actually physically occupy the building include:

- Planners, Architects, Designers, Engineers, Artists, Landscape Architects as well as
- Policy Developers, Consultants, Researchers, Brokers and Investors [18]

It is also because of such disconnection that such stakeholders need BEA tools to provide for:

- Well defined objectives/ benchmarks/criteria/priorities/issues and
- Direction setting for strategic decisions in planning, briefing and tendering [18,26,27].

STAKEHOLDER BEA APPLICATIONS

BEA Stakeholders use many types of tools for various outcomes as instruments to:

- Plan, Control, Communicate, Benchmark, Monitor, Regulate and Educate [26, 27] plus
- Tender, Bid, Procure, Build, Design, Specify, Model, Estimate, Calculate and Report [13].

An overview of building industry professional application typology [26,27,33] in Table 3 shows their status. Barton et al argues that such applications need to be integrated rather than add-ons to facilitate management decision-making towards sustainable building outcomes [33].

Table 3 Industry Professional Application Type ands Status in LCADesign

Profession	Application	Type	CRC CI Status
Planners	Asset Plans FM, Costing, Rating & Reporting	Policy	Potential
Investors	Literature, Data, Research and Analysis	Benchmark	Proposed
Developers	Bid Development, Project Initiation, Planning	Tender/Bid	Potential
Designers	Brief Development, Design Specification	Guide/Calculator	Proposed
Managers	Concept/Tender/Bid Preparation/Assessment	Guideline	Potential
Owners	Tactical Operations, Maintenance, Disposal	Manual	Potential
Operators	Pre/Post Occupancy Commissioning Report	Standard	Potential
Manufacturer	Product Profile, Operations, R&D, Analysis	Assessment	Potential
Providers	Procurement, Profiles, Literature, Data	Eco-label, Estimate	Potential
Occupants	Fitout Guide, Tenancy Assessment	Checklist	Potential
Consultants	Reports, Data, Research and Analysis	Report	Potential

The earliest opportunity to influence ESD in Strategic Asset Management is in setting Project Delivery Objectives [26,27,33]. This is shown in Figure 6 (a) a schematic of the asset management life cycle when planners, investors and developers consider:

- Strategic planning and policy development relevant to new asset/facility needs/budgets,
- Communicating, educating and reporting on proposals during project initiation and
- Monitoring stock and benchmarking tender development for proposed new stock.

The second opportunity is in investment and consulting [26,27,33] as shown in Figure 6 (b) the Design Process phase, when managers, designers, providers and consultants consider:

- Procurement/budget/bid development relevant to asset service delivery needs;
- Modelling concept/detail design development, specification and documentation and
- Building product literature/profiling for cost estimation, construction and operations.

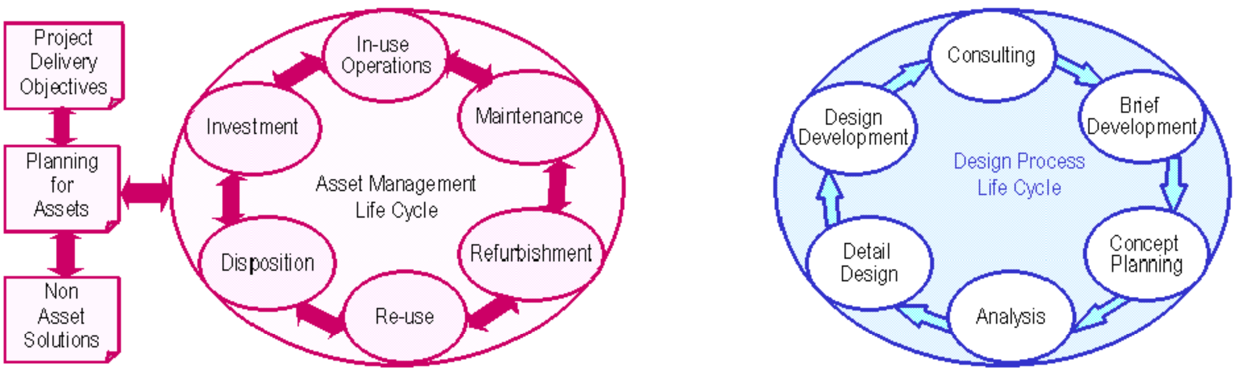

Figure 6 The (a) Asset Management Life Cycle and (b) Design Life Cycle

LCADESIGN TOOL TYPOLOGY

Few BEA tools apply to consulting, brief development and concept planning and the initial focus of many, including LCADesign, is design [34 to 36] and particularly design analysis as shown in Figure 6 (b) the design process life cycle [14]. The main application of LCADesign is as a design calculator of model data, as listed in Table 4.

Table 4 Professional LCADesign Applications and Tool Type

Profession	Application	Tool Type
Designers	Design Development/Assessment Report	Calculator
Manufacturer	Product Profile	Model
Providers	Consultants Data and Analysis	Model

These same stakeholders also require the further LCADesign applications/outputs in Table 5.

Table 5 Further LCADesign Applications and Outputs

Profession	Application	Type	Output
Designers	Concept/Design Development/Assessment Report	Calculator	Report, Guidelines
Manufacturer	Product Profile, Operating Research, Analysis	Model	Analysis, Profiles
Providers	Procurement, Product Profiles, Literature, Data	Model	Estimates, Profiles

To apply to initial processes BEA tools need to provide policy, benchmark and rating applications as shown in Table 6 [13, 25 to 27]. Timing is critical because prior allocation to master plan, infrastructure, orientation and budget limits later opportunities [35]. As Lovins [35] and Watson [18,37] stress when designs are developed it is too late to integrate most new initiatives. In order to effectively consider sustainability initiatives they must be viewed:

- By professionals through a lifecycle perspective to understand the true situation;
- Holistically and in context considering users/occupants and never in isolation and
- As cyclic and holistic concepts that need early consideration and budget allocation.

Table 6 Initial Asset and Design Applications

Profession	Application	Tool Type
Planners	Asset Plans FM, Costing, Rating & Reporting	Policy Selections
Investors	Literature, Data, Research and Analysis	Benchmarks, Rating Systems
Developers	Bid Development, Project Initiation, Planning	Tender and Bid Proforma

There is also potential to provide for such as managers, owners, purchasers, operators and occupants with features as listed in

Table 7 for:

- Alignment with ESD principals and policy [3,39,40];
- Enhanced user assessment of building product impacts over the full life cycle and
- Comparisons against best building practice performance benchmarks [13, 35, 37 to 40].

It is also desirable to provide design professionals with the means for:

- Appraisal of design performance against a sustainability criteria
- Documentation/templates of briefs specification, contract and evaluation as well as
- Interactivity across framework, guideline and checklist applications [13, 18, 33,35].

Table 7 Potential LCADesign Stakeholder Applications

Stakeholder	Class	Application	Type
Manager	Portfolio, Project & Site	Tender/Bid Preparation/Assessment	Guideline
Owner	Corporate, Community,	Tactical Operation, Maintenance	Manual
Purchaser	Labeling, Operating cost	Procurement	Specification
Operator	Site, Facility & Building	Pre/Post Occupancy Commissioning	Standard
Occupant	Tenant, Owner, Employee	Fitout Guide, Tenancy Assessment	Checklist
Providers	Builder/Developer/Supplier	Prequalification/Marketing	Brief/Proforma

STAKEHOLDER BEA NEEDS AND OUTCOMES

As previously described, numerous stakeholders use tools to affect the physical environment of building/development and to assess environmental credentials & sustainability issues. The Environment Australia commissioned study of leading BEA tools by Royal Melbourne Institute of Technology, Centre for Design reported that users felt that their objectives were not being met [36] and this section outlines possible reasons for this outcome.

Arguably the most fundamental needs of industry stakeholders for clear communication requires adoption of a common language that is evolving from the very broad ESD platform. It must bridge client service delivery needs, development/professional applications, management systems, design/construction processes as well as building users/occupants psychology. Watson and Cole argue the importance of ensuring BEA tool applications facilitate adoption of:

- Interaction with stakeholders throughout the project deliver process;
- High level principals untypical up-front in computer based guides;
- Suites of tools structured around environmental theory to meet all criteria;
- Packaging of tool types to suit particular occupancy scenarios;
- Criteria that has been restructured to accommodate design support;
- Best practice building design as well as building operations and
- Support for decision-making not only trade-offs and communicate outcomes [13,18].

The listings in Table 8 show that stakeholders use many and various applications to communicate and document information.

Table 8 Professional Applied Communication and Documentation

Stakeholde	Professional Type	Communication	Documentation
Investor	Broker, Client, Agent	Feasibility Literature	Policy, Benchmarks
Owner	Corporate, Community,	Policy and Class	Classing System Guides
Developer	Urban, Land, Builder	Bid, Estimate	Development Applications
Manager	Facility, Portfolio, Estate, Asset	Strategy/tactics, Standard	Management Systems
Planner	Portfolio, Asset	Analysis, Assessment	Guidelines, Benchmarks
Purchaser	Eco labeling, Operating costs	Brief/Tender Eco-Values	Tender/Bid Assessments
Provider	Logistics, Marketing	Marketing Assessment	Advertising Presentations
Designer	Architectural, Interior System	Design/Modeling process	Plan, Specifications
Consultant	Engineer, Environment	Investigations R&D Data	Specifications, Reports
Surveyor	Quantity	Calculations, Estimates	Bills of Quantities, LCC
Manufacture	Resource/Emission Control	Specification, Eco-profile	Label, MDS, Warrantees
Manager	Project, Site	Schedule, Performance	Project Planners
Builder	Commercial	Plan, Integrity	Construction Planners
Operator	Facility & Building	Operating Procedures	Manuals
Occupant	Tenant, Owner, Employee	Tenancy Accommodation	Checklists, Contracts

Watson also argues most stakeholders need BEA tools to specifically deliver the means for:

- Providing direction to all stakeholders in documenting/reporting building decisions;
- Ensuring communications are facilitated via agreed sustainability principles;
- Clear definition of sustainability objectives/criteria/priorities/issues at all stages;
- Well defined sustainability criteria/priorities/issues throughout;
- Capturing an holistic picture in a context to make decisions with life cycle information;
- Covering planning, briefing and tender development through to building assessment;
- Structured information streamlined for application against consideration/action points;
- Communicating, presenting and reporting of achievements against set objectives;
- Reducing environmental impacts and benchmarking environmental achievements [18].

Designers needs

As shown in Figure 7 (abridged from Watson [18]) designers need support in steps that each call for direction, information and assessment involving:

- Brief development along with early project consultation;
- Concept development as well as master planning;
- Analysis and comparative assessment;
- Design as well as tender development and
- Detailed design that continues throughout construction [18, 34 to 42].

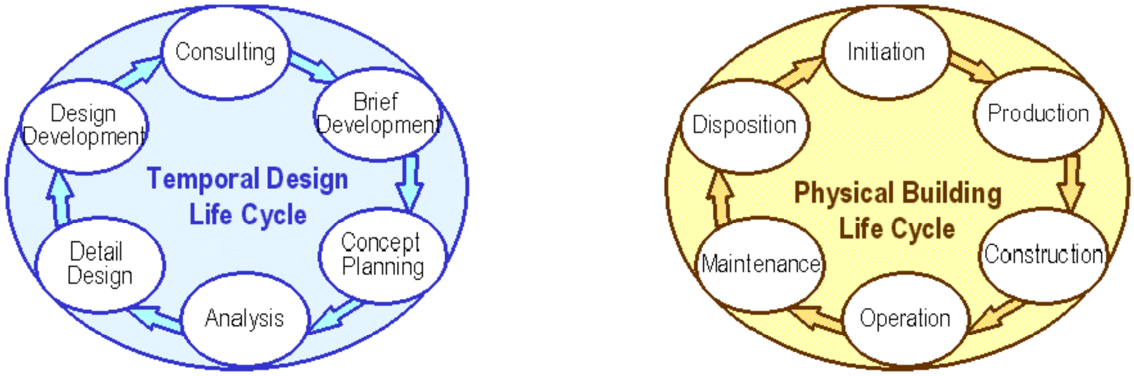

Figure 7 Diagrams of (a) Physical Building and (b) Temporal Design Life Cycles

BEA tools bridging of users scientific assessment and design decision-making psychology is dealt with by Watson's characterization of the design process [18] where he identifies:

- Distinctions between valid assessment and design facilitation with the need for both;
- The potential for application of different types at each stage of the design process;
- Parameter listings with which to develop such tools from a designer's perspective;
- Definitions of tool typologies with diagrammatic explanation and definition;
- Relationships between scientific and design processes and tool end-uses;
- Scientific aspects versus design process tasks in a stakeholder framework and
- Tools as facilitators of processes and to bridge paradigms and professional languages.

Features, for example, that designer's need are listed in Table 9 [34 to 42].

Table 9 BEA Tool Outputs and Forms

Outputs	Various Forms	
Interactive support	Compare With Sustainable End-Points Measure With Recognised Eco Indicators	Compare With Improvement Points Measure With Recognised Ratings
ESD support over project	Strategic Decision Support Planning Guidelines	Tactical Decision Support Checklists At Key Times
Generate sections of documentation	Communication Structures & Support Brief/Tender Development And Evaluation Development Application/Report Building Specifications/ Contracts	Graphics Tables, Reports & Presentations Procurement/Performance Specifications Templates/Frameworks Pre & Post Occupancy Evaluation

Moreover he argues that designers need BEA tools to deliver the means for:

- Well-defined sustainability criteria/priorities/issues at all temporal steps in design;
- Information for strategic decision-making throughout key temporal design processes;
- Facilitating interaction with building design assessment during the design process;
- Assessing design processes, contiguity and gaps;

- Assessment of design objectives according to trade offs/strengths and weaknesses;
- Building design performance prediction and specification;
- Guidelines that facilitate design and project team work as well as
- Accessing detail, strategic and summary information in ready appropriate formats [18].

Commercial industry needs

Cole discusses the importance of ensuring the practicality and cost of making a BEA assessment with valid methodology that is consistent, repeatable, transparent and reliable as well as criteria that are accepted, dynamic and comprehensive [48]. As previously noted there is also a need for industry BEA tools to provide:

- Decision-making frameworks from project inception or earliest in the design process;
- Temporally arrayed frameworks with information relevant to crucial process points and
- Formatted mediums to support decision-making processes.

The industry uses many contracts/practices where, for example, design of floor plates may be separate to facades and sun shading separate from base-structure. One result of such practice is sub-optimal environmental performance. Tools can facilitate integration over such discontinuities [12] such as those listed in Table 10. One application to facilitate integrated decision-making is shown in Figure 8 [13] an interactive wizard drawn as a hub of aims, driving strategies between spokes, in a rim of phases, with tactics on a tread.

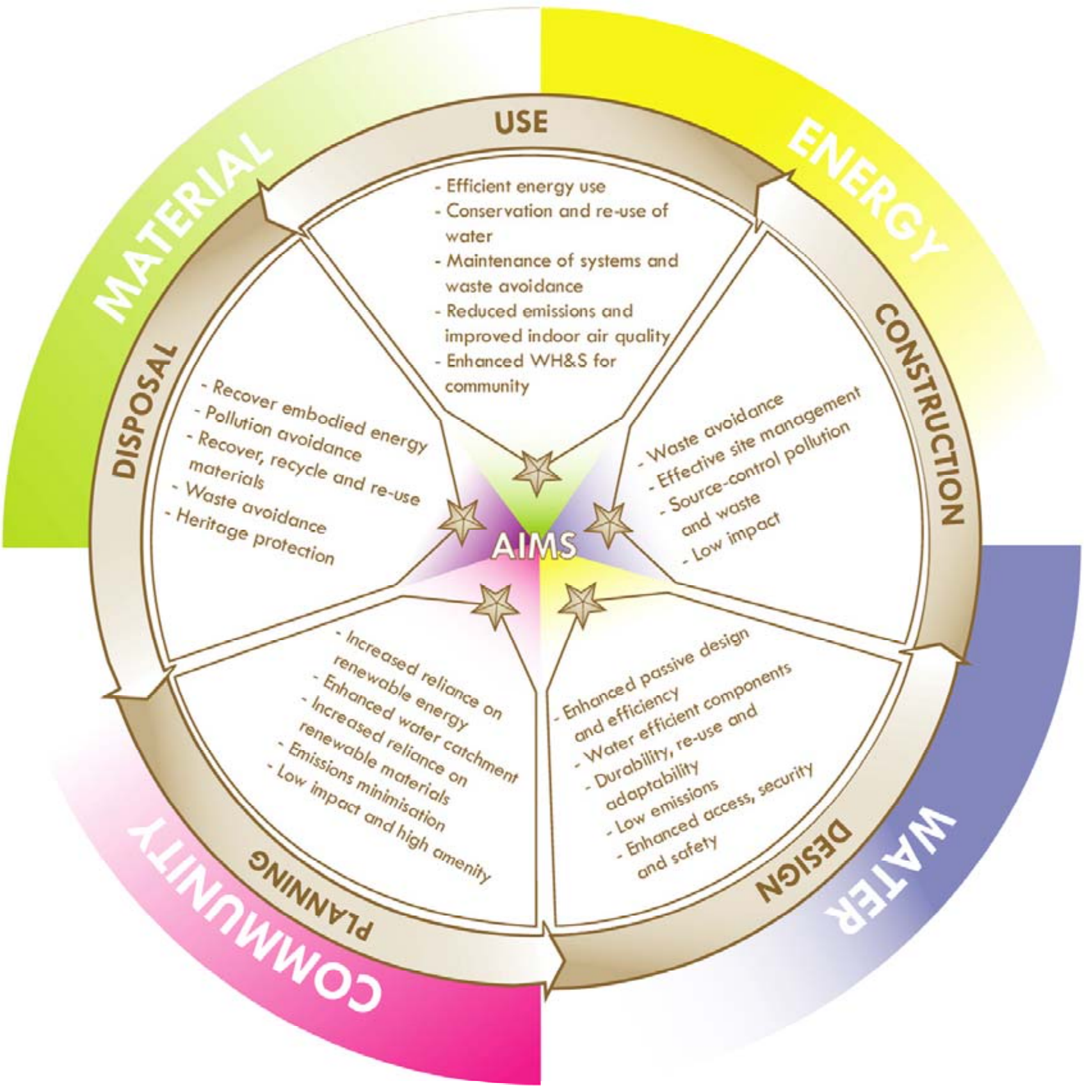

Figure 8 Asset Life Cycle ESD Considerations

It applies a BEA tool box including a:

- Presentation in PowerPoint and on video to provide an overview and introduction;
- Wizard to guide users over the project lifecycle and relate to the issues;
- Rating system to provide for performance assessment and easier appraisal;
- Checklists for tracking effort at each phase of work to facilitate effective responses;
- An eco calculator and icons to facilitate performance reporting and
- Project planner for resource allocation and auditing progress against milestones [12].

Table 10 LCADesign Potential Deliverables

Profession	Affecting Physical buildings	Profession	Communication/ Benchmarking
Facility manager	Maintenance/replacement costing	Asset Manager	ESD Planning, Feasibility assessment
Manufacturer	Eco-label supply chain/packaging	Project Manager	Coordinate cost schedule, SWOT

POSITIONS OF STAKEHOLDER IN BUILDING PROCESSES

To make informed decisions, stakeholders need to know the environmental implications of upstream and downstream operations [38 to 40]. Only half of the BEA tools Seo reviewed covered from planning to disposal at end of life as shown in Table 11 [34].

Table 11 BEA Tool Life Cycle Coverage

Tool	Plan	Design	Use	Dispose
LCADesign, CASBEE, GBTool, BREEAM	√	√	√	√
Evergen Guide, EPGB, BRE Profiles, BASIX with LCAid	√	√	√	
LEED, ECOPROFILE, BEAT, GreenCalc, EQUER, LISA		√	√	√
ATHENA and Green Globes, AccuRate		√	√	
BEES, ECO-QUANTUM, EcoSpecifier		√		√
ENVEST and Green Star		√		
NABERS, ABGR, Firstrate			√	

Some BEA tools are designed to focus on one or two phases rather than many as in Table 12 adapted from [18]. This is not an issue if tools still reflect a stakeholder's policy, position and scope of work or timeframe. Without a common language, however, the use of separate tools to get life cycle cover confuses already complex tasks.

Table 12 Stakeholders BEA Tool Applications by Life Cycle Coverage

Stakeholders/ coverage	Strategic planning	Design/Construction	Operations	Disposition
Provider, Manager	ISO 14000 Environmental Management Systems			
Investor, Client, Designer		Design		
Supplier, Developer		Rate new built		
Operator, Occupant, Broker			Rate as built	

Stakeholders require tools with appropriate applications at appropriate times, early on, as well as in later phases of the project [13] but as Watson points out their understanding of the building lifecycle varies significantly [18]. Many needs are shown in Table 13 where, for example, in investment tools are used to benchmark and communicate policy whereas in construction uses them for scheduling and certification.

Table 13 Professional BEA by Application and Phase

Stakeholder	Profession	Communication	Documentation	Phase
Investor	Broker, Client, Agent	Feasibility Literature	Policy, Benchmarks	*Investment*
Owner	Corporate, Estate	Policy and Class	Classing System	*Acquisition*
Developer	Urban, Land, Builder	Bid, Estimate	Development Apps.	*Development*
Manager	Facility, Portfolio	Strategy, tactic, Standard	Management System	*In-use*
Planner	Portfolio, Asset	Guide, Benchmark	Guide, Benchmarks	*Planning*
Purchaser	Specifier, Costings	Brief/Tender Eco-Values	Bid Assessments	*Procurement*
Provider	Logistics, Marketing	Marketing Assessment	Campaigns	*Project Initiation*
Designer	Architecture/Interior	Design, Model	Blueprints/Plans	*Design*
Consultant	Engineer, Research	Data, Efficiency/IAQ	Reports	*Operations*
Surveyor	Quantity	Specification	Bills of Quantities	*Procurement*
Supply Chain	Plant Control	Eco-label, Product profile	Label, MDS	*Procurement*
Manager	Project, Site	Schedule, Specification;	Project Plans	*Construction*
Builder	Commercial	Plan, Certification	Construction Plan	*Project Delivery*
Operator	Facility & Building	Manual	Manuals	*Occupancy*
Occupant	Tenant, Owner,	Tenancy Checklist	Checklists	*Pre Occupancy*

The term 'building lifecycle' loosely covers the 'planning and design development process' and the building life cycle from cradle to grave. One view of a building life cycle in Figure 9 is becoming accepted [17].

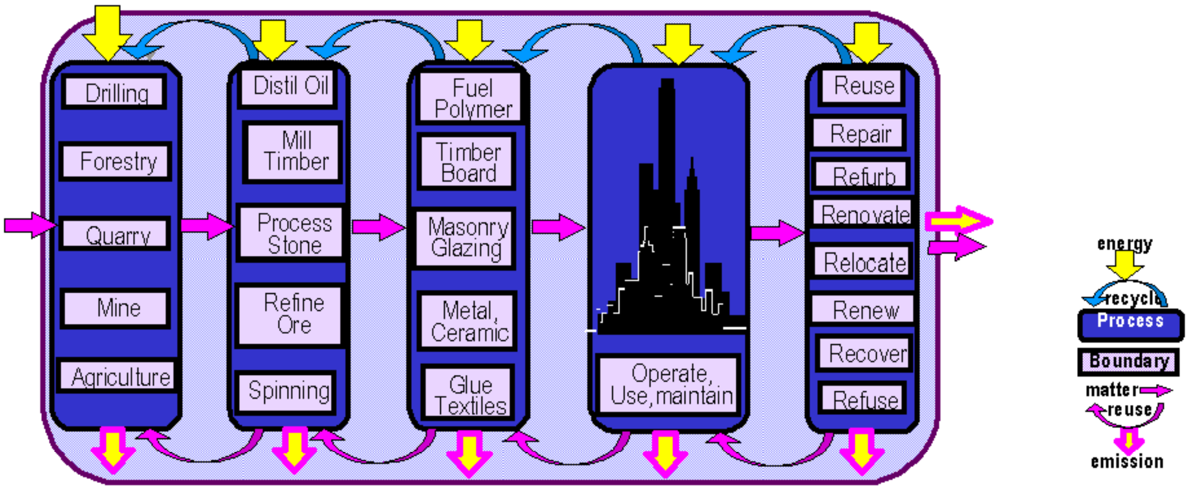

Figure 9 Flow of Product Manufacture Life Cycle to New and Existing Assets

The authors assert that with life cycle terminology undefined, key BEA elements/associations remain undifferentiated and obscured. Watson applies the terms temporal and physical to differentiate the building life cycle from actions in design processes and asset management planning that go to build it [18]. His physical life cycle relates to material flows in forming objects and his temporal life cycle to sequencing decisions [x]. Physical operations defined in the key are depicted over (a) product, (b) project and (c) building phases in Figure 10

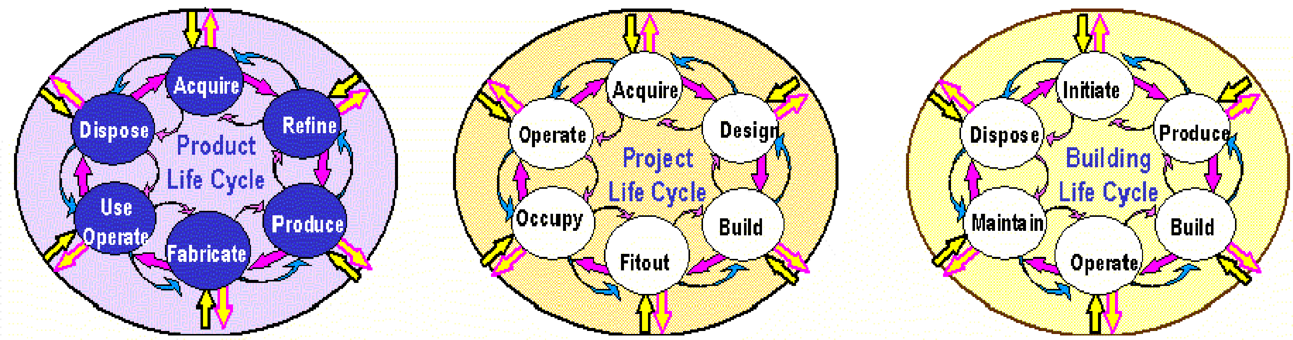

Figure 10 Concept Diagrams of PHYSICAL Product, Building and Asset Life Cycle Phases

By comparison, temporal sequences of operations in (a) asset [26] and (b) design life cycles are given in Figure 11. Watson's differentiation of the physical and temporal is a basis to consider tool applications to facilitate designers and managers adoption of LCADesign.

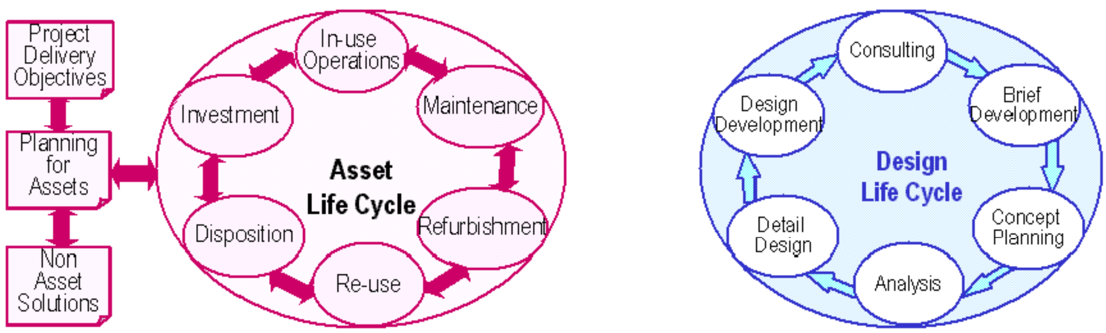

Figure 11 Concept Diagrams of (a) TEMPORAL Asset and Design Life Cycle Phases

REVIEW OF BEA TOOLS

Seo reviewed tools considering level, coverage and weighting, data needs, design/building, end-use and impact assessment/scale as well as weighting including BEA Impact Criteria [14]. A summary of this work without social criteria is given in Table 14.

Table 14 BEA Impact Criteria adapted from Seo

Tool Criteria	GBC	BEES	LCAid	BREEAM	EcoProfile	EcoQuantum	LEED
Energy embodied	+	+	-	+	-	-	-
Energy in operation	+	-	+	+	+	+	+
Land	+	-	-	+	+	+	+
Water	+	+	+	+	+	+	+
Materials	+	+	+	+	+	+	+
Air Outdoors xx	+	+	+	+	+	+	-
Solid	+	+	+	+	+	+	+
Water	+	+	+	+	+	+	-
Others	+	+	+	-	+	+	-
Air Indoors xx	+	+	-	+	+	+	+
Thermal	+	-	-	+	+	-	+
Visual	+	-	-	-	-	-	-
Noise	+	-	-	-	-	-	-
Life Cycle	+	+	+	-	-	-	-
Economic	-**	+	+	-	-	-	-

Key: +included and - = not included ** GBC includes but does not apply economic criteria

All tools except one assessed buildings while one covered both buildings and products. Three tools considered economic and none social or any community related criteria. All tools applied weightings based on judgment with variable transparency as shown in Table 15 [14]. As noted previously only half applied to more than three building life cycle phases

Table 15 BEA Tools Weighting Systems and Transparency

MODEL	Weighting System	Transparency
GBC	Default/modified weights reflect country/region conditions	Evident
LEED	Equal weighting for all criteria	Evident
BREEAM	Fixed weighting through national consultation	Obscured
BEES	Relative weighting –user/other system specified e.g. EPA	Evident
ECO-QUANTUM	LCA-based impact assessment	Relative
ECOPROFILE	Fixed weight ranging from 1-3 except for energy rates 10	Obscured
LCAid	LCA-based impact assessment	Relative

The study concluded that:

- No tool covered all criteria listed with the Green Building Challenge framework the best tool;
- Users preferred dynamic checklists that reflect differences;
- Regional differences are not well addressed;
- No consensus on weighting but user weighting systems were the most flexible;
- No tool considered performance of occupied buildings and
- Real-world design calls for assessment of social community and economic issues [14].

REVIEW OF ADDITIONAL BEA TOOLS

ENVEST 2

The Building Research Establishment (BRE), a U.K. Institute for Construction Industry Research and Development has seven centres including the Centre for Sustainable Construction that has developed BEA tools/methods [51]. Their Environmental and Whole Life Cost Estimating Tool (ENVEST) exists in a system including BREEAM [52]. Together they are used to improve building material assessment, construction, on-site waste and maintenance.

The recently re-released ENVEST 2 simplifies the complex process of designing sustainable office buildings. It helps to predict elements with most influence on a building's environmental impact as well as the effects of choices in building operations and services. The software uses an ecopoint ratings system based on BRE's Environmental Profile database as well as a whole of life costing database and in future it is to include key social and economic criteria. Table 16 summarises a review of ENVEST 2 and its Material database.

Table 16 Review of ENVEST 2 Against CRC-CI Criteria

CRITERIA	ENVEST	Material Profiles
REQUIRED DATA	Quantitative: Energy/Resource consumption, Materials Data	Not transparent within Envest, but assesses all life cycle impacts of materials.
END-USE	Building Design Assessment Tool	Building Element/Material Assessment
ASSESSMENT CONTENT		
Resource Consumption	Operational Energy, Water Use, Material Consumption, Water Extraction, Fossil Fuel/Minerals Depletion, Waste Disposal	
Environmental Loading	Ambient Air, Climate Change, Acid deposition, Human Toxicity and Ozone depletion, Transport Pollution and Congestion, Water Eutrophication Eco-toxicity	
Indoor Air Quality	Ventilation, daylighting thermal comfort, min IAQ	
Economics	Whole Life Costs	
Scale of Assessment	Office Building System Boundary Material Profile Database	Ecopoint rating using impact reduction for long term environmental protection/preservation
Weighting System	Determined via national consultation	Obscured in Envest. No user's weighting
Status	Version 2 for Offices released 2003, for Schools/Hospitals being developed	New/Specific Material Profiles constant review Database is public access
Life Cycle	Building operation and maintenance	Cradle to grave product profiles

Application of ENVEST 2

ENVEST exploits user inputs, ecopoints and whole of life costs to identify and detail where environmental impacts occur for different material selections, building operations and servicing strategies. Designers can generate graphical presentations to communicate a design's eco-credentials to clients/stakeholders. They manually input information including about building:

- Site issues such as location, soil type, etc;
- Design issues such as shape, height, window size, etc;
- Operational issues such as occupancy, period used etc;
- Element choices such as wall structure, window type, finishes, etc and,
- Services requirements such as ventilation, heating/ cooling requirements, lifts etc.

Environmental profiles

The Environmental Profiles database presents information on construction products using a standardized method of identifying/assessing building material impacts from extraction, processing, use, maintenance and disposal. It is the most widely accepted construction materials database in the U.K and was developed in conjunction with representatives from the U.K. industry and government using a standard LCA methodology. It provides raw inventory data as inputs/outputs or impacts e.g. climate change to generate:

- Cradle to grave for building elements using a 60 year lifetime;
- Installed used when a different life span or maintenance plan is envisaged and
- Building Material to provide building blocks for elements/ compare specific products.

Environmental Profiles, for example, are used by:

- The "Green Guide to Specification" to select components on building life performance;
- Suppliers to present credible information using a universal measuring system and
- Envest to present material performance data to identify those that best meet a brief.

Associated tools and systems

Envest, BREEAM and Environmental Profiles occupy an integrated toolbox with rating systems and methods to improve building production from material assessment, construction, and on-site waste to building maintenance as shown in Table 17.

Table 17 A Selection from BRE's Sustainable Building Tools Tool Kit

TOOL/ PROGRAM	BRIEF DESCRIPTION
BREEAM	To assess improved environmental performance-office, retail, industrial building
ECOhomes	Spin off of BREEAM for housing.
Sustainable Refurbishment	Assess refurbishment/redevelopment options via building parameters.
ENVEST	Asses impacts/ whole life costs of building early in design stage.
Environmental Profiles	Certified system for measuring products and materials sustainability.
Environmental Benchmarking	Calculates environmental profiles of large commercial building stocks.
Environmental Management	Kit for offices, local authorities, schools and utilities.
MaSc	Aids construction companies improve business through sustainability.
Planning for Sustainability	Guides developers, local authorities and regional agencies.
Construction Benchmarking	Management Tool to compare improve competitive performance
Design Build Foundation	Aids delivery smarter projects-high standard service, supply, value for money
SABRE	Construction site safety.
Conquas	Standard quality assessment system.
Process Assessment Tool	For studying the whole property maintenance process.
CaliBRE	Toolkit facilitates project team waste avoidance
TEAMS	How time is utilised on Construction Sites.
BREPlan	Determines the predictability of delivery process.
Site Environmental Assessmt	Measures environmental impact/workings on construction sites.
SMARTWaste	Identifies waste streams to enable teams develop plans to avoid it.

Review results

This review found that Envest 2 and Material Profiles database were:

- Not comprehensive, but other BRE tools cover most specific areas of necessity;
- Uses the database for all impact information with alterable defaults for all element choices;
- Uses a hierarchical building element structure and gives choices of generic shapes;
- Determines ecopoint/whole life cost ratings for each material, element component;
- Addresses occupancy and services criteria to assess maintenance/occupancy issues.
- Dynamic with new community, social and economic criteria;

- Developed in conjunction with industry;
- U.K.'s most accepted database with manufacturers keen to have products assessed,
- Material profiles database raises BRE's profile and revenue for further research and development from users subscriptions to access information on issues.

Ecologically sustainable asset management system

Strategic Asset Management SAM [26] and Total Asset Management TAM [27] involve the planned alignment of physical assets with service demand achieved by systematic management of decision-making processes throughout the life of physical assets. A focus on service delivery is the cornerstone because physical assets exist only to support delivery of services such as housing or health. In 1997 The CGI 97 Industry, Community and Government Forum recommended national moves to resolve issues of [10, 38]:

- environmental health performance of buildings, indoor and ambient pollution, ventilation systems and material emissions;
- asset management in planning for resource conservation, energy efficiency, applications of solar and renewable energy, water quality, land use and construction waste to landfill;
- analysis and costing of environmental impacts over the life cycle of built assets;
- development of national strategies for improved communication and establishment of ecologically sustainable procurement and
- environmental management, audit and corrective action, risk and priority assessment in construction and asset management

Subsequently the Building Division of DPW developed a framework for integrating Ecologically Sustainable Development throughout Strategic Asset Management (ESSAM) [53]. Key objective were to enhance capacity to increase reliance on renewable resources, avoid polluting tools and promote healthier and more sustainable practice by agencies and suppliers over the asset life cycle. This framework is a set of self-assessment tools designed to support decision making to [53]:

- towards economically, socially and environmentally responsible development
- promote integration of resource conservation and pollution abatement initiatives;
- improve asset planning, procurement, management, refurbishment and disposal and
- monitor progress in agencies, buildings and suppliers.

Application of ESSAM

ESSAM decision-support tools address stakeholder needs and provide planners, designers, contractors and end-users the policy instruments, guidelines, checklists and rating systems to do this work [13]. They also provide for auditing and accreditation of Agencies, Suppliers, Contractors, Projects and Project Teams to facilitate:

- Benchmarking performance, improved project timing and communication;
- Third party validation, self-assessment/auditing and performance reporting.
- Professional initiatives, product specification and design for ESD solutions and
- Conserving resources of and reducing emissions to community, air, land and water.

Use of the rating systems involves responding to 140 questions about documented management practice. Responses may score from 1 to 4 each with automatically summed results shown as scorecards as depicted in Figure 12. Adoption of ESSAM is a starting point for agencies, suppliers and buildings to initiate an integrated and strategic approach toward ESD by auditing profiling improved performance to facilitate accreditation of environmental management systems and prequalification. Table 18 shows a review of the ESSAM system and attributes listed in Table 19.

Present status

It has been tested on Queensland Government Agencies but not adopted yet as Whole of Government Policy. The system clearly identifies entities that have incorporated sustainable management practice, suppliers promoting ESD and more sustainable building operations.

Table 18 Summary of ESSAM Rating System Review against CRC-CI criteria

SYSTEM	BRIEF DESCRIPTION	
Required data	Quality Management System linked via common point rating system for life cycle steps	
End-use	Improving Strategic Asset Management	Policy, Element/ Planning and Assessment
Scale	ESD of all Asset Types	Compliant economic, social & environmental control
Weighting	Compare Against Full Compliance	Transparent in tool
Status	In house DPW and client Agencies	
ASSESSMENT CRITERIA		
Economics	Whole Life Costs	Whole life most economic cost neutral for service delivery budget
RESOURCE CONSERVATION		
Energy	Passive, Embodied and Operational	Passive Design, Embodied Energy, Thermal Mass, Daylighting, Efficient Use And Waste Avoidance
Material	Consumption	Material Durability, Waste Avoidance, Reliance On Renewables
Land	Conservation	Natural Heritage, site management for habitat protection, local habitat
Water	Consumption	Efficiency In Use, Waste Avoidance And Waste Management
Community	Social and Cultural	Built/Cultural Heritage, Adaptive Reuse, Visual Amenity, Access/Safety
EMISSIONS ABATEMENT		
Energy	Ambient Pollution	Climate Change, Particulates, Noise
Material	Pollution	Construction Waste, Recycled Materials, Toxic Waste, Reparability
Water	Water Pollution	Effluent Reduction, Waste Treatment, Potable Water Quality
Community	Air Indoors	IAQ, Fresh Air Supply, VOCs, Ventilation, hazardous emissions
	Community Protection	Service needs, Interactivity, equity, W& EH&S knowledge
Life Cycle	Full	Cradle To Cradle Life Cycle Boundary including Purchasing
Operation	In-use	Thermal Comfort, Energy Efficiency, Low Water Use, Waste Recycling

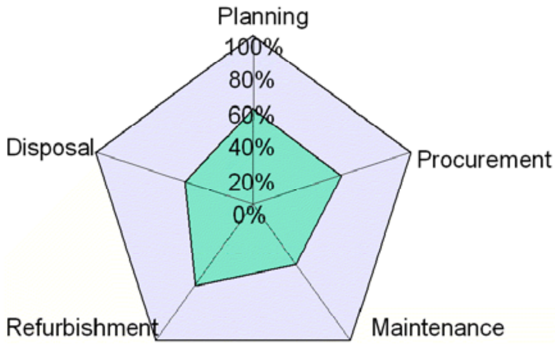

Figure 12 Emergency Services Training Facility ESSAM Profile

Review results

This review found that the ESSAM Rating System was:

- Designed to facilitate five star rated best practice asset management of large estates;
- Based on Environmental Management Approaches to continuous improvement;
- Utilising a hierarchical ESD Strategic planning structure throughout;
- Determining whole life cost ratings for each decision-making process addressing criteria;
- Addressing material and occupancy as well as lifetime maintenance and churn issues;
- Comprehensive being on www/CD with a set of Microsoft Office based applications.

- Lacking any material/buildings database to strongly support specification/procurement.

Table 19 ESSAM Rating System Attributes

ASPECT	POSITIVE ATTRIBUTES	ASPECT	POSITIVE ATTRIBUTES
Coverage	Comprehensive eco, social, economic issues	Weighting	Quality Improvement systems points flexible
	Community, region, service issues	Database	Continuing performance improvement basis
	Whole building life issues addressed	Checklist	Can facilitate varied aspects e.g. location
		Software	XL, hierarchical asset management structure

Ecologically sustainable office fitout guideline

The Queensland Government Guideline for Ecologically Sustainable Fitout of Office Accommodation (GESFOA) provides guidance for conserving resources and minimising emissions over the asset life cycle in planning, design and documentation, procurement, demolition, construction and pre occupancy assessments. A review of this Guideline is shown in Table 22 and attributes are listed in Table 23.

Table 22 Summary of GESFOA Review

CRITERIA	ESD OFFICE FITOUT GUIDELINE	
Required data	Qualitative: Strategies/Tactics linked via common point rating system for life cycle steps	
End-use	Office Fitout Design Guide & Tools	Policy, Element/ Planning and Assessment
Scale	fitout system boundary improvement	Sums points impacts over life cycle cradle to cradle
Weighting	Developed via national Forum	Rating is transparent in tool
Status	http://www.build.qld.gov.au/aps/ApsDocs/esdmain.asp 8000 DVDs released free in 2001	
ASSESSMENT CRITERIA		
Economics	Whole life economic cost neutral for service delivery budget	
Life Cycle	Cradle to Cradle, Pre/post Occupancy, Operations in-use, Efficient Use And Waste Avoidance	
RESOURCE CONSERVATION		
Energy	Passive Design, Embodied, Thermal Mass, Daylighting, Efficiency, Efficiency In-use,	
Material	Reparability Recycling, Durability, Waste Avoidance, Renewables	
Land	Natural Heritage, Manage Site For Habitat Protection, Local Habitat, Recycled Waste	
Water	Low Use, Efficiency In Use, Waste Avoidance/Management	
Community	Social, Cultural & Built Heritage, Security, Access & Safety, Visual Amenity Thermal Comfort,	
EMISSIONS ABATEMENT		
Energy	Ambient Pollution Greenhouse & Acid Gas, Ozone Depletion, Particulates, Noise	
Material	Construction Waste, Recycled Materials, Toxic Waste	
Water	Low Effluent, Effluent Reduction, Waste Treatment, Potable Quality	
Community	Health Protection Air Indoors, Interactivity, WH&S Fresh Air, VOCs, Ventilation, IAQ,	

Application of the guideline

The guideline was launched on the web and DVD as a suite of applications featuring an interactive wizard to guide users decision-making and reporting processes over the project lifecycle and relate to community, energy, materials and water issues. Applications that focus effort, provide for an easier appraisal and facilitate effective responses comprise a:

- Presentation in PowerPoint and on video to provide an overview and introduction;
- Wizard of a wheel to guide users over the project lifecycle and relate to the issues;
- Star-rating system to provide for performance assessment and easier appraisal;
- Excel spreadsheet to act as an eco calculator and facilitate performance reporting;
- Checklists for tracking effort at each phase of work to facilitate effective responses;

- Project planner for resource allocation and auditing progress against milestones and
- Benchmarking material and a trouble-shooter to addresses problems.

Table 23 Summary of Attributes of GESFOA against CRC-CI criteria

ASPECT	Positive Attributes	ASPECT	Positive Attributes
Coverage	Comprehensive eco, social, economic issues	Weighting	Quality Improvement systems points flexible
	Community, region, service issues	Database	Industry benchmark basis
	Whole building life issues addressed	Framework	User friendly and accessible
	Comparison embodied/operational energy	Checklist	Can facilitate varied aspects e.g. location
		Software	MS applications with management structure

Rating initiatives

The objective of this tool is to facilitate managers' decision-making for large-scale asset portfolios where sustainable, best and standard practice vary according to building type, climate, region, occupancy and services delivery. A database of best practice case studies provided relevant performance benchmarks. A combined numerical and "star" rating system differentiates approaches required of the many agencies/suppliers in fitout. Each item has a numerical value depending on its contribution/ importance and users tally scores to a total between 1 and 300. To achieve a star rating an aggregated total is compared against five performance levels that establish the overall star rating. Such approaches to rate performance, facilitate decision-making, provide tools for clients and project teams to summarise/analyse progress and discern the level of performance required from initiation. They can also be used to prioritise responses. The primary objective is to promote healthier and more sustainable practice by agencies/suppliers over the asset life cycle, focus the efforts in areas of concern, compare, verify and analyse strengths and weaknesses; plan for an overall outcome as well as to differentiate organisational approaches. They can drive improvements in overall performance, return on investment and sustainable technology.

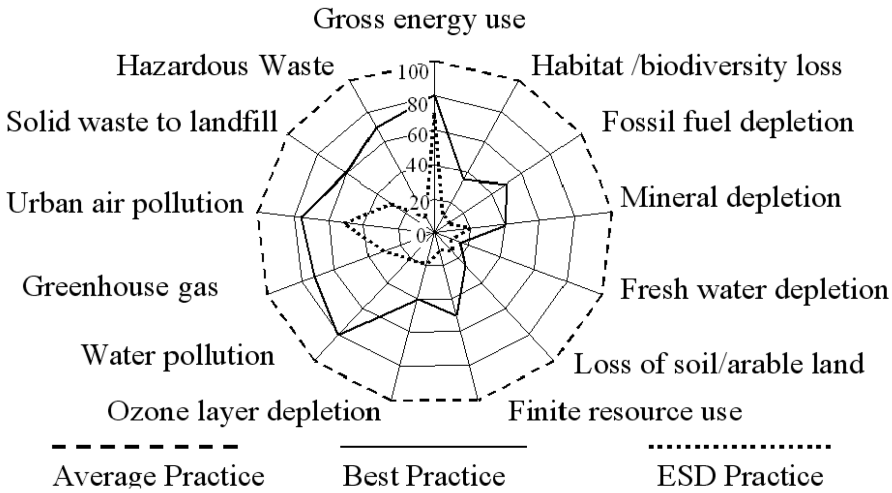

Figure 13 Model Building Fitout Eco Star Diagram

Present status

The guideline was launched in 2001 on the web and DVD. New Government office-building projects implementing the Guideline include the Cairns project that achieved a four and half star eco-rated fitout and was the first awarded a five star Australian Greenhouse Building Rating following one full year of occupied operation. In this case use of and eco-decision support tools designed to facilitate strategic asset management achieved new industry best practice benchmarks.

Review results

This review found that the Guideline was:

- Designed to facilitate project management;
- Achieving a new industry best practice benchmark in first implementation;
- Internet based Software as well as DVD and interactive CD;
- Utilising a hierarchical ESD Strategic planning structure throughout;
- Determining whole life cost ratings for each issue, decision, component;
- Addressing material, occupancy, issues and lifetime maintenance and churn issues;
- Developed in conjunction with industry that uses impact measures/weightings;
- Comprehensive with a range of Microsoft Office applications
- Lacking detail and material profiles to strongly support specification/procurement.

Green Star

Green Star environmental rating system for buildings [54] was created to:

- Establish a common language;
- Set a standard of measurement for green buildings and recognise leadership;
- Identify building life-cycle impacts and reduce environmental impact of development and
- Promote integrated, whole-building design and raise awareness of green building benefits;

It was has built on existing BEA tools including BREEAM and LEED systems and Australian criteria as well as that from VicUrban Melbourne Docklands ESD Guide, the Sustainable Energy Development Authority, Sustainable Energy Authority Victoria and Sydney Water. The Green Star rating system rewards Best Practice, Australian Excellence and World Leadership. Allocation of credits was determined by the GBCA Technical Working Group after consultation with key stakeholders including industry organisations and industry feedback in October 2003.

Green Star - Office Design Rating Tool

The first Green Star rating tool for commercial office buildings evaluates the environmental potential of the design of base building construction or refurbishment. Within each category credits awarded are weighted by virtue of those awarded versus total. The tool aims to:

- Encourage development of new and emerging technologies;
- Provide the potential to reduce environmental impact through direct/ indirect initiatives;
- Encourage a new approach to building design by rewarding best practice/excellence;
- Ensure effective design strategies are accounted for without the overlay of operational management and user behaviour.

Present status

Established late in 2003.Green Star Existing Office provides a complementary rating allowing delivery of initiatives to be validated post-construction. Results of Review of GreenStar Against Assessment Criteria are summarised in Table 24.

Table 24 Review of GreenStar Against Assessment Criteria

CRITERIA		
Required data	Quantitative and Qualitative	
End-use	Improving New Build	Planning and Assessment
Scale	Green Buildings	Building rating considering environmental efficiency
Weighting	Developed via global council	Rating is transparent in tool
Status	Released end 2003	
ASSESSMENT CRITERIA		
Economics	Nil	
Resource Conservation		
Energy	Passive Solar Energy	Embodied Energy, Daylighting
	Operational Energy	Efficient Use And Waste Avoidance
Water	Consumption	Efficiency In Use, Waste Avoidance And Waste Management
Social	Nil	
Emissions Abatement		
Energy	Ambient Pollution	Greenhouse & Acid Gas, Ozone Depletion
Material	Pollution	Construction Waste, Recycled Materials,
Water	Water Pollution	Effluent Reduction, Waste
Operation	In-use	Energy Efficiency

NABERS

The following text was taken from the website in February 2004 [55]. The National Australian Built Environment Rating System (NABERS) is a voluntary performance-based rating system that measures an existing building's overall environmental performance during operation. It is provides investors, designers, builders, owners and tenants a reliable and easy-to-use tool [56]. The system is appropriate for rating existing buildings but inappropriate for use in a regulatory context for new construction. It is intended to be used in a mutually supportive way with other systems currently in the market and was developed to:

- Rate the performance of operational commercial offices and residences;
- Provide separate ratings for office base buildings and tenancies;
- Provide an explicit consistent rating system with clear performance-based structure;
- Provide a realistic rating scale rewards current performance and best practice;
- Take into account building and user considerations recognising occupant behaviour;
- For voluntary self-assessment and options for accredited providers certified rating;
- Primarily use measured quantities or if not feasible use practice-based/default scores;
- Contain appropriate normalisations for factors such as climate and occupancy pattern.

Applications

It can be used to

- define and set operational performance targets
- measure and rate actual performance.
- disclose and report on performance to interested parties,
- establish commercial relationships for monitoring/maintenance of performance targets,
- enlist professional services to improve a rating, and
- make decisions about priority actions or investment options.
- to encourage stakeholders and provide incentives for environmental improvement.

Rating system

Designed for existing buildings during the *operational* phase with benefits including:

- rating things that a building owner/operator can reasonably assume responsibility.
- measuring actual performance with a framework for in-use effectiveness of design.

It will rate a building on the basis of its measured operational impacts with indicators for:

- energy, refrigerants (greenhouse and ozone depletion potential),
- water, stormwater runoff and pollution, sewage,
- waste and toxic materials;
- landscape diversity, transport and
- indoor air quality, occupant satisfaction.

It provides separate ratings for:

- Commercial office whole building: Base building and tenancies with ill-defined boundaries;
- Commercial office base building: Base building with ill-defined boundaries;
- Commercial office tenancy: Tenancies with ill-defined boundaries;
- Residential: For occupants of homes carrying own services and land as a single package.

Performance criteria

It will measure environmental performance against the set of key impact categories listed below. The relevance of these impact categories in a NABERS assessment will depend on whether the rating is for a *Commercial Office Base Building, Commercial Office Tenancy, Commercial Office Whole Building, or Residential Home*. NABERS is structured this way because it is important for a rating system to recognise the:

- different realms of commercial building owners/tenants or home owners; and
- varying key issues relevant to different building types.

Present status

NABERS is currently available in trial form for stakeholder feedback for use and comment. These spreadsheets allow input of required data to complete an assessment and generate a rating score for a particular building. The spreadsheets explain and define the data inputs required and provide clear instruction Review of NABERS Against Assessment Criteria are summarised in Table 25.

Table 25 Review of NABERS Against Assessment Criteria

CRITERIA	
Required data	Quantitative
End-use	Rating Offices and Homes
Scale	ESD end point
Weighting	Transparent
Status	Available, For commercial release end of year
ASSESSMENT CRITERIA	
Economics	
Resource Conservation	
Energy	Embodied
	Energy use, Transport
Material	Waste
Land	Landscape diversity
Water	Water use, Stormwater runoff
Social	Occupant satisfaction
Emissions Abatement	
Energy	Indoor air quality, greenhouse emissions, Ozone Depletion Potential
Material	Toxic materials
Water	Stormwater pollution, Sewage outfall volume
Social	Occupant satisfaction
Life Cycle	In use Operations Rating but Framework for Design for operations
Operation	In use Operations Rating

SCOPE OF BEA TOOLS OVER BUILDING LIFE CYCLE

Cole [44 to 48], Sarja [9], Gilbert [19 to 23], Barton [24, 25, 33] Jones [16,17, 38 to 40] Lovins [35], and Watson [18] and others [29,42,43] all stress that it is critical to identify points of successful intervention in the process before considering/applying effort to integrate key environmental strategies. This is because whole of life strategies apply in each phase and at each point in time pre-existing and subsequent operations need assessing such as shown in Table 26 [13] and for example in design for cleaner production, adaptive re-use and disassembly [49,50].

Table 26 Phase/Flow Considerations Across The Asset Life Cycle

Phase/Flow	Planning	Design/Procure	Construct	Operate	Disposition
Strategies to Conserve Sources Considering					
Energy	Renewables	Passive	Comfort	Efficiency	Embodied
Water	Catchment	Harvesting	Catchment	Low use cycle	Groundwater
Material	Renewables	Interoperable	Disassembly	Recycling	Recover, re-use
Community	Welfare	Educative	Amenity	Interactive	Heritage & habitat
Strategies to Protect Sinks Considering					
Air	IAQ	Breeze flow	Dust & noise	Fresh air	Toxic exposure
Water	Potable quality	Clean delivery	Zero effluent	Low effluent	Contaminants
Material	Re-use existing	Zero toxicity	Zero waste	Repairability	OH&S
Community	Habitat	Equity	Refuges	WH&S	Ecosystem

A further review of Seo's findings revealed most tools studied ignored existing buildings in-use, fitout, refurbishing and disposal phases. The initial review found limitations of restricted scope, shallow focus, time-consuming application and inattention to economic and social criteria as well as specificity to country that limits their relevance to Australia [14]. A recent CSIRO study of BEA tools [34] found only three applied to all four phases from planning to disposal, ten applied to three phases, nine applied to one or several phases only as shown in Table 13. A contrast was found in coverage of:

- Environmental Estimating tool (ENVEST 2);
- Guideline for Ecologically Sustainable Office Fitout (GESOF);
- Ecologically Sustainable Asset Management Rating System (ESSAM);
- Green Star Environmental Rating System For Buildings (Green Star) and
- National Australian Building Environment Rating Scheme (NABERS).

Here three out of the five tools related to all four phases, one to new building design and the other to existing buildings use phase. The RMIT study of over forty tools (all LCA based) reinforces the finding of limitations as it reported that users felt their objectives were unmet [36]. So while there is worldwide interest in and substantial backing for research and development of BEA tools and Australia lags in such development it has not yet inherited their flaws. Australian government and industry are developing such tools as codes and regulations and the emergent BEA tools Green star [54] and NABERS [56]. As Figure 14 shows [12] it was appropriate to develop NABERS that applies to existing buildings considering, for example, Queensland government spending on existing is tenfold that on new buildings.

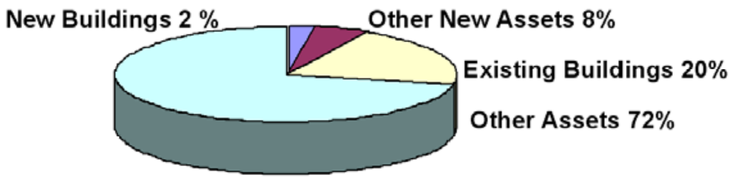

Figure 14 Government Asset Capital Investment in Queensland 2000-01

LCADesign current applications and outcomes

LCADesign has been developed to optimise decisions and assess environmental impact of buildings, combinations of elements/services and building designs [57]. This review has argued that in addition to planned outcomes supplements are required to meet deficiencies as summarised in Table 27.

Table 27 LCADesign Outcomes and Existing issues

Outcomes	Issue	Outcomes	Issue
Design against Sustainability Criteria	Product trade-off only	Whole of Building LCA	To construction
Audit/Assess current code/standard	Needs supplement	Detailed Design Evaluation	Material only
Written Project Applications Brief, DA	Needs supplement	Compare all levels analysis	Lacks space, light
Flexible for varied input/product/ ESD	Needs supplement	Subjective Qualitative LCIA	Lacks user input

LCADesign could further building environmental performance assessment if it facilitated:

- Definition of intent, brief development, concept/tender development;
- Documentation, interactivity, technical and linguistic coordination with other tools;
- Industry/product eco-profiling, specification and eco-labelling;
- Prediction of pre/post occupancy indoor environment;
- Fitout, Acceptance, Commissioning and Maintenance as well as
- Full cradle-to-cradle assessment from investment to end of life deconstruction.

LCADesign could also provide decision support supplements as shown in Table 28.

Table 28 Desirable Attributes of BEA Tools

ASPECT	Attribute Requirement	Solutions
Coverage	Use of other tools as 'plug-ins' to fill gaps.	LCIA Economic, Recycling
	Address whole life cost /building life issues	Maintenance link *2002-010-B- Component Life*
	C-to-G energy operational energy	Look up table from SEDA/ABGR
	Comparison embodied/operational energy	Provide performance simulation
	Comprehensive	plug-ins *2001-005-B Indoor Environment*
	Whole building life issues addressed	Regional, service issues
	User friendly and accessible	Provide Checklists
LCI/ LCIA Database	Requirement for information dissemination	Industry liaison for broad acceptance
	Manufacturer need for product assessment	Revenue and profile raisers
	Selection of real-time products in program	Accepted database for material impact
Weighting	Use 'ecopoints'/ratings to define impacts	eco-labels
Framework	Required performance simulation ability	Data analysis and model plug-ins
	Can facilitate varied aspects e.g. location	User inputs expanded GIS
	Concept Design Modeling	link to *2002-060-B Parametric Building Design*
	Hierarchical building element structure	concept design modellng;
Software	Generic shape/building type choice	link to *2002-060-B Parametric Building Design*
	Uses best practice defaults	Web-based state-of-art information
	Web based for state of art information	Licensing
	Uses defaults that are best practice	Benchmarks
	Hierarchical building element structure	Industry Standard

Furthermore to avoid the ad hoc and linguistically confused array of separate tool the authors recommend that integrated supplements and plug-ins are needed in the right sequence and appropriate level of detail as shown in Table 29.

Table 29 Redressing Deficient Outputs from LCADesign with Outcomes Provided by Plug-ins

Deficient Output	Required Outcome	Plug in
Show Sector Footprint	Load Based Reasoning & Responsibility	Sector LCI
Estimate In Use Energy	Integrate Climate Change Benchmark	NBGRS
Estimate In Use Water	Integrate Water-Wise Design Benchmark	Water Wise
Rate Sustainable Asset	Integrate Sustainability Asset Benchmark	NABERS
Minimum Codes	Avoid Least Sustainable Practice	BCB codes
Rate New Buildings	Integrate New Green Building Rating	GreenStar
Design for Climate	Enhance Reliance on Renewable Supply	Passive Design
Design for Daylight	Enhance Reliance on Renewable Supply	Daylighting
Indoor Air Quality	Protect Occupant Health & Satisfaction	IAQ estimator
Check Supply Chain	Product Supply Chain Integrity	Activity Cards

LCADesign sustainability applications and outcomes

LCADesign could in future become a platform providing SUSTAINABLE building design outputs. As shown previously ESD requires tools to support all stages of temporal delivery:

- Communication support and structures
- Compare against sustainable end points
- Strategic decision support at key times

This entails the following SUSTAINABLE building design outputs:

- Presents whole building life (contextual an holistic)
- Whole of asset/building LCA and LCC, measured with recognised eco indicators;
- Performance predictions and benchmark comparisons;
- Alignment with project targets and Interactive support and assessment;
- Easy to use and understand tools with audits against associated codes and standards
- And enhanced integration with tools (as plug ins).

To become comprehensive LCADesign could also provide various forms of outputs and generate sections of design documentation including:

- Templates/frameworks, Strategic guidelines and checklists
- Briefs and Development applications and Pre and post occupancy evaluation
- Specifications and Performance clauses

As suggested previously, LCADesign should facilitate decision support via key features. A summary given in Table 30 describes ways of adding plug ins for the tool box integratedness with other tools or development of new tools where this is inappropriate.

Table 30 Attributes/Outcome of ESD Tools

ASPECT	Attribute Outcome Requirement	Solution
Coverage	Future development areas	Ecology, community & economy issues
	Whole building life issues addressed	Community, region, service issues
	Design against Sustainability Criteria	◯ Benchmark practical/theoretical criteria
	Comparison against best practice benchmarks	◯ Rated benchmarks
	Alignment with (ESD) principals and policy	Only eco-efficiency ◯ needs supplement
	Design Performance Appraisal Against ESD Criteria	◯ Benchmark needs supplement
	Audit/Assess current codes/standards/contracts	◯ IAQ /Disabled Access BCA codes specs
	Written Project Applications Brief, DA	◯ ESSAM supplement
	Facilitate establishment/alignment of project targets	◯ ESSAM supplement
	Flexibility for different inputs/products/ ESD	◯ Profile
	Whole of Building Life Cycle Assessment	◯Fitout ◯Operate ☐Maintain ◯Deconstruct
Weighting	Use 'ecopoints'/ratings to define impacts	Eco-labels
Frame-work	Hierarchical building element structure	Use existing hierarchies from RAIA etc
	Sustainability Decision Support Hierarchy	Use ESSAM
Software	Generic shape/building type choice	Links 2002-060-B Parametric Building Design
	Detailed Design Evaluation	☐ With Plug-in of other tools
	Compare alternatives all levels design analysis	☐ With Plug-in of other tools
	Subjective Qualitative LCIA methods	☐ no regional /user selection

Key: ◯=in planning ☐=potential

Finally the desired stakeholder applications, features and attributes were classed as having a temporal or physical process association as well as by life cycle phase as shown in Table 31.

FUTURE LCADESIGN APPLICATIONS AND OUTCOMES

To facilitate consistent implementation of initiatives throughout the life cycle LCADesign needs to feed forward/back to cover all life cycle phases and to support decision making over the definition, design, detailing, delivery and deconstruction stages. This requires an underlying sustainable building and procurement framework for supporting/integrating new supplements as well as existing design tools to:

- Facilitate sustainable buildings encapsulate original environmental specifications;
- show cost effectiveness and impact on indoor air quality as part of the design process;
- use acquired knowledge on material selection to the construction industry as a whole.

LCADesign can then serve as a keystone in the whole process of creating sustainable building. The authors propose a comprehensive BEA toolbox is required as depicted in Figure 15.

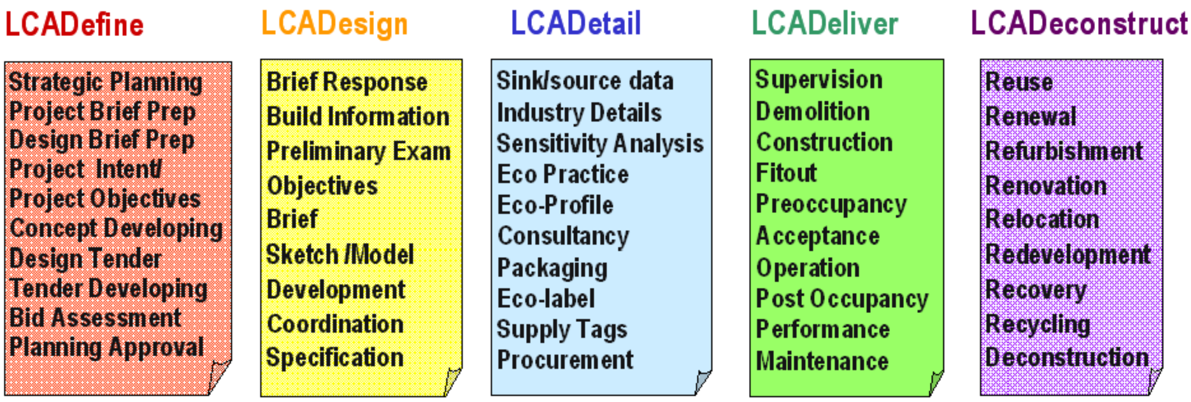

Figure 15 LCADefine, LCADesign, LCADetail, LCADeliver and LCADeconstruct

Modules the authors assert that in the short and long term a one stop BEA shop requires provision of:

- Enhanced initiation of objectives, tenders, bid evaluation for sustainable building;
- Performance Assessment of supply chain;
- Development of a national independent tool to assess impacts of construction products;
- Applications for delivery processes from design to end of life;
- A module to credit end of life recovery and reuse of material elements.

Such a comprehensive integrated a one stop BEA is described in Table 31 and discussed in the following. To start at the beginning in any project a module such as LCADefine is essential for defining investment/planning targets in setting project objectives in concept development/initiation and strategic decision-making. Apart from front-loading LCADesign selections/building information it is needed to link to national BEA tools such as the NGBRS, NABERS and Greenstar as well as to exemplar concept models. Integration is to ensure:

- Technical/Linguistic coordination with other BEA tools
- Documentation and interactivity with frameworks, guidelines and checklists
- Additional life cycle components on operational energy, water and resource etc demands
- Linkage to parametric models and economic cost estimation

A web based LCADetail for procurement module to obtain industry input would acquire knowledge from suppliers to enhance the existing LCI database and provide profiles to the construction industry as a whole for improvement planning and procurement guidance. This service would service an industry that is under growing pressure to improve its bottom line and those needing to select building products on the basis of environmental impacts. Many advanced overseas countries have such systems, albeit less advanced in ICT terms.

Table 31 Integrated LCADevelop, LCADesign, LCADeliver and LCADeconstruct Tool Box

Tool	Requirement	Supplement/Plug in
LCADefine		
Strategic Asset; Planning; Project Intent/Objectives; Project & Design Brief as well as Concept & Tender Development; Design Tender; Bid Assessment; Strategic Asset Planning.	Design Performance Appraisal Against ESD Criteria	◯ ESSAM supplement
	Alignment with (ESD) principals and policy	◯ ESD supplement
	Comparison against building best practice benchmarks	◯ Rated benchmarks
	Facilitated establishment/alignment of project targets	◯ ESSAM supplement
	Interactive supporting framework, guideline, checklists	◯ ESSAM supplement
	Written Project Applications Brief, DA	◯ ESSAM supplement
	Incorporating economic life cycle costing	◯ CRC CI supplement
	Documentation/templates for early in planning	◯ ESSAM brief
	Facilitated communication in strategic decision-making	◯ ESD bid evaluation
	BEA throughout building development process life cycle	◯ ESSAM supplement
LCADesign		
Design Brief Response; Building Information; Preliminary Exam; Design Objectives; Design Brief; Sketch Design.	Audit/Assess current codes/standards/contracts	◯ BCA codes specs
	Detailed Design Evaluation With Plug-in other tools	□ Daylight thermal
	Compare all levels design analysis Plug-in other tools	□ Orient, space, light
	Subjective Qualitative Regional or User LCIA methods	□ Climate, city, GIS
	Design against Sustainability Criteria	◯ Benchmark
	Audit/Assess current codes/standards	◯ IAQ AS Access
	BEA through building design process life cycle plug in	□ Process, Schedule
	Technical/Linguistic coordination with other BEA tools	□ NABERS, GreenStar
LCADetail		
Sink/source data; Industry Supply Detail; Eco Practice/Profile; Sensitivity, Eco-label/ Supply Tags; Procurement.	Sink/source data on state of domestics sources/sinks	Links to SOE
	Industry Details of best /typical/poor practice	◯ eco-practices
	Sensitivity Analysis for improved practice opportunity	◯ Service Consultants
	Eco-Profile reports of industry sectors performance	◯eco-practice reports
	Provide LCA report cards for eco-marketing/labeling	◯eco reports
	Supply Tags to confirm procurement /avoid substitution	□ Avoid substitution
	Green Supply, Marketing and Eco specification	□ Ecoprofile & label
LCADeliver		
Construction; Fitout; Supervision; Acceptance Occupancy; Operation, Maintenance.	Green Procurement/Eco specification	□ Ecoprofile & label
	Project management support plug ins	◯ Supervision apps
	Written Project Applications Brief, DA	◯ Construction
	Written Project/Supply affirmation tags	◯ Acceptance
	Flexibility for different inputs/products/ ESD	◯ ESD Profile
	Whole LCA and links with 2002-010-B- Component Life	□ Maintain ◯ Fitout
LCADeconstruct		
Reuse, Refurbishment, Renewal, Recovery, Renovation, Redevelop.	Enhanced user assessment over full life cycle	◯ Reuse,◯ Recovery,
	Whole of Life Cycle Assessment supplements	◯ Recycling, ◯ Disassembly, ◯ Refurbishment,
	Whole of life coding in Inventory database	◯Renovation, ◯ Occupancy,

Key: ◯=planned □=potential

The LCADeliver module is to provide applications post-design to facilitate construction decision-making and checking to ensure that as-specified, calculated and assessed is implemented. And finally to complete the building life cycle, an LCADeconstruct module for 3D CAD design of building/fitout is needed for assessment and decision support of:

- Product reuse, recovery, disassembly, deconstruction and recycling options
- to credit design for deconstruction and recovery not demolition and waste.

CONCLUSIONS

This report presented LCADesign tool development criteria and characterisations of stakeholder reach and needs for BEA tool applications, attributes, features and functionality. Characterisations were presented with respect to assessing and reporting over the building life cycle to support asset, project, design, product, construction and building processes. Gap analysis of previous/new reviews showed the extent that needs were being met over the building life cycle and found deficiencies in BEA tools and applications. Review of BEA tools in the context of asset, design and building lifecycles and found many lacked:

- Support for stakeholder decision making
- Whole of life considerations integrated from investment /planning
- Consideration of policy development and pre/post-occupancy assessment
- Functionality focussing on physical dimensions rather than service delivery measures.

LCADesign was depicted as a forerunner to an interactively packaged comprehensive toolbox inclusive of:

- A high quality, whole of life tool for built environment professionals
- Better understanding of environmental issues within the built environment professions,
- True building environmental and economic cost assessment,
- Better benchmarking capacity to source appropriate benchmarks,
- Improved decision making support facilitating more sustainable buildings
- Increased use of design support tools through integration across building applications,
- More successful application of environmental goals to built environment projects.

Design performance Appraisal requires consideration of ESD criteria and best practice performance benchmarks/end points, communication of ESD principals/policy for strategic decision-making as well as interactivity with supporting frameworks, guidelines and checklists. Planned attributes of LCADesign were reviewed including provision of:

- Objective detailed and comparative assessment rather than subjective assessments;
- Real time detailed design appraisals and evaluations with tool automatic take-off CAD;
- Generation of meaningful comprehensive graphics, tables and reports;
- Comparing alternatives at all level of design analysis and
- Environmental assessment of building's development from cradle to construction.

Attributes of BEA tools compared to LCADesign were described according to development opportunity to enhance integrated packaging to provide an user-friendly comprehensive flexible tool and appropriate features were summarised for:

- Communication in planning and strategic decision-making towards ESD.
- Documentation and interactivity with frameworks, guidelines and checklists
- Plug ins to facilitate future LCADesign deliverables/attributes in a development timeline.

Prospective LCADesign Attributes were mapped and gaps between needs and tool attributes assessed considering supplements/plug in tools needed to meet stakeholder needs. Concepts were depicted showing alignment of technical/linguistic needs with other Australian BEA tools.

The authors depict a future set of life cycle assessment with computer aided design integrated BEA tools to assess social; functional, economic and technical aspects of sustainable building design considering community, air, land and water resource consumption and pollution. This report provides a detailed case for a set of recommendations it has put forward.

RECOMMENDATIONS

LCAD modules that are considered essential to support the construction industry's efforts leading to sustainable buildings include:

- LCADefine that starts at the beginning of projects to facilitate project initiation/definition;
- LCADesign integrated in a one stop green tools shop to avoid existing overlaps/confusion;
- LCADetail for procurement by exploiting the web based acquisition of credible data from the supply chain to facilitate profiling and eco-labelling of industry sectors and products.
- LCADeliver to carry/check the planning and design effort through to handover/operation
- LCADeconstruct to credit design for recovery not demolition and waste at end of life.

This report recommends that the CRC CI give due consideration to proposals for development of an LCADevelop toolbox as outlined in the following:

- LCADefine a project on investment/ asset planning and links to 2002-060-B Parametric Building Design During Early Design where leadership relies on Asset Management as well as plug ins for concept design modelling.

- LCADesign to Pre-commercialisation trials where leadership relies on integrating the aforementioned as well as such as NABERS, Green Star and other applications, modules of LCADesign across the related modules on the ICT platform.

- LCADetail from Specification and Supply Chain Profiling to Marketing and Procurement that also incorporates product-profiling linking to 2002-010-B- Component Life. Here leadership relies on relies on linking product LCI, industry profiles of processes and potentially to e.g. ecospecifier and ecolabelling regimes

- LCADeliver a project on project/building commissioning/operations linking to 2001-005-B - Indoor Environments. Leadership relies on relies on integrating plug ins for construction scheduling/planning and building operational assessment.

- LCADeconstruct a project on existing building renewal linking to 2003-028-B Regenerating Construction to Enhance Sustainability. Leadership relies on presentation to users of an array of existing and new plug ins yet to be developed.

GLOSSARY OF TERMS

Cradle to gate analysis	Covers impacts from acquisition of raw materials to factory gate.
Cradle to grave analysis	Impact analysis from extraction, manufacture, use to disposal.
Environmental burden	Total release of pollutants of different classes to the environment.
Environmental profile	A list of environmental effects associated with lifecycle of a product.
Functional unit	Functional performance unit e.g. for one square meter over 10 years.
Gross air emission	A description of air emission type and quantity over a product life cycle.
Gross water emission	The water emission type and quantity over a product life cycle.
Gross solid waste	Description of solid waste type and quantity over a product life cycle.
Gross energy requirement	All energy use over product life cycle as fuel or other uses.
Gross fuel & feedstock	All sources and use of energy in a product life cycle.
Gross raw material	Gross raw material use over the product life cycle.
Impact analysis	Analysis of environmental impacts over the defined product life cycle.
Industrial system	Group of operations over a product life cycle that go to make a product.
Inputs	Resources and energy entering the system from the environment.
Inputs to unit operations	Cumulative results of prior calculations plus final operation.
Intermediate materials	Materials made from raw materials that go to make final products.
Life cycle analysis	Environmental inventory, impact and improvement assessment method.
Life cycle inventory	LCI identifies and quantifies resources and emissions in an operation.
Life cycle phases	Production steps from resource acquisition, manufacture, use to disposal.
Operation	A step in a process described by a name, data set and a unique number.
Outputs	Burdens exiting the system boundary include as emissions to the environment.
Process	An operation performed over the defined product life cycle.
Product	An item or service with an existing, previous or potential use or value.
Raw material	A material or feedstock used for a subsequent manufacturing process.
Recycling	A system to reclaim resources otherwise disposed of.
Renewable resource	A resource naturally regenerated in the contemporary time frame.
Solid waste	Solid material waste released to soil from an industrial system.
System	A set of operations acting together to perform a function within a bounded system.
Useful life	A time period from product commissioning to end-of-useful life for an application.
Waste	Output without marketable value released from system to air, water or soil.

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AUTHOR BIOGRAPHIES

Phillipa Watson

Phillipa is an environmental consultant and designer and has been involved in tool theory and the comparative assessment of tools for eight years. Her interest and focus on design decision-making frameworks and the building delivery process has developed through a need for structure and method behind the application of environmental theories and philosophies in her work.

Phillipa graduated from a Bachelor of Architecture in 1999. During her time as a student she worked in a manner of jobs, including architectural research and assistance, disability support for children and their families, other office work and for a short stint, as a member of a stage crew!

Her interest in the environmental impacts of the built environment developed during her architectural studies. Working with Gareth Cole Architects, a passive design firm, she researched materials in detail, having recognised that there was a lack of information available on the environmental consequences of materials/product choices for architects and designers.

Phillipa completed her graduate thesis on this topic, reviewing the state of tool development and arguing for more emphasis on materials/product awareness in research, to assist architects and designers in their move towards environmentally and socially sound designs.

She has worked with professionals, community groups, schools and individuals. Working with the Brisbane City Council as an Integrated Solutions Coordinator for 2 years she consulted closely with Landscape Architects, Architects, Building Service Engineers, Environmental Scientists and policy development Officers to improve environmental implementation on projects and to develop strategies and frameworks for environmental decision-making within the organisation.

She now works with the CSIRO in the CRC for Construction Innovation on Life Cycle Inventory research and tool framework development for the CRC project 'LCADesign'.

She also continues her private practice partnership, designing and consulting on environmental implementation for domestic building projects.

She won a joint award for the Thuringowa Climatic Responsive Housing Design competition, integrating affordable design with climatically responsive design solutions.

Phillipa co-founded the Queensland Life Cycle Assessment Network (QLCA) in 2000 to encourage the discussion of life cycle thinking and assessment across divergent research groups and to assist the progression of life cycle strategies within the Queensland research and building professions. She is also a member of the Royal Australian Institute of Architects Environment Committee.

Penelope Mitchell

Pene is an environmental designer and scientist. She has been involved with sustainability practices, particularly environmental and social sustainability, since 1989. During her Architectural degree Pene obtained work experience with Urban Ecology Australia and Community Aid Abroad (now Oxfam) in Adelaide. Her Bachelor of Architecture degree was conferred in 1994 and she was then involved in many environmental architecture projects as a design consultant. In 1996 she became involved with the Centre for Sustainable Design in the Department of Architecture, University of Queensland and was awarded the 1996 PAA Award. This enabled her to examine ecological possibilities of plywood in sustainable architecture and lead her to the exploration of Life Cycle Assessment (LCA).

In 1997 Pene was awarded an industry based Australian Postgraduate Award (APA-I) in order to complete a PhD on Environmental Life Cycle Assessment (LCA) Implementation within the Australian Building Materials Industry. Since this time she has been involved with the Australian Plywood and Timber Industries and also with Australian LCA development. In 1997 she was awarded a Gottstein Memorial Trust Fund Fellowship that enabled her to travel and explore LCA development in Europe, USA and Canada. On her return from overseas she published a state-of-art LCA report: Mitchell, Penelope (1997) “Environmental Life Cycle Assessment (LCA): 1997 Gottstein Fellowship Report,” Gottstein Memorial Trust Fund, The National Educational Trust of the Australian Forest Products Industry.

While part of the Architecture Department, Pene produced papers and attended conferences in the sustainability and environmental assessment arena, including the EcoDesign’99 Conference in Japan, where she met her partner Paul. She was also active in Environmental Design education and spent time coordinating courses, lecturing and tutoring, as well as organising Environmental Assessment Principles and Practices Seminars for people in industry. She also worked on Environmental Brief and Specification documents.

In 2000 Pene co-founded the Queensland Life Cycle Assessment Network (QLCA) providing a forum for discussion and dissemination of ideas, research and implementation in the LCA area. The monthly meetings generated discussions on information development in Queensland and most importantly, application of LCA in industry. Continuation of this network is planned and integration with other Australian LCA groups is being considered.

Pene moved to the U.K. in 2001 and worked for the world-leading Centre for Sustainable Construction at the Built Research Establishment in 2001 and 2002. There she consulted on (amongst other things) environmental building assessment tools (ENVEST), Life Cycle and sustainable refurbishment initiatives and environmental material assessment tools and reports (Materials Profiles and Green Specification). She also had a son, Toby in March 2002.

In 2003, Pene travelled back to Australia and began work with the CSIRO as a consultant to the Cooperative Research Centre for Construction Innovation (CRC CI) on the LCADesign project. She has been working on developing a life cycle inventory for wood and timber products and on expanding LCADesign to adopt a more holistic life cycle thinking strategy. Through continuation of her PhD degree Pene has gained an extensive knowledge of the state of the art in LCA and has developed a unique approach for industry to adopt LCA principles and disseminate environmental information. She has an established contact network of key LCA practitioners, researchers and interested parties in Queensland, Australia, and overseas. In her work with industry she has developed broad and deep understanding of industry needs, demands and concerns with respect to environmental strategies and the implementation of LCA. Pene will be submitting her Doctoral Thesis in July 2004.

Delwyn Jones

Delwyn began her career in 1965 as a trainee chemist in the Steel industry and gained technical qualifications initially in Physical Chemistry and later in Analytical Instrumentation and Transmission Electron Microscopy. She was awarded her Bachelor of Science Degree in 1980 after majoring in Environmental Studies at Wollongong University. As a BHP research scientist from 1980 to 1995 she also read for a Master of Arts (Hons) from 1983 to 1986 focusing on Technology Management.

Her publications include three books, many book chapters and invited lectures, well over a hundred papers in journals and conference proceedings, numerous research reports and a handful of patents. She was elected to become the inaugural Australian International Delegate to the European Glow Discharge Optical Emission Spectrometry Workshop in 1999, an Associate of the Australian Institute of Physics in 1983 and a Spectroscopy Working Group Member of the Australian Standards Organisation in 1995.

In 1995, Delwyn joined NSW Public Works and Services: Environment Design Unit (EDU) as Principal Consulting Scientist to develop an LCA database, to assess environmentally responsible building design, NSW Supply Contracts and Homebush Bay Development. EDU won the 1997 Banksia Environment Government Initiative Award for this and related work.

She joined Queensland Public Works Built Environment Research Unit, as a Principal Scientific Officer, in 1997, to coordinate a National Community Government and Industry "CGI 97-Directions" Forum for a Healthy and Sustainable Built Environment. She produced the scientific method, strategic planning, communications and publications used to develop the forum's Built Environment Protocol and BEST Force Website exploiting interactive multimedia technology. She jointly won the 1998 Banksia Environment Award for built environment initiative and forum outcomes remain a platform for ESD policy development.

With colleagues she aims to facilitate ecologically sustainable planning, management rating and assessment of commercial, residential and educational buildings. In 1999 she incorporated social and environmental considerations into the Government Asset Management System across each economic and risk assessment procedure therein. She has since co-developed Ecologically Sustainable Asset Management (ESSAM) systems, policy and guidelines applied in projects such as the Emergency Services Training Academy.

In 2000, in collaboration with government, industry and academic colleagues she developed the Ecologically Sustainable Office Fitout Guideline for planning and designing effective conservation of resources and heritage and emissions abatement for health protection in office fitout. In 2001 this work was awarded the Facilities Managers Association Research Award and the NAWIC Award for Innovation in Product Supply. In 2002 Delwyn was seconded to a CSIRO project team at the core of the CRC CI Program B - *Sustainable Built Assets* to develop an Australian life cycle inventory database for use in whole of life environmental costings to facilitate best practice.