SUSTAINABILITY MEASURES FOR DECISION-SUPPORT

REDEFINING LIFE CYCLE FOR A BUILDING SUSTAINABILITY ASSESSMENT FRAMEWORK

Phillipa Watson, [1, 2] Delwyn Jones [1,3], and Penelope Mitchell [1, 2]

1. Cooperative Research Centre for Construction Innovation (CRC CI)
2. Commonwealth Science and Technology Organisation (CSIRO) Manufacturing and Infrastructure Technology
3. Queensland Department of Public Works (QDPW)

ABSTRACT

Understanding the differences between the temporal and physical aspects of the building life cycle is an essential ingredient in the development of Building Environmental Assessment (BEA) tools. This paper illustrates a theoretical Life Cycle Assessment (LCA) framework aligning temporal decision-making with that of material flows over building development phases. It was derived during development of a prototype commercial building design tool that was based on a 3-D CAD information and communications technology (ICT) platform and LCA software. The framework aligns stakeholder BEA needs and the decision-making process against characteristics of leading green building tools. The paper explores related integration of BEA tool development applications on such ICT platforms. Key framework modules are depicted and practical examples for BEA are provided for:

- **Definition of investment and service goals at project initiation;**
- **Design integrated to avoid overlaps/confusion over the project life cycle;**
- **Detailing the supply chain considering building life cycle impacts;**
- **Delivery of quality metrics for occupancy post-construction/handover;**
- **Deconstruction profiling at end of life to facilitate recovery.**

Keywords: building environmental assessment, life cycle assessment, 3D CAD, information and communications technology

1.0 BACKGROUND

The theoretical Building Sustainability assessment (BSA) framework discussed in this paper evolved during the development of LCADesign. LCADesign is a prototype Building Environmental Assessment (BEA) tool developed in a joint project through the Cooperative Research Centre for Construction Innovation (CRC CI) [4]. LCADesign is an acronym for Life Cycle Assessment (LCA) with Computer Aided Design (CAD). It incorporates a national Australian Life Cycle Inventory (LCI) database, three dimensional (3D) Computer Aided Drafting (CAD) information and Life Cycle Impact Assessment (LCIA) on an integrated Information Communication Technology (ICT) platform, which manages the information.

LCADesign was developed with the understanding that there is a deficit of holistic BEA tools and that by stakeholders required such tool to assist in the complex move towards more sustainable practice within built environment professions. The aim is to make it the preferred environmental appraisal tool for Australian commercial buildings. It currently covers commercial building environmental and economic cost assessments, obtaining information directly from 3D CAD models to, for example, facilitating environmental impact calculations and reporting on them [4].

The authors recognised that for LCADesign to consistently facilitate decision-making on sustainability initiatives, throughout the building life cycle, it had to feed both forward and back from design to phases of definition, design, detailing, delivery and deconstruction [5, 6, 7, 8]. This called for an underlying framework on which to devise, support, integrate, and network existing and new BEA tools [8].

The BSA framework needed to be comprehensive, flexible and interactive and its primary role was to act as a ‘hub’ of communication between various tasks on a building project and the varying stakeholders, who are from numerous disciplines. The ‘hub’ would allow environmental documentation to be tracked throughout projects from the earliest budget planning, through brief and design development, construction, use and disposal. To achieve this end the framework, based on holistic environmental theory, called for further definition of the life cycles of built environment development and use processes.

The built environment is recognised as a large environmental impact and has been identified by numerous authors as requiring sound ecological management [. Mitchell [19] Watson [3, 8, 17], Jones [5] and Sarja [1] have all supported holistic life cycle structures as the basis for sustainable decision-making for the built environment. They consider this as a fundamental starting point for discussion and development of BEA tools. This paper and the greater BSA framework being discussed, begins from this holistic platform. Holistic considerations that need to be 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 biodiversity and resource depletion plus air, water and soil pollution [1].

2.0 INTRODUCTION

This paper provides an overview of new Life Cycle Thinking (LCT) theory, as conceptualised for a theoretical BSA framework. It examines the relationship between material flows and temporal decision-making, BEA tools and their management possibilities within an integrated ICT platform. It discusses:

- relevant findings from a BEA tool review report (focussing on life cycle issues);
- background motivations for the development of the life cycle theory;
- redefined life cycle theory in the context of the BSA framework;
- relevance to stakeholders as decision-support towards sustainability

3.0 OBJECTIVE

To introduce the redefined Life Cycle theory as it relates to assessment and decision-making support of the built environment through Building Sustainability Assessment (BSA) tools.

4.0 METHOD OF REVIEW

As part of the LCADesign project, research was undertaken, to comprehensively review and develop understanding of the context of building stakeholder requirements and needs to be addressed in tool development that incorporated:

- Review of previous studies of tools and stakeholders;
- Review of other’s emerging theories of tool development, design process, life cycles and sustainability;
- Mapping of stakeholder needs, existing tools and gaps in tool functions;
- Consolidation of a list of tool requirements for improved, holistic performance of BEA tools.

Previous reviews of such tools were re-examined including studies from:

- Independent work on BEA tools from architectural design perspectives [3, 8].
- CRC CI of BEA international tools and databases [3, 7] as well as
- RMIT of international tools and databases [9].

In addition newer BEA tools were reviewed by the authors including:

- Environmental Estimating tool (ENVEST 2) [8];
- Guideline for Ecologically Sustainable Office Fitout (GESOF) [5];
- Ecologically Sustainable Asset Management Rating System (ESSAM) [6];
- Green Star Environmental Rating System For Buildings (Green Star) [8] and
- National Australian Building Environment Rating Scheme (NABERS) [8].

5.0 BEA TOOLS AND LIFE CYCLE CONCEPTS

5.1 Traditional BEA Life Cycles and Tool Coverage

Some of the tools reviewed aimed for holistic assessment and some on a life cycle style method, including LCA. A view of a product and then a building life cycle as shown in Figure 1 is accepted as it refers to physical flows. At the beginning of the review such results seemed reasonable so what were stakeholders' issues and what should BEA tools really do? Firstly there are accepted attributes that are considered useful for most tools and it is against these attributes that they must be compared.

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 and an extract of this work is given in Table 1 . It shows all tools with sound coverage of criteria with the exception of air pollution and all except one assessed buildings while one covered both buildings and products. All tools applied weightings based on judgement with variable transparency and half those Seo studied applied to more than three building life cycle phases

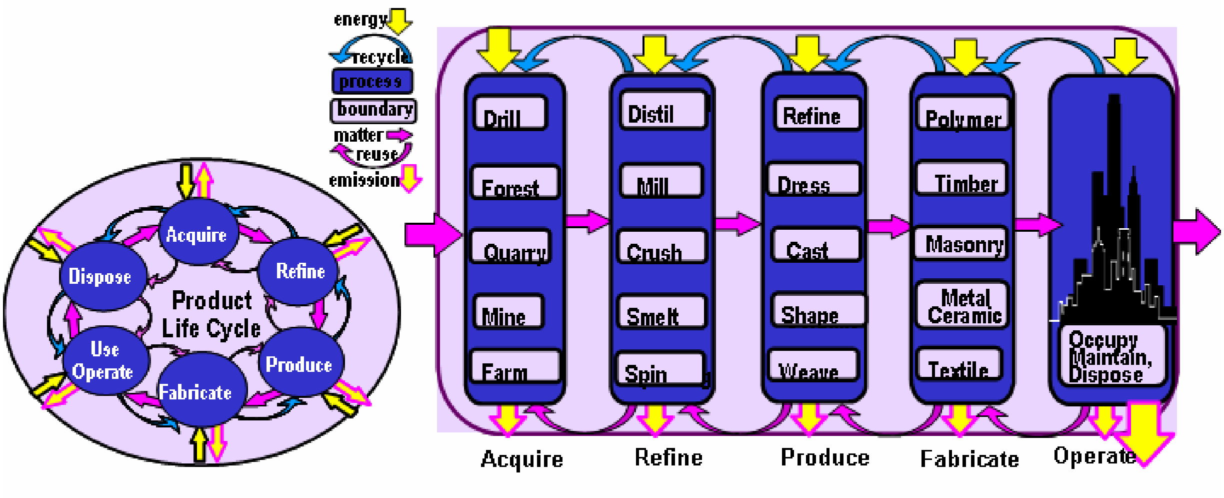

Figure 1 Flow of Product Manufacture Life Cycle to New and Existing Assets through use and Disposal.

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 and an extract of this work is given in Table 2 . The Table shows all tools with sound coverage of criteria with the exception of air pollution. All except one assessed buildings while one covered both buildings and products. All tools applied weightings based on judgement with variable transparency and half those Seo studied applied to more than three building life cycle phases.

Table 1 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

Seo found that when tools were reviewed it became apparent that most focussed on physical metrics and lacked:

- Integration of whole-of-life considerations;
- Consideration of policy or principles behind a project;
- Operational service delivery parameters;
- Flexible outputs for a range of stakeholders and therefore;
- Comprehensive support for stakeholder decision-making.

Table 2 BEA Impact Criteria adapted from Seo

Tool Criteria	GBC	BEES	LCAid	BREEAM	EcoProfile	EcoQuantum	LEED
Energy	+	+	+	+	+	+	+
Water	+	+	+	+	+	+	+
Materials	+	+	+	+	+	+	+
Air Pollution	+	+	+	+	+	+	-
Solid Waste	+	+	+	+	+	+	+
Effluents	+	+	+	+	+	+	-

5.2 Reviewing Basic Tool Uses and Performance Attributes

Stephen Watson defines tools as making a job easier or more efficient and argues BEA tools should bridge assessment and actions, professions, ideologies and also divergent paradigms. Tools also direct and facilitate clear communication, hopefully structuring and streamlining information for the stakeholders [3]. Direction and communication, for example, is facilitated when a BEA tool clarifies definitions, aims, objectives, policy positions, strategies, and tactics and provide material for presentations and outcome reporting. Reijnders and Van Roekel class BEA tools as mainly checklists, manuals, eco-labels, blueprints, scoring systems, computer based guidance, building component, LCA and eco preference lists [3].

Addressing sustainability issues requires built environment professionals to work through increasingly complex problems while instigating new systems/ideas to overcome difficulties in gathering, analysing and verifying knowledge [4]. To this end there is an increasing demand for detailed design performance appraisal systems, a uniform level of broad criteria information, and tools that use new methods to access environmental, social and economic costs and impacts [3, 4].

Tools must also encourage interaction and flexibility in the project delivery process while remaining comprehensive [8]. Cole [10 to 14], Sarja [1], Gilbert [15], Barton [6], Jones [5,] Lovins [16], Watson [17] and Todd [18] all stress that it is critical to identify points of successful intervention in the process before considering and applying effort to integrate key environmental strategies. This is because whole of life strategies apply in each phase and at each point in time and pre-existing and subsequent operations need assessing [3], for example in design for cleaner production, adaptive re-use, and disassembly [8].

As previously noted, BEA tools were reviewed with particulars investigated including:

- Attributes, functionality and stakeholder reach;
- Stakeholders and their need for such applications and
- Features and functionality needed to meet such stakeholder needs.

5.2 Stakeholder Applications by Life Cycle

Stakeholders require tools with appropriate applications both in the early stages and later phases of the project [8] but as Watson points out; understanding of the building lifecycle varies significantly [8]. To make informed decisions, users need to know the environmental implications of upstream and downstream operations [1 to 20]. A variety of needs are shown in Table 3 where, for example, investment tools may be commonly used to benchmark and communicate policy, whereas the construction industry sector commonly uses tools for scheduling and certification.

If they are to apply to initial processes of the building life cycle, BEA tools need to provide policy, benchmark and rating applications at investment as the earliest phase. This is because timing is critical with prior allocation to master plan, infrastructure, orientation and budget limiting later opportunities. As Lovins [16], Watson [3, 17] and Jones et al [20] all stress, by the time designs are developed it is too late to integrate most sustainability initiatives. To consider such initiatives effectively 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 3 Professional BEA by Application and Phase

Stakeholder	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 Development, Estimate	Development Applications
Manager	Facility, Portfolio, Estate, Asset	Strategies/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, Landscape, System	Design/Modeling process	Blueprint/Plan, Specifications
Consultant	Engineer, Research, Environment	Investigations R&D Data	Specifications, Reports
Surveyor	Quantity	Calculations, Estimates	Bills of Quantities, LCC
Manufacturer	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

But as Table 4 shows only half the BEA tools Seo, Foliente and Tucker reviewed covered the full building life cycle [7, 21] and furthermore none were applicable to the earliest investment phase [21]. Breaking down the Seo et al findings by life cycle, three tools applied to all four phases investigated (ie planning to disposal), ten applied to three phases and nine applied to one or several stages only [21]. A further review for the found that most tools ignored existing buildings in-use, fitout, refurbishment and disposal phases [7]. Seo found limitations including little emphasis on economic and social criteria and lengthy assessments. A contrast was found in results of the later review of the newer tools ENVEST 2, GESOF, ESSAM, Green Star and NABERS where their cover was more extensive, except for NABERS that focussed on existing building phases.

Table 4 BEA Tool Life Cycle Cover Marked by ■ (from results ex Seo [47], Foliente et al [48] Watson et al [49])

Tool	Plan	Design	Use	Dispose
BDP EDG, Your Home, ESOFG, BREEAM+ BRE tools	*	*	*	*
GreenStar, GBTool, CASBEE	*	*	*	
Evergen, EPGB, BRE Profiles, BASIX, LCAid		*	*	*
LEED, Ecoprofile, BEAT, Greencalc, EQUER, Envest,		*	*	*
ATHENA, Green Globes, AccuRate, Firstrate, LISA		*	*	
NBGR	*		*	
BEES, Eco-Quantum, EcoSpecifier		*		*
NABERS,			*	

One final finding from the author's reviews was that while the worldwide interest in research and development has produced many BEA tools and although Australia lags behind in development, it has not yet inherited their deficiencies. It was also accepted that the newer tools, many developed by Australian government and industry including codes and regulations as well as Greenstar, NABERS, the GESOF and ESSAM may be designed to better suit stakeholder applications. The LCADesign team set out to identify key strategies that would achieve a better tool, which they thought began with and integrated life cycle basis.

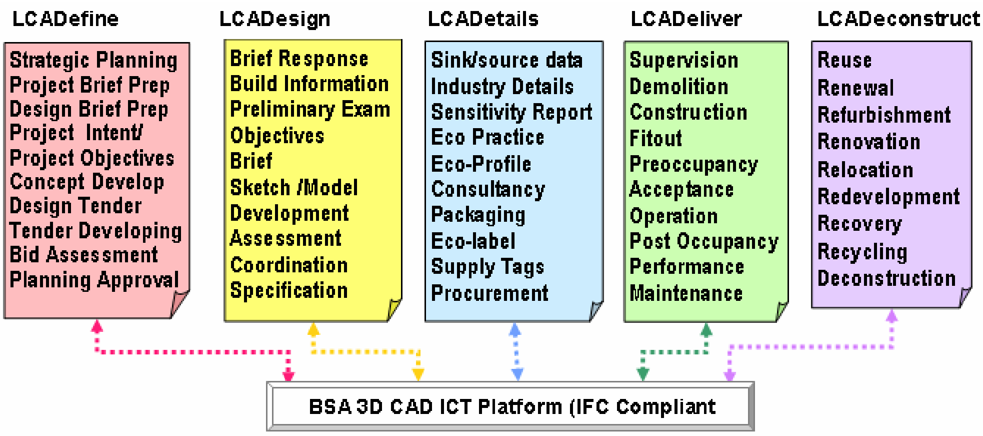

Figure 2 BEA Framework Skeleton, Modules and Basic Information Flow

LCADesign set out to cover a comprehensive list of stakeholder needs as shown in Table 3 and using its integrative ICT platform as Depicted in Figure 2. It was recognised that an ICT platform such as the one used could be the basis for a flexible, broad ranging support framework. The ICT platform could also provide the opportunity to coordinate the currently disparate tools, enhancing their applicability and usefulness

6.0 REDEFINING BUILDING LIFE CYCLE PHASES

6.1 Life Cycle Definition

Life cycle systems are inherent to the BSA framework developed and Life Cycle Theory (LCT) needed to be re-defined, or further defined in order to structure conceptual thinking. The re-thinking of LCT was important as it identified critical areas of decision-making for built environment stakeholders who can be targeted as needing effective support in the move towards their sustainability goals. A breakthrough in thinking by Steve Watson, in his thesis on environmental implementation strategies in the building design process, distinguished the temporal design phases as separate to the physical life cycle of the building [3].

This basic distinction offered a new perspective when reviewing existing tools. It was envisaged that if the temporal activities could be distinguished from the physical it would offer some freedom in application of information to different and diverse temporal applications. Watson applies the terms to differentiate the building's physical life cycle from actions over a temporal life cycle in design processes and asset management planning that go to build it [3].

His physical life cycle relates to material flows in forming objects such as depicted in Figure 3 and his temporal life cycle to sequencing decisions as in Figure 4 [3] Defining the temporal phase separately, decision-making has a distinct space in the building process and distinguishes it for the BEA tools. Stakeholders and their decision-making mechanisms are given clear consideration aside from and before the quantitative analysis takes place.

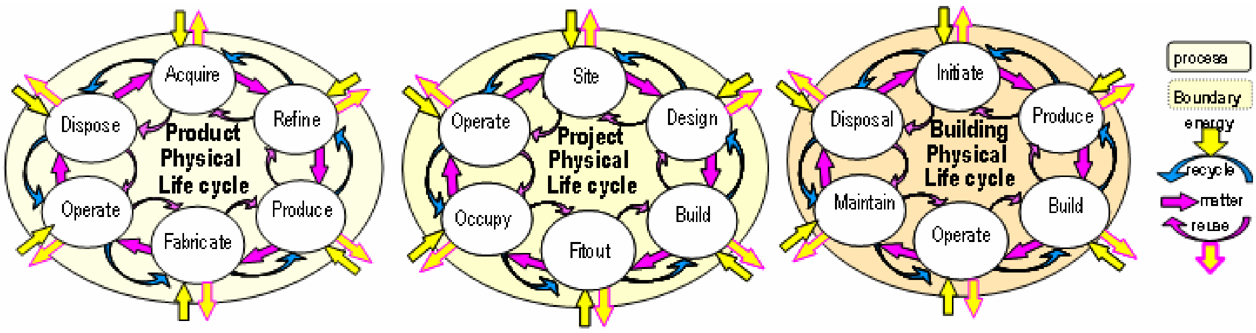

Figure 3. Flow Diagrams of Product and Building Physical Life Cycle Phases

Further to this concept, Jones et al [x ESSAM] and Watson [x] had developed models identifying the life cycles within the built environment which the LCADesign team again used to separate applications and measurements. This was considered essential to facilitate consideration of the numerous up-and-down stream effects and the implications they may have over the building life span.

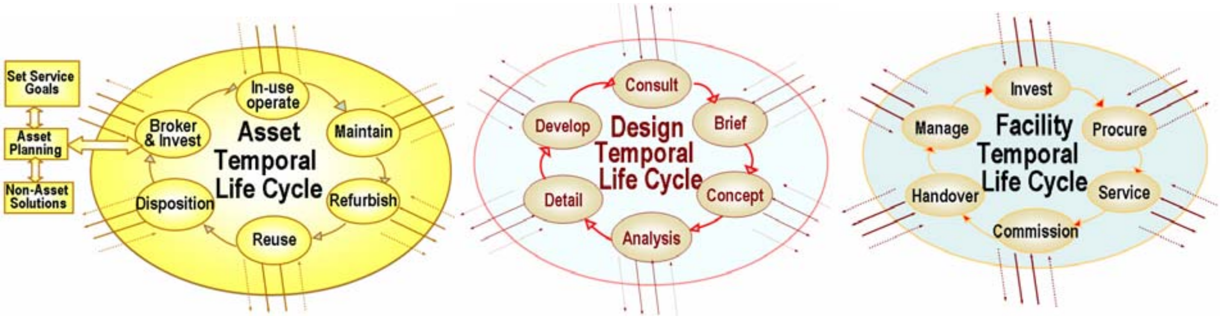

Figure 4. Flow Diagrams of Asset and Design Temporal Life Cycle Phases (adapted from Watson [x])

It was accepted that the philosophical foundation for development of this theoretical framework would be based on considerations of integrated and cyclical interior, shell and built environmental systems as ecological systems. It was asserted that life cycle thinking has lead to more objective strategic planning when used to support decision-making as it can achieve more comprehensive outcomes where economic and environmental assessment can be seen side-by-side rather than obscured by subjective assessment [4, 5, 6, and 20].

6.2 Building Life Cycles

The term 'building lifecycle' loosely covers the 'planning and design development process and the building life cycle from, conceptions through building life and disposition [7, 8] and as shown in Figure 5 for example end of building life is now a focus of urbane renewal as land becomes limited and traffic means people seek to live close to the CBD.

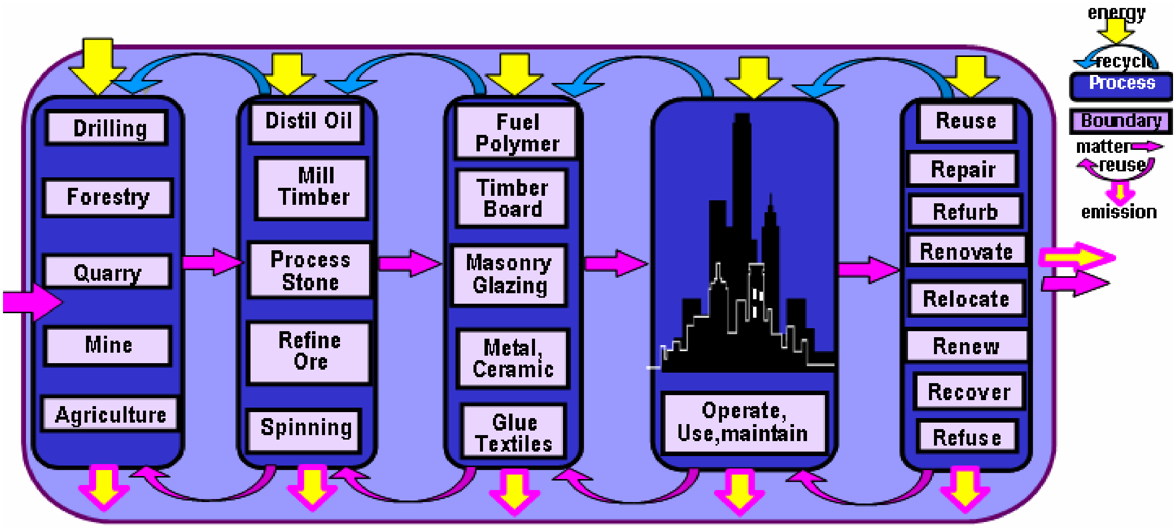

Figure 5 Operational Flows over the (a) Product Life Cycle and (b) Built Life Cycle

The authors asserted that with such life cycle terminology undefined, key BEA elements/associations would remain undifferentiated and obscured. Because of the history of development of LCA it is asserted that LCA-based BEA tools more often tend to apply their scope of assessment, cradle to gate rather than cradle to grave, possibly because they apply to physical theory and metrics for material and energy flows in industrial operations rather than to temporal theory and metrics for management decision flows on asset and facility operations [50].

LCA, as an assessment method, however, is only now emerging in tool applications. "As discussed by Watson et al (04) ANzasca, the American Institutes of Architects publication The Environment Resource Guide, BEA tools have drawn on LC theory developed historically around heavy industry sectors and to consumer concerns in the greener market. Rather than management of asset, facility, building design, construction and in use processes, BEA tools have drawn on life cycle theory developed around a primary industry sector picture of mines, factories, consumer goods and transportation.

Dimension-based functional assessment provides a more appropriate and practical platform to inform dimensionally defined product performance, essential in aeronautical, automotive, civil, transport and industrial applications, rather than as typically occurs based per unit mass. Comparable ICT applications, for example, in large scale project case studies reveal the potential of this approach as adopted for Boeing's design and maintenance, Stanford University's 4D modelling build-ability for Disney World and large hospital construction, [25] and Queensland University of Technology's airport precinct ESD and creative industries visualisation projects [26]. In addition, a BPI web-based portal is considered a practical way to input and disseminate information from any such national database that is essential to determine product eco-profiles.

WHOLE OF LIFE BSA FRAMEWORK

This life cycle theory was applied to a theoretical BSA framework in work that was attempting to conceptualise how to:

- Incorporate the full while distinguishing between temporal and physical life cycles
- Act as a bridge between disparate stakeholders and application
- Facilitate communication and alignment with ESD principals, policy, planning and strategies;
- Reflect Technical and linguistic coordination with other environmental assessment tools;
- Exploit comparative assessments against best building practice/performance benchmarks;

- Provide documentation/templates for briefs specification, contract and evaluation;
- Ensure interactivity with supporting frameworks, guidelines and checklists and
- Capture proposed plug in tools to meet user needs for operation assessment and ESD criteria.

Its aim was to provide a 'hub' which moved from the common description of Building Environmental Assessment to the broader but increasingly called for Building Sustainability Assessment incorporation economic and social costing. The name of framework was coined as 'LCADevelop' and was structured around processes occurring over the temporal property development life cycle stages as depicted in Figure 1, definition, design, detailing, delivery and deconstruction. These stages were chosen as representative and essential considerations in each stage for ESD. The LCA Develop framework aligns these temporal stages with physical operations over the building life from acquisition of material from the earth to disposition of material back to the earth. An example of some differing phases is shown in Physical flows Figure 3 as well as temporal flows in Figure 1Concept diagrams of temporal design and physical building life cycles [8]

As depicted in Figure 6, this new framework is called LCADevelop, and it is also to be automated from an ICT platform to integrate LCA with CAD for sustainable building development.

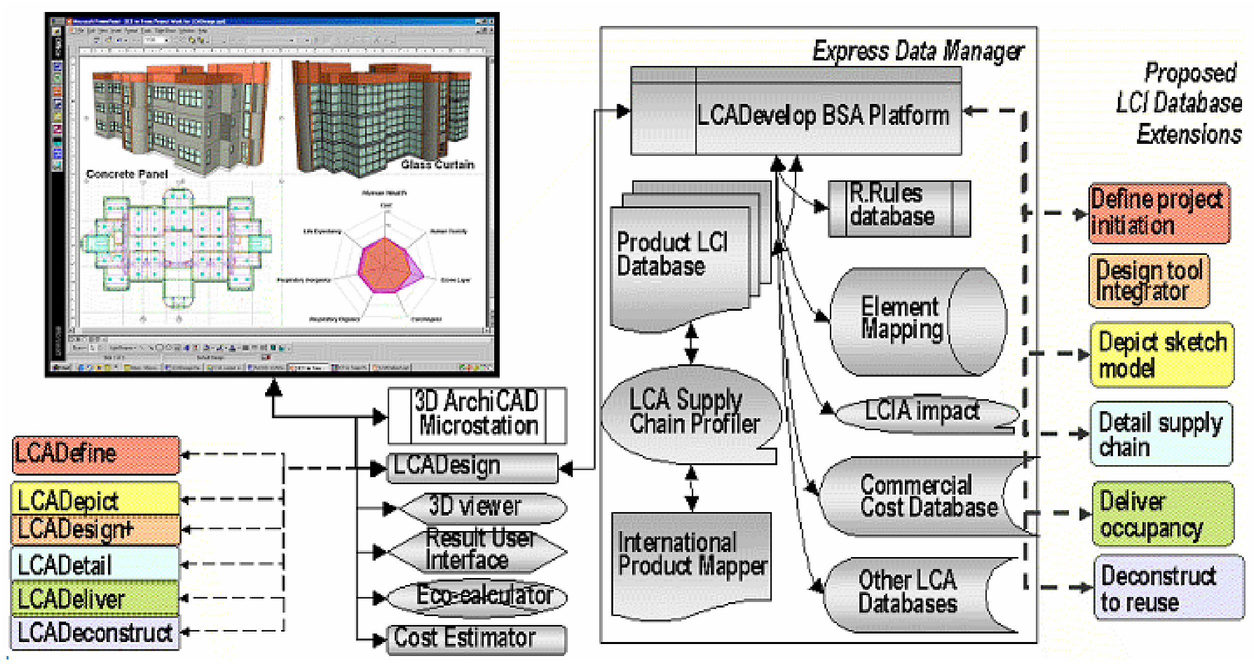

Figure 6. Schematic ICT Flow of Sets of BEA Tools in the LCADevelop Tool Kit.

A critical aspect of LCADevelop is the ICT platform (from the concept of LCADesign) from which it leverages its functions. Creating a hub of credible information and then facilitating its use for various outputs would be much more difficult without such a platform. The authors had presupposed use of the framework was essential to provide a theoretical platform that would act similarly to the ICT platform that connected databases and data managers to CAD programs. The concept of integrating disparate programs by allowing them to interconnect and share information for efficient/effective use is not a new concept, except possibly in complex tasks such as BEA.

A Temporal and Physical ICT Framework

The earliest intent of the LCADevelop framework was to facilitate improved definition, guidance, communication, decision-making support and assessment for sustainable solutions throughout a built asset's life cycle. Established conceptually on an ICT platform that encompasses many traditional tool types, the framework reveals various focus points to meet the broad range of stakeholders needs to integrate economic, social and environmental cost/benefit assessment. Developed as a consequence of reviewing existing theory, tools and stakeholder opinion the framework is also grounded on the authors' diverse experience as well as knowledge assimilated during their research as it:

- Encompasses both temporal and building life cycles;
- Establishes a platform for the networking and the exchange of information;
- ICT platform allows integration of applications from other key sources of overview and detail;
- Supports building, asset, design, construction and facility management professionals; and,
- Identifies applications/formats of information useful at key points of building processes

Since its development, the authors have proposed a BEA toolbox as shown in the ICT Schema in Figure 6 and as depicted in Figure 2. Also with some few details listed in Tables 5 to 9, such as platform is considered a platform on which further integration of plug-ins/supplements to existing tools in the right sequence and level of detail could avoid issues with the current ad hoc, linguistically confusing, separate tools. The authors also assert that in the short and long term a one stop BEA shop requires provision of:

- Enhanced definition of objectives, tender and 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 recovery of material elements

Modules of the Framework

Used as a conceptual guide/map to the whole process of creating sustainable building the framework indicates that key support for sustainable building should be staged 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 considering whole of life cycle issues;
- Deliver high quality construction as well as management in-use; and,
- Deconstruct considering recovery credits as apposed to demolition or waste.

Theoretically the LCADefine module Table 5 summarises incorporates defining of investment targets and setting of project objectives during concept development/initiation and strategic decision-making. It facilitates up-front acquisition of key information in a project to better inform the planning process.

Table 5 An Integrated LCADefine Tool Box

Asset Planning	Design Performance Appraisal Against ESD Criteria	ESSAM supplement
Brief Development	Comparison against building best practice benchmarks	Rated benchmarks
Design Brief/Tender/	Documentation/templates for early in planning	ESD brief bid evaluation
Concept	BEA throughout building development process life	ESSAM supplement
Bid Assessment	Incorporating economic life cycle costing	CRC CI supplement

As Illustrated in Table 6 tools such as LCADesign also need to link to related tools and incorporate and integrate exemplar concept models as well as plug-ins to ensure:

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

Table 6 A Selections from the LCADesign Tool Box

Design Brief Response	Audit/Assess current codes/standards/contracts	Codes, IAQ, Access
Building Information	Compare all levels design analysis Plug-in other tools	Orient, space, light
Preliminary Examination	Design against Sustainability Criteria	Benchmark
Design Objectives	BEA through building design process life cycle plug-in	Process supplement
Sketch Design	Technical and Linguistic coordination with other tools	NABERS, Green Star

LCADetails as shown in Table 7 is a procurement module of supply-chain knowledge acquired from suppliers LCI, with material profiles and guidance to improve planning, procurement and the industry bottom line. This would service an industry that is under growing pressure to reduce its impact and also those selecting building products on the basis of environmental impacts. It is much needed in the areas of sustainability decision-making that is currently under-informed and especially as many overseas countries have advanced procurement systems, albeit less advanced in ICT terms.

Table 7 A Selections from the LCADetails Tool Box

Sink/source data	Sink/source data on state of domestics sources/sinks	Links to SOE/Resources
Supply Details	Sensitivity Analysis for improved practice opportunity	Service Consultants
Eco Practice	Eco-Profile reports of industry sectors performance	Eco-practice reports
EcoProfiles/Labels	Industry Details of best /typical/poor practice	Eco-profiles/practices
Supply Tags	Green Supply, Marketing and Eco specification	EcoProfile & labelling

As summarised in Table 8 an LCADeliver module would provide post-design applications to facilitate construction decision-making and checking to ensure that as specified and assessed is implemented.

Table 8 A Selections from the LCADeliver Tool Box

Construction,	Written Project Applications Brief, DA	Construction
Fitout Supervision,	Project management support plug ins	Supervision apps
Acceptance	Written Project/Supply affirmation tags	Acceptance
Pre/Post Occupancy	Green Procurement/Eco specification	EcoProfile & labelling
Operation, Maintenance	Whole LCA links with Component Life	Maintain Fitout etc

LCADeconstruct, summarised in Table 9 would facilitate 3D CAD design of building/fitout such that it credits design and industry initiatives for deconstruction and recovery for product reuse, disassembly, and recycling options to avoid demolition and waste.

Table 9 A selections from the LCADeconstruct Tool Box

Reuse, Refurbishment	Enhanced user assessment over full life cycle	Reuse, Recovery, Recycling
Renewal, Recovery	Whole of Life Cycle Assessment supplement	Refurbishment, Renovation
Renovation, Redevelop	Whole of life coding in Inventory database	Occupancy, Disassembly,

Features, for example, that designer's need in various form and outputs, for example, are listed in Table 10 BEA tool outputs and forms and moreover they 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].

Table 10 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

CONCLUSIONS

The paper has depicted stakeholders' BEA needs, a theory summary and an emergent BSA framework of integrated tools. It has revealed what BEA tools lack in terms of providing adequate support for stakeholder decision-making. Many existing tools reviewed focused on physical rather than stakeholder required metrics such as functionality measures for operational service delivery. Overseas developed tools have limited relevance to Australian conditions and most have restricted scope, shallow focus, and time-consuming application and ignore economic and social criteria.

The mapping of stakeholders needs in a building life cycle framework against potential tool deliverables found no tools covered the entire building life cycle and also highlighted the many gaps in current tool attributes/applications. Newer tools had increasing coverage by phase so these better fill stakeholder needs than earlier ones. There remains considerable potential to provide applications for managers, owners, purchasers, operators and occupants in most tools.

The theoretical BSA framework foreshadowed at least one step change with potential to create improved tools to meet Stakeholders BEA need by exploitation of ICT platforms facilitating collection/connection from divergent sources for flexible and varied outputs covering many building aspects, criteria, processes and life cycles. Key points BEA tool developers need to address in future by include provision of:

- Whole of temporal and physical life tools with true building environmental, social and economic cost assessment;
- Better capacity to select appropriate goals and benchmarks over asset, design, project and building life cycles;
- Increased stakeholder and design support via integration of professionally and temporally aligned applications;
- ICT technology to manage the vast amount of information necessary for credible assessment; and
- Full development of shared information platforms that facilitates consistent decision-making.

REFERENCES

1. Sarja, A. (2002) Integrated Life Cycle Design of Structures Spon Press, London.
2. Energy Efficient Strategies and Faculty of Science and Technology, Deakin University: LCA of Queensland Building Energy Consumption and Greenhouse Gas Emissions for Building Division of Public Works, 2001.
3. Watson, S. (2004) Improving the implementation of environmental strategies in the design of buildings, University of Queensland Doctoral Thesis, St Lucia Queensland.
4. Tucker, N., Ambrose, M., Johnston, D., Seo, S., Newton, P. and Jones, D. (2003) LCADesign: An integrated approach to automatic eco-efficiency assessment of commercial buildings. Procs Int CIB W078 Conference, New Zealand.
5. Jones, D., Lyon Reid, K., and Gilbert, D. (2003) Sustainability Assessment Considering Asset and Building Life Cycles. In Proceedings of the International CIB Conference: Smart and Sustainable Buildings (SASBE2003) Brisbane Nov 2003.
6. Barton, R.T., Jones, D.G. and Gilbert, D. (2002), Strategic Asset Management Incorporating ESD, Journal of Facilities. Management, Henry Stewart Publications, London, UK.
7. Seo, S. (2002) International review of environmental assessment tools and databases, Report 2001-006-B-02, CRC for Construction Innovation, Brisbane
8. Watson. P, Mitchell P and Jones D.G., (2004) Environmental assessment for commercial buildings: Stakeholder requirements and tool characteristics Cooperative research Centre for Construction Innovation (CRC CI Report 2001-006-B-01
9. Royal Melbourne Institute of Technology (RMIT) Centre for Design, Greening the Building Life Cycle, http://buildlca.rmit.edu.au/menu8.html as Feb 2004.
10. 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.
11. Cole, R. J. and Larsson, N. (1997), Green building challenge: Lesson Learned. '98, Proc. of CIB 2nd Int. Conf. On Buildings & Environment, Paris, France, V1, 19-29.
12. Cole, R. Chapter 16 Environmental Performance of Buildings: Setting Goals, Offering Guidance and Assessing Progress in Kibert, C. (ed) 1999 Reshaping the Built Environment: Ecology, Ethics, and Economics, Island Press, USA.
13. Cole, R. J. and Larsson, N. (1999) Green Building Challenge'98 and Green Building Tool: Background, Building Research and Information, 27(4/5), 221-229.
14. Cole, R. J. and Larsson, N. K. (2000) Green Building Challenge: Lesson Learned from GBC 1998 and GBC 2000, Proceedings of International Conference on Sustainable Building 2000, 22-25 October, Maastricht, The Netherlands, 213-215.
15. Gilbert, D.L. and Jones, D.G. (2000) Healthy Sustainable Buildings: A Queensland Perspective, in Proceedings of the International CIB Conference: Shaping the Sustainable Millennium, Queensland University of Technology.
16. Lovins, A, (2004) Green Development, Rocky Mountain Institute.
17. Watson, S. (2003), The building life cycle: a conceptual aide for environmental design, 37th ANZASCA Conference Proceedings, Sydney 2003, Editor S. Hayman, pp 642-652.
18. Todd, J. A., Crawley, D., Geissler, S. and Lindsey, G. (2001) Comparison assessment of environmental performance tools and the role of the Green Building Challenge, Building Research and Information, 29 (5), 324-335.
19. Mitchell (2004 final draft) Life Cycle Assessment (LCA) implementation: a life cycle thinking approach for the Australian building materials industry, University of Queensland Doctoral Thesis, St Lucia Queensland.

20. D.G. Jones, G Messenger and K Lyon Reid (2004), (Submitted) Delivering Building Sustainability Clients Driving Innovation' - International Conference 2004
21. Foliente, G., Seo, S. and Tucker, S. (2004) A Guide to Environmental Design and Assessment Tools CSIRO MIT.
22. Australian Green Building Council (GBC), Green Star Environmental Rating System For Buildings (Green Star) www.gbcaus.org/greenstar/page.asp?id=11 as at Oct 2004
23. Environment Australia, National Australian Building Environment Rating Scheme (NABERS), www.deh.gov.au/industry/construction/nabers/overview.html
24. B. J. Fogg, 2003 Persuasive Technology, Morgan Kaufmann Publishers.
25. Fisher, M., Keynote: Visualisation and Information on Recent Stanford University Projects, QUT CRCCI: International Conference: Clients Driving Innovation', Gold Coast, Queensland, Australia.
26 Betts. M., Keynote: Visualisation and Information in QUT Projects. CRCCI: International Conference: Clients Driving Innovation', Gold Coast, Queensland, Australia.