INTERNATIONAL INNOVATION

Full Paper

A BUILDING SUSTAINABILITY ASSESSMENT FRAMEWORK

Phillipa Watson
Commonwealth Science and Technology Organisation CSIRO
Cooperative Research Centre for Construction Innovation
phillipa.watson@csiro.au

Delwyn Jones
Cooperative Research Centre for Construction Innovation
Queensland Department of Public Works
delwyn.jones@publicworks.qld.gov.au

Penelope Mitchell
Commonwealth Science and Technology Organisation CSIRO
Cooperative Research Centre for Construction Innovation

ABSTRACT

This paper describes a sustainable building framework developed to facilitate:

- Definition of service needs, goals and outcomes at project initiation;
- Design integration to avoid overlaps/confusion over the project life cycle;
- Detail of the supply chain for procurement, considering life cycle impacts;
- Delivery of accreditation for construction handover and in-use operations;
- Design-for-deconstruction credits for future recovery/re-use at disposition.

The intent of the theoretical framework is to support decision-making through better definition, communication and assessment of sustainable solutions over the building life cycle. It evolved from efforts to characterise stakeholder needs of building environmental assessment (BEA) tools that were found to focus on physical metrics and lack:

- Support for stakeholder decision making;
- Integration of whole of life considerations from early investment planning;
- Consideration of policy development and pre/post-occupancy assessment
- Functionality measures for operational service delivery.

This framework is depicted as five modules in series, with provision for vertical and horizontal integration on an Information and Communications Technology (ICT) platform. The ICT provides for interactive linkage of characteristic application typologies at process points considering temporal and physical development life cycles. To illustrate potential deliverables, examples are shown where the framework was applied to prototype BEA technology, for which it was initially developed.

Keywords: Building Sustainability Assessment Framework

1. INTRODUCTION

This paper describes a building sustainability assessment (BSA) framework developed alongside a prototype building environmental assessment (BEA) tool founded on a 3D object-oriented CAD information and communication technology (ICT) platform. The framework evolved from efforts to characterise and resolve issues in meeting stakeholder needs for BSA applications. After introducing the context, prototype, scope and methodology the paper:

- Critiques basic tool theory and life cycle thinking;
- Reviews characterisations of user needs for such applications;
- Discusses early findings and introduces the framework's key modules; and
- Predict BEA tools leverage off object-oriented CAD ICT platforms.

1.1. BUILDING SUSTAINABILITY ASSESSMENT

In the context of ecologically sustainable development (ESD) and building design, Sarja (2002) argues that buildings are long lasting products of our society that need sound ecological management. Indeed, it is commonly accepted that building greenhouse emissions (GGE) as shown in Figure 1 need such management. Jones et al (2003) reported the building sector GGE share in 1999 was 22% of the total with residential and commercial operations dominant.

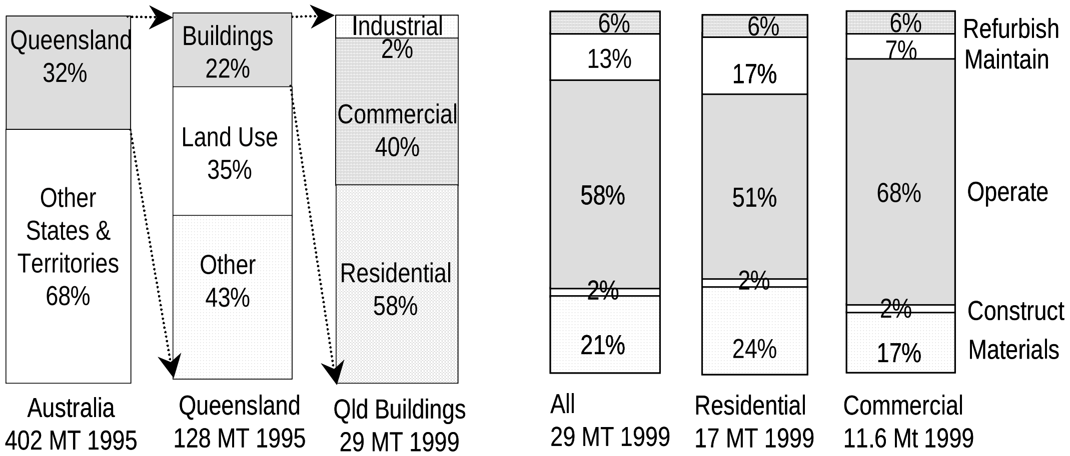

Figure 1. (a) Building National Share GGE and (b) QLD Building Phase Share GGE

More sustainable building to reduce such environmental as well as social and economic impacts involves coordinating stakeholder needs across an array of criteria. Sarja (2002) argues that such design criteria include:

- Social aspects of welfare, health, safety and comfort;
- Functional and economic aspects of use incorporating flexibility;
- Technical aspects of serviceability, durability, reliability; and
- Ecological aspects of resource depletion and pollution abatement.

To consider a building (for ESD in parenthesis) users apply such tools as:

- Classing systems for (sustainable), premium and typical accommodation;
- Rating systems to compare (sustainable), best and typical operations;
- (Environmental) condition assessment in procurement and tenancy;
- Acquisition systems to support policy direction in a corporate portfolio; and
- Benchmarks and labels of (sustainable), best and typical operations.

Cole et al (2000) and Tucker et al (2003) stress that addressing sustainability issues requires professionals to work through increasingly complex problems while instigating new systems to overcome difficulties in gathering, analysing and verifying knowledge. Watson (2004) and Seo (2002) reveal increasing demand for detailed design performance appraisal, a uniform level of broad information, and tools that use new environmental, social and economic costing methods.

1.2. A PROTOTYPE BEA TOOL CALLED LCADESIGN

In response, the CRC for Construction Innovation funded development of a software tool, with the aim that it should become the preferred environmental appraisal tool for Australian commercial buildings. This software tool is called LCADesign, an acronym for life cycle assessment (LCA) with computer-aided design (CAD). It provides environmental and economic cost assessment of commercial building design across planning and checking applications. LCADesign is automated to obtain data directly from 3D CAD object-oriented models from a comprehensive information and communications (ICT) platform. The software calculates and reports design impacts via the Express Data Manager that links information from CAD models to life cycle inventory and environmental impact indicators databases.

1.3. AN ICT PLATFORM FOR A NEW THEORETICAL FRAMEWORK

A critical aspect is the ICT platform from which LCA Design leverages its function. The concept of integrating disparate programs, in a hub, to share information effectively is not new. However, creating a hub and facilitating its use for various outputs would be much more difficult without such a platform. Barton et al's (2002) argues that BSA requires consideration of impacts throughout the building life cycle. So to consistently facilitate decision-making LCADesign had to feed both forward and back between phases of definition, design, detailing, delivery and deconstruction.

Apart from the ICT platform, a theoretical framework was needed to provide reference points for and inform connections to databases, data managers and CAD models. Such a framework, called LCADevelop, emerged as an integrated set of modules as depicted in Figure 2.

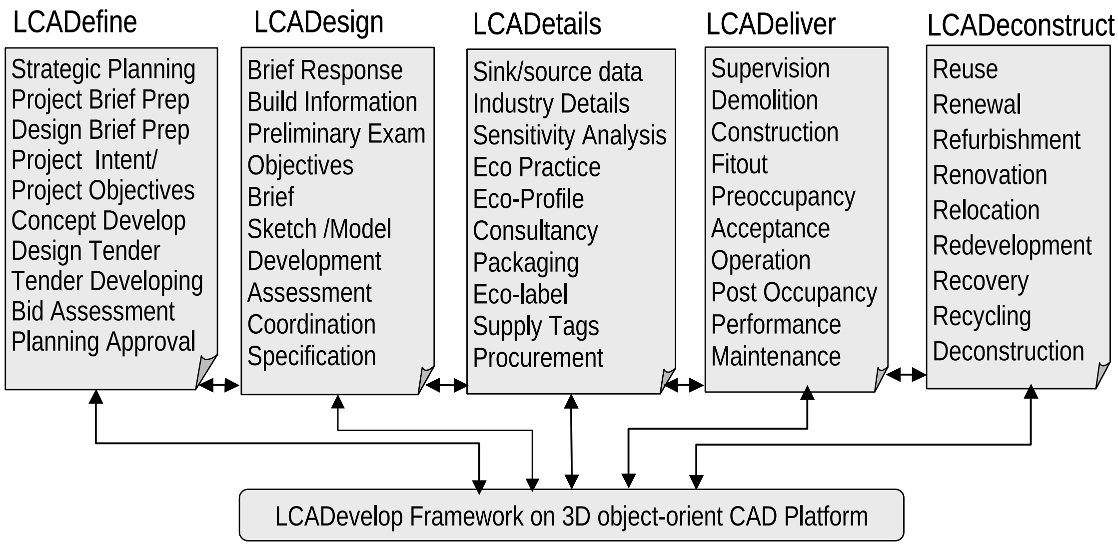

Figure 2. LCADevelop Framework for BSA Tools

2. SCOPE AND METHOD

The framework's theoretical foundation evolved from interrelated work including:

- Reviews of theory related to BEA and BSA tool development to date;
- Reviews of leading international and national tools;
- Consultation with stakeholder groups; and
- Assimilation of background knowledge with that acquired in this process.

Tools listed in Table 1 were evaluated to gain an understanding of:

- There attributes, functionality and stakeholder coverage;
- Professional users and their need for various applications; and
- Features and functionality needed to meet such user needs.

Table 1 Building Environmental and Sustainability Assessment Tools Studied

Source	Building Environmental Assessment Tools and Reference to Developer
Europe	Ecoprofile NBI (2002), BEAT DBUR (2002), GreenCalc NIBE (2002), Life Cycle Simulation Tool (EQUER) EMCEP (2002), ECO-QUANTUM IVAM (2002)
USA	Leadership in Energy & Environmental Design (LEED), USNAGBC (2002) Building for Environmental & Economic Sustainability (BEES) NIST (2002)
Canada	Green Building Tool (GBTool) NRC (2002), Green Globes CEE&EEC (2004), ATHENA Environmental Impact Estimator TASMI (2002)
Britain	BRE Environmental Assessment Method (BREEAM) BRE (2002a), BRE Material Environmental Profiles BRE (2002b), Environmental Estimator (ENVEST 1) BRE (2002c), ENVEST 2 BRE (2003)
Japan	Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) JSBC (2002)
Australia	Green Star AGBC (2004), Evergen CSIRO (2002a), AccuRate CSIRO (2002b); National Building Environment Rating Scheme (NABERS) Environment Australia (2002); LCA In Sustainable Architecture (LISA) BlueScope Steel (2002).
NSW	Australian National Building Greenhouse Rating scheme (NBGR) by SEDA (2002), Building Sustainability Index (BASIX) DIPNR (2002), LCAid DPW&S (2002), Environmental Performance Guide For Building (EPGB) DPW&S (2002)
Victoria	EcoSpecifier RMIT & Eco-Recycle Victoria (2004), House Energy Rating First-Rate SEAV (2002)
QLD	Guideline for Ecologically Sustainable Office Fitout (GESOF) Qld Govt. (2002), Ecologically Sustainable Asset Management (ESSAM) Barton et al (2002)

Studies that characterised tool applications and their capacity to meet user needs across asset, design, project, and building lifecycles were reviewed considering:

- Findings of Seo (2002), RMIT et al (2002) and Watson et al (2003);
- User applications over the full life cycle from cradle to cradle;
- Evaluation of deliverables by temporal and physical life cycles;
- Stakeholder applications against potential tool deliverables;
- Gaps between user needs and tool attributes/applications; and,
- Prospective plug-in tools needed for their work to fill such gaps;

Characterisations were then considered from previous and new studies including:

- Architectural design process reviews by Watson (2004);
- Building product supply chain and industry studies by Mitchell (2004); and
- ENVEST2, GESOF, ESSAM, Greenstar and NABERS tools.

3. BASIC THEORY AND CHARACTERISATION

Watson (2004) defines tools as things that make a job easier or more efficient and argues that BEA tools should:

1. Act as a bridge between assessment and user tasks to be undertaken;
2. Connect different professions, ideologies and essential paradigms;
3. Provide direction and facilitate clear communication; and,
4. Structure and streamline information.

Direction and communications, for example, is facilitated as tools clarify definitions, aims, objectives, policy, strategies and tactics and provide material for presentation and outcome reporting.

Watson classes BEA tools mainly as checklists, manuals, eco-labels, blueprints, scoring systems, computer based guidance, building component lists, LCA and eco preference lists. While such tools should be comprehensive and flexible, Cole (2000) warns they must be practical and cost effective. And furthermore they must use accepted criteria and apply transparently consistent methodology.

Barton et al (2002), Jones et al (2004), Lovins (2004) and Todd et al (2001) all stress that it is critical to identify successful intervention points in the process before applying effort to integrate key environmental strategies. This is because whole of life strategies apply at each point in time and pre-existing as well as subsequent operations need assessing, for example in design for cleaner production, adaptive re-use, and disassembly.

Watson (2004) argues the key to ensure BEA tool adoption is their facilitation of:

- Interaction with stakeholders throughout the project delivery process;
- Adoption of high level principals untypical in computer based guides;
- Structuring as tool suites around environmental theory to meet all criteria;
- Packaging of tool types to suit particular occupancy scenarios;
- Criteria restructuring to accommodate design support;
- Best practice building design as well as building operations;
- Support for decision-making and communicating of outcomes and
- Assessment provided in a life cycle framework with benchmark impacts.

3.1. REDEFINING LIFE CYCLE THINKING

Barton et al (2002) and Lovins (2004) assert that compared to the linear norm, life cycle thinking applied in decision-making drives more objective strategic planning to better economic and environmental outcomes. Sarja (2002), Watson (2002 and 2004), Mitchell (2004), Jones et al (2003) and Watson et al (2004) all stress that a holistic life cycle structure is required for built environment decision-making.

The RMIT (2002) study found the term building lifecycle loosely covers the planning and design development process from cradle-to-grave. Rather than management of asset, facility, design, construction and in use processes it is asserted that BEA tools have drawn on life cycle theory developed around a primary industry sector picture of mines, factories, consumer goods and transportation. It is to be expected then with life cycle terminology poorly defined that key BEA elements would remain undifferentiated and associations obscured.

The BSA framework was founded on Steve Watson's (2004) life cycle theory that defines life cycle phases as being temporal or physical in nature. He differentiates the building's physical life cycle from actions over a temporal life cycle in design processes and asset planning that go to build it. His physical life cycle relates to material flows in forming objects and his temporal life cycle to sequencing of decisions as shown, for example in Figure 2. With physical and temporal processes each essential for ESD, the framework, depicted in figure 2 was structured around temporal building life cycle processes considering the physical operations in material acquisition from and disposal back to the earth.

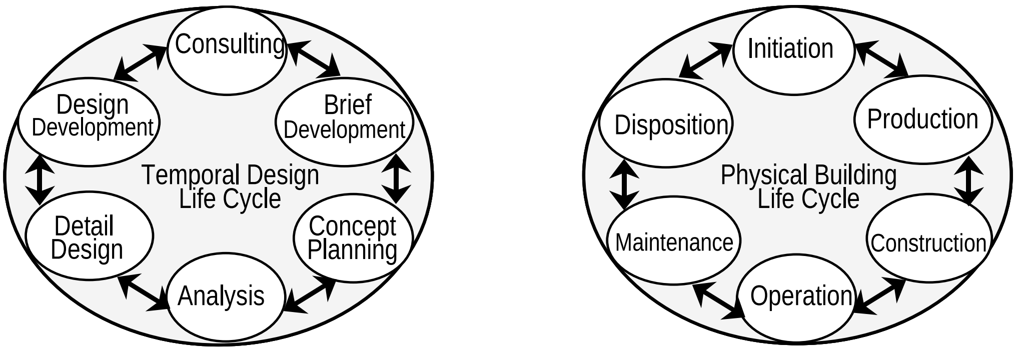

Figure 2 Concept Diagrams of (a) Temporal Design and (b) Physical Building Life Cycles

4. RESULTS AND DISCUSSION

In current sustainability practice a fundamental user requirement is for clear communication to be derived from a common national platform. This requires adoption of a common language between disparate professions with fundamentally different application needs. Seo (2002) found existing tools and frameworks were focused on physical metrics and most lacked:

- Comprehensive support for stakeholder decision making;
- Integration of whole-of-life considerations from investment planning;
- Consideration of policy development or pre/post occupancy assessment;
- Functionality measures for operational service delivery; and
- Flexible outputs for the broad range of potential users.

Watson (2004) found tools did not cover critical applications to address, such as:

- Stakeholder needs and relationships in the built environment;
- Different contexts in relation to the building industry; and,
- Local environmental, and standard social and economic criteria.

As shown in Table 2, a reconfigured set of results from Seo (2002) and Folient et al (2004), some tools focus on one or two phases rather than most which by itself is not an issue if they reflect stakeholder policy, position, scope and timeframe. Without a common language, however, the use of separate tools to achieve life cycle coverage was found to add confusion to already complex tasks.

Table 2 BEA Tool Life Cycle Coverage

BEA Tool	Plan	Design	Use	Dispose
CASBEE, GBTool, BREEAM, Green Star				
Evergen, EPGB, BRE Profiles, BASIX, LCAid				
LEED, Ecoprofile, BEAT, Greencalc, EQUER, Envest, LISA				
ATHENA and Green Globes, AccuRate				
BEES, Eco-Quantum, EcoSpecifier				
NABERS, NBGR, Firstrate				

Watson’s (2004) argument that BEA tools must act to bridge service delivery needs, professional applications, management systems, design and construction processes as well as occupant psychology was supported by overall results. Few tools applied to brief development or concept planning and the focus of most was design. Potential to provide applications for managers, owners, purchasers, operators and occupants was considerable with features required for:

- Alignment with ESD principals and policy
- Enhanced user assessment of product impacts over the full life cycle and
- Comparisons against best building practice performance benchmarks.

Watson (2004) showed BEA tools providing design professionals the means to:

- Appraise design performance against sustainability criteria;
- Document/ template briefs, specifications, contracts and evaluation; and,
- Interact across framework, guideline and checklist applications.

4.1. REDEFINING APPLICATIONS BY LIFE CYCLE

To make informed decisions BEA stakeholders need to asses upstream and downstream operations but as Watson (2004) and others point out, understanding of the building lifecycle varies significantly. Stakeholders require tools with appropriate applications in the early as well as later project phases as in the variety shown in Table 3 where, for example, investment tools may be used to benchmark and communicate policy, whereas in construction scheduling and certification tools are common.

Table 3 Professional Tools by Application and Phase

Stakeholder	Profession	Communication	Documentation	Phase
Investor	Broker, Client	Feasibility Study	Policy, Benchmark	Investment
Owner	Corporate, Family	Policy and Class	Classing System	Acquisition
Developer	Urban, Builder	Bid, Estimate	Development Apps.	Development
Manager	Facility, Portfolio	Strategy, Standard	TQM System	In-use
Planner	Portfolio, Asset	Guide, Benchmark	Guide, Benchmark	Planning
Purchaser	Labeling, Costing	Brief/Tender	Bid Assessments	Procurement
Provider	Logistics, Marketing	Market Analysis	Campaigns	Initiation
Designer	Architect/Interior	Design, Model	Blueprints/Plans	Design
Consultant	Engineer, Research	Data, Efficiency	Reports	Operations
Surveyor	Quantity	Specification	Bills of Quantities	Procurement
Supplier	Plant Control	Label, Profile	Label, MDS	Procurement
Manager	Project, Site	Schedule,	Project Plans	Construction
Builder	Commercial	Plan, Certification	Construction Plan	Delivery
Operator	Facility & Building	Manual	Manuals	Occupancy
Occupant	Tenant, Owner,	Tenancy Checklist	Checklists	Commission

As Barton et al (2002) conclude, unless they embody ESD requirements then as most commonly occurs tools will exclude ESD by their application. This is critical from the earliest phase in which BEA tools need to provide investment policy, benchmarks and rating applications. This is because timing is critical with prior allocation to master plan, infrastructure, orientation and budget limiting later opportunities. As Lovins (2004), Watson (2004) and Jones et al 2003 all stress, by the time designs have developed it is already far too late to integrate most sustainability initiatives that Watson argues must be viewed:

- Professionally from a lifecycle perspective to understand the true situation;
- Holistically in context considering occupants and never in isolation; and,
- As cyclic concepts that need early consideration and budget allocation.

Table 2 showed that 16% of the BEA tools, Seo and Folient et al reviewed, covered four phases, 48% did three, 24% applied to two and 12% to one only.

None had investment applications or aimed for BSA. A further review of Seo's work revealed most tools ignored extant buildings in-use, fitout, refurbishing and disposal. He found limitations including restricted scope, shallow focus, time-consuming application and inattention to economic or social criteria as well as specificity to country of origin that limits their relevance to Australian conditions.

Some contrast was found in review of newer tools where the ENVEST2, GESOF, ESSAM, Green Star tools covered four phases. The exception was NABERS that fills a void for extant buildings where renewal is critical for ESD, because as Jones et al (2003) report State governments may spend up to10 times more on existing than new building stock annually. Apart from LCADesign, no newer tools directly assessed economic costs. However the NABERS, GESOF and ESSAM tools considered social or community impacts of, for example, biodiversity and equity. Also BRE (2002a,b, c) Watson et al (2004) show Envest 2 is a component of a large tool kit with some economic and social applications. Newer tools had increased coverage of assessment by phase, economic and community aspects.

So while the worldwide interest in research and development has produced many BEA tools and although Australia may have lagged behind in development, it has not yet inherited the deficiencies in narrow coverage. The newer Australian government and industry-developed tools may also better suit stakeholder applications than earlier ones. Other tool attributes critical for future development of LCADesign were identified, for example, as summarised Table 4.

Table 4 Some Desirable Attributes of BEA Tools

Aspect	Attribute Requirement	Potential Solutions
Coverage	Address whole life building cost issues	Maintenance linked to component life
	Cradle to cradle operational energy	Integrated look up table as in NBGR
	Comprehensive Interior occupancy	Plug-ins for indoor environment
LCA Database	Industry broad acceptance	Industry liaison & information dissemination
	Manufacturer product assessment	Licensed access industry web portal
	Select products in real-time program	Industry web portal used for material impact
Weighting	Use 'ecopoints'/ratings to define impacts	Building industry product eco-labels
Framework	Design performance simulation ability	4D CAD model with plug-ins for data analysis
	Concept design modeling	Link to parametric building design exemplars
	Hierarchical building element structure	Link concept to detail design model
Software	Generic shape/building type choice	Link to parametric building design
	Uses best practice defaults	Industry web portal for logging benchmarks
	Hierarchical building element structure	Advantageous 3D CAD Building and Product

4.2. THE FRAMEWORK

The earliest intent in developing the BSA framework for many types of tools was to facilitate improved definition, guidance, communication and decision-making support throughout the building life cycle. It was developed from reviewing theory, tools and stakeholder opinion and was grounded on the authors' experience and knowledge assimilated in this research to:

- Encompass both temporal and building life cycles;
- Establish a platform for the networking and the exchange of information;
- Facilitate integration of applications of both overview/detail;
- Support asset, design, construction and management professionals and,
- Identify application/format of information useful at key process points.

The emergent framework, then, was founded philosophically on consideration of built shell, interior and engineering systems theoretically as ecological systems. This was essential to facilitate consideration of the numerous up-and-down stream implications over lengthy building life spans and at all technology levels.

Early on, the framework revealed key points where a broad range of stakeholders' economic, social and environmental cost/benefit assessment needs had to be addressed. It has been asserted that in the short and long term, a comprehensive BSA framework, as depicted in Figure 1, requires provision of:

- Enhanced definition of objectives, tender and bid evaluation;
- Performance Assessment over and of the supply chain;
- Development of national tools to assess impacts of construction products;
- Applications for delivery processes from design to end of life; and,
- End-of-life recovery and reuse of material elements.

Recently, the theoretical BSA framework was used to define proposed interactive tool prototypes (automated from a 3D CAD) considering:

- Communication and alignment with ESD principals, policy and planning;
- Technical and linguistic coordination with other BEA tools;
- Comparative assessment against best building performance benchmarks;
- Documentation/templates for briefs specification, contract and evaluation;
- Interactivity with supporting frameworks, guidelines and checklists and
- Plug in tools to meet user needs for in-use assessment on ESD criteria

As a conceptual guide/map to the process of creating sustainable building the framework indicated practical tools needed to stage their cover to apply to:

- Define service needs, goals and outcomes at project initiation;
- Design with outcomes integrated over the project temporal life cycle;
- Detail the supply chain with information on whole of life cycle issues;
- Deliver high quality construction as well as management in-use; and,
- Deconstruct considering recovery credits as apposed to waste.

4.3. MODULES OF THE FRAMEWORK

The authors developed this framework in modules, required for a practical toolbox. This demanded further integration of plug-ins and supplements in the right sequence and level of detail to avoid issues with the current ad hoc, linguistically confusing, separate tools.

The first BSA module called LCADefine as depicted in Table 5 has components to define investment planning targets and setting of project objectives as they occur in project initiation. This is to facilitate up-front acquisition of key information in a project to better inform the planning process.

Table 5 A selection from the LCADefine Module of the BSA Framework

Applications	Requirements	Solutions/Plug-Ins
Asset Planning	Asset Performance Appraisal Vs ESD Criteria	ESSAM supplements
Brief Development	Compare with best practice benchmarks	Rated benchmarks
Design Brief/Bid	Incorporating economic & environmental costing	LCADesign capacity
Tender/ Concept	Documentation/templates for early planning	ESSAM supplements
Bid Assessment	BSA over building development process life cycle	ESSAM supplements

In addition, as shown in Table 6, design tools need to ensure technical and linguistic coordination with other BEA tools and linkage to parametric models.

Table 6 A selection from the LCADesign Module of the BSA Framework

Applications	Requirements	Solutions/Plug-Ins
Design Brief Response	Audit/Assess current codes/standards/contracts	Codes, IAQ, Access
Building Information	Compare all levels design analysis Plug-in tools	Orient, space, light
Preliminary Exam	Design against Sustainability Criteria/Exemplars	Concept, NABERS
Design Intent	BSA through building design process plug-in	Process supplement
Sketch Design	Technical/Linguistic coordination with all tools	Greenstar

As depicted in Table 7, the third element is a procurement module for selecting lower impact products. Called LCADetails, it contains material profiles, supply-chain knowledge and guidance that is currently under-informed compared to other countries with advanced procurement systems, albeit less so in ICT terms.

Table 7 A selection from the LCADetails Module of the BSA Framework

Applications	Requirements	Solutions/Plug-Ins
Procurement	Eco specification & Marketing	EcoProfile & labeling
Sink/source data	On state of domestics sources/sinks	Link to Resources
Supply Chain Detail	Industry Details of best /typical/poor practice	Eco-profiles/practice
Eco Practice Notes	Sensitivity Analysis for improvement opportunity	Service Consultants
Eco Profiles/Labels	Reports of industry sector/product performance	Standardised reports

As shown in Table 8, an LCADeliver module contains applications for project decision-making to ensure that as assessed and specified is delivered.

Table 8 A selection from the LCADeliver Module of the BSA Framework

Applications	Requirements	Solutions/Plug-Ins
Acceptance	Template Project Applications Brief, DA	Eco practice notes
Construction Delivery	Eco specification & Supply affirmation tags	Product eco-labeling
Accommodation Fitout	Project management support applications	LCADesign link GESOF
Pre/Post Occupancy	Project Guides, Benchmarks &Templates	Occupancy checklists,
Maintenance	Whole LCA links with Component Life	ESSAM supplements

Finally, the LCADeconstruct module contains applications to facilitate crediting design for disassembly and industry recovery initiatives for reuse and recycling.

Table 9 A selection from the LCADeconstruct Module of the BSA Framework

Applications	Requirements	Solutions/Plug-Ins
Design Disassembly	Credit recovery and re-use potential	Code LCI to credit reuse
Refurbishment, Reuse	Refurbishment recovery eco practice notes	Rate, guide & checklist
Redevelop, Renewal	Disassembly eco practice notes	Rate, guide & checklist

5. PERSUASIVE TECHNOLOGY

To date, the LCADevelop framework has been employed to identify gaps in tool coverage and as a theoretical foundation for new modules of BSA tool development. The authors have presented this summary of their work for wider audience review in the expectation that it may be equally useful to other practitioners. It may enable practitioners identify gaps pertaining to their own work and facilitate their efforts to compensate with novel applications.

The effects and potential of such novel 3D CAD ICT platforms, new BEA tools such as LCADesign, coupled with BSA frameworks such as LCADevelop need to be reassessed and refined particularly in the light of persuasive technology theory. The authors believe that the developments they have described may well be better exemplified by the work of others and that together such works can have a more persuasive effect. They share the hope common to sustainability practitioners that aligned developments may link at points, unforeseen by themselves, to evolve together into what is termed influential technology.

6. CONCLUSION

This paper has summarised work undertaken to improve BEA tool structure and attributes providing appropriate features for:

- Communication in planning and strategic decision-making towards ESD.
- Documentation and interactivity with frameworks, guidelines and checklists

The goal was to depict a theoretical BSA framework for integrated tool development so that together they may all that much sooner become adopted as persuasive and enacted as influential technology. The paper described how the framework evolved was given as a basis for a future toolbox inclusive of:

- High quality, whole of life tools for BSA professionals;
- True building environmental, social and economic cost assessment;
- Better capacity to source appropriate goals and benchmarks;
- Increased design support via integration of stakeholder applications; and
- Improved decision-making support to facilitate sustainable building effort;

The authors have depicted a future set of LCAD integrated tools to assess social, functional, economic, technical and ecological aspects of sustainable building.

7. REFERENCES

Australian Green Building Council (AGBC) (2004), Green Star Environmental Rating System For Buildings (Green Star) www.gbcaus.org/greenstar/page.asp?id=11 July 04.

Barton R.T. Jones D.G. and Gilbert D. (2002) Strategic Asset Management Incorporating ESD, Journal of Facilities Management, Henry Stewart, London, United Kingdom, UK.

BHP (2002), LCA In Sustainable Architecture, LISA: www.lisa.au.com/ Aug 2004.

Building Research Establishment (BRE) (2002a) Built Research Establishment Environmental Assessment Method (BREEAM), UK.

BRE (2002b) BRE Material Environmental Profiles, BRE, United Kingdom

BRE (2002c) Environmental Estimating tool (ENVEST 1) BRE, UK.

BRE (2003)Environmental Estimating tool (ENVEST 2) BRE, UK.

Canadian Energy Efficiency Centre Energy & Env Can (CEE&EEC) (2002), Green Globes Environmental Assessment of Buildings, www.energyefficiency.org/ at Feb 2004,

Cole, R. J., Lindsey, G. and Todd, J. A. (2000) Assessing Life Cycle: Shifting from Green to Sustainable Design, Proc, Sustainable Buildings 2000, The Netherlands.

Commonwealth Scientific Industrial Research Orgainsation (CSIRO) (2002a), Evergen Product Guide, http:// www.cmit.csiro.au/news/viewpress.cfm/111 in Feb 2004, Australia

CSIRO (2002b), AccuRate, in house application www.cmit.csiro.au Aug 2004, Australia

Danish Building Urban Research (DBUR) (2002) BEAT www.sbi.dk/english/ Aug 2004.

Department Infrastructure, Planning & Natural Resources (2002), Building Sustainability Index: BASIX, http://www.planning.nsw.gov.au/settingthedirection/basix.html Feb 2004.

Department Of Public Works and Services (DPWS) Environmental Performance Guide For Building (EPGB), http://www.asset.gov.com.au/EnvironmentGuide/ehp/frameset.htm

Dept. Public Works and Services, www.projectweb.gov.com.au/dataweb/lcaid/ Feb 2004.

Ecole des Mines Center d'Energétique (EMCEP) (2002), Life Cycle Simulation Tool EQUER: http://www-cenerg.ensmp.fr/english/logiciel/cycle/html/15log.html Paris, France.

Environment Australia (2003) National Australian Building Environment Rating (NABERS), www.deh.gov.au/industry/construction/nabers/overview.html in Aug 2004.

Foliente, G., Seo, S. and Tucker, S. (2004) A Guide to Enviro. etc, CSIRO MIT Australia.

IVAM (2002), ECO-QUANTUM, www.ivambv.uva.nl to Aug 2004, UvA, The Netherlands

Jones D.G., Messenger G. & Lyon Reid K. (2004), Delivering Building Sustainability (Submitted) CIB Conference: Clients Driving Innovation', Queensland Australia.

Jones, D.G., Lyon Reid, K., & Gilbert, D., (2003)., Sustainability Assessment Considering Asset etc. Proc CIB Conference: Smart and Sustainable Buildings, Brisbane Australia.

Japan Sustainable Building Co., (JSBC) (2002) Assessment of Building Environmental Efficiency (CASBEE) http://www.ibec.or.jp/CASBEE/CASBEE_Ever1/index.htm Japan.

Lovins, A., (2004), Green Development, Rocky Mountain Institute, USA.

Mitchell. P., (2004), Life Cycle Thinking Implementation: An Approach for 'Greening' the Building Material Supply Chain, University of Qld Doctoral Thesis (Submission pending)

National Institute of Standards & Technology (NIST) (2002), Building for Environmental & Economic Sustainability (BEES). www.bfrl.nist.gov/oae/software/bees.html Feb 2004.

Norway Building Research Institute (NBI) (2002), ECOPROFILE, www.byggsertifisering.no/oekoprofil/ in August 2004, Norway.

Netherlands Institute for Building and the Environment (NIBE) (2002), GreenCalc. www.dgmr.nl/new/software/software_gc.html in Aug 2004,The Netherlands.

National Research Council (NRC) (2002) GBTool, http://greenbuilding.ca/ Canada,

Queensland Government (Qld Govt.) (2000) Ecologically Sustainable Office Fitout Guideline. http://www.build.qld.gov.au/aps/ApsDocs/ESDMasterDocument.pdf Aug 2004.

Royal Melbourne Institute of Technology (RMIT) Centre for Design (2001) Greening the Building Life Cycle, http://buildlca.rmit.edu.au/menu8.html in July 2004.

RMIT & EcoRecycle-Vic. (2004)., ecospecifier.rmit.edu.au/flash.htm as of 02.02.04.

Sarja A. (2002), Integrated Life Cycle Design of Structures Spon Press, London.

Seo, S. (2002), International Review Of Environmental Assessment Tools And Databases: 2001-006-B-02, CRC for Construction Innovation, Brisbane, Australia.

Sustainable Energy Authority Victoria (SEAV) (2002), FirstRate: House Energy Rating, www.seav.vic.gov.au/buildings/firstrate/ in Feb 2003 Victoria, Australia.

Sustainable Energy Development Authority (SEDA) (2002) Australian Building Greenhouse Rating scheme (ABGR), www.abgr.com.au as of Feb 2004, NSW, Australia.

The Athena Sustainable Materials Institute (TASMI) (2002) ATHENA-V3.0 (2002) Environmental Impact Estimator, www.athenaSMI.ca as of Feb 2004. Canada.

Todd, J. A., Crawley, D., Geissler, S. & Lindsey, G. (2001), Comparative Assessment Of Environmental Performance Tools Etc. Building Research and Information. 29 (5).

Tucker, N., Ambrose, M., Johnston, D., Seo, S., Newton, P. & Jones, D., (2003) LCADesign: An integrated approach to etc. CIB W078 Conference, New Zealand.

United States of America Green Building Council (USAGBC) (2001), LEEDTM: Rating System V2 Draft US Green Building Council, San Francisco, CA. USA.

US North American Green Building Council (USNAGBC) (2002), Leadership in Energy & Environmental Design (LEED) www.usgbc.org/LEED/LEED_main.asp as of Aug 2004.

Watson, S. (2003) The building life cycle: a conceptual environmental design aide, 37th ANZASCA Conference, Sydney, S. Hayman (Ed) pp 642-52.

Watson, S. (2004) Improving The Implementation Of Environmental Strategies In The Design Of Buildings, University of Queensland Doctoral Thesis, Queensland.

Watson. P, Mitchell P & Jones D.G. (2004) Environmental Assessment For Commercial Buildings: Stakeholder etc, 2001-006-B-01 CRC for Construction Innovation, Australia.