SUSTAINABILITY MEASURES FOR DECISION-SUPPORT

REDEFINING LIFE CYCLE FOR A BUILDING SUSTAINABILITY ASSESSMENT FRAMEWORK

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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 Building Sustainability Assessment (BSA) framework for aligning Life Cycle Assessment (LCA) of material and energy flows with temporal decision-making over building development phases. This framework was derived during development of a prototype commercial building design tool based on a 3-D CAD information and communications technology (ICT) platform and LCA software. The framework aligns stakeholder BEA needs and decision-making processes against characteristics of leading green building tools. The paper explores related integration of BEA tool applications on such ICT platforms. Key framework modules are depicted and practical BEA examples 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

For sustainable building development fundamental holistic considerations requiring assessment include:

- Core 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].

The theoretical Building Sustainability Assessment (BSA) framework [2] discussed in this paper evolved during the development of LCADesign, a prototype Building Environmental Assessment (BEA) tool [3] developed in a joint project through the Cooperative Research Centre for Construction Innovation (CRC CI) [4]. LCADesign, an acronym for Life Cycle Assessment (LCA) with Computer Aided Drafting (CAD), incorporates a national Australian Life Cycle Inventory (LCI) database, Life Cycle Impact Assessment (LCIA) and three-dimensional (3D) object-oriented CAD information integrated via an Information Communication Technology (ICT) platform and Express Data Manager. The aim is to make LCADesign the preferred environmental appraisal tool for Australian commercial buildings. It currently covers commercial building environmental and economic cost assessment, obtaining information directly from 3D CAD models to, for example, facilitate and report on environmental impact calculations [4].

The built environment is recognised as having a large environmental impact and has been identified by numerous authors as requiring sound ecological management. LCADesign was developed with the understanding that there is a deficit of holistic BEA tools and that stakeholders required such tools to assist them in the complex moves towards more sustainable practice within built environment professions. The authors recognised that for LCADesign to consistently facilitate decision-making on sustainability initiatives, over the building life cycle, it had to feed both forward and backward from design to phases of definition, detailing, delivery and deconstruction [5 to 9]. This called for a framework upon which to devise, support, integrate, and network existing information flows and new BEA tools [8]. Sarja [1], Watson P et al [2, 7, 8,], Watson S [11], Jones et al [5] and Mitchell [10] have all asserted the need for holistic life cycle structures as the basis for sustainable built environment decision-making. The authors considered this as a fundamental starting point for discussion and development of BEA tools.

Such a BSA framework needed to be comprehensive, flexible and interactive. Its primary role was to act as a theoretical ‘hub’ of communication between various tasks on a building project and the varying stakeholders from numerous disciplines. This ‘hub’ would allow environmental decision–making, assessment and documentation to be tracked throughout projects from the earliest budget planning, through brief definition and design development, construction, use and disposal. To achieve this end the framework, based on holistic environmental theory, called for further definition of built environment development and the use of life cycle processes. This paper and the greater BSA framework, being discussed, begin from this holistic platform [8].

2.0 INTRODUCTION

This paper provides an overview of new Life Cycle Thinking (LCT) theory [2, 6 to 12], as it was conceptualised for a theoretical BSA framework as well as an integrated BSA toolkit. It examines the relationship between physical material and temporal decision-making flows, BEA tools and ICT management of their stakeholder applications [8]. It discusses:

- Relevant findings from a BEA tool scoping report that focused on a review of BEA life cycle issues [7];
- Background motivation for development of new life cycle theory integrating physical and temporal flows [11];
- Redefined life cycle theory in the context of the BSA framework and BEA tool development [8]; and
- Stakeholder needs criteria relevant to provision of decision-support facilitating effort toward sustainability [13].

The aim is to introduce a redefined life cycle theory with a BSA framework for BEA decision-making applications.

3.0 METHOD OF REVIEW

As part of the LCADesign project, research was undertaken to review and develop understanding of the context of BSA stakeholder needs and applications that had to be addressed in BEA tool development [7]. This incorporated work to:

- Evaluate previous studies of BEA tool coverage and stakeholder applications [14 to 16];
- Review emerging BSA and BEA theory [1 and 24], design process [11], asset life cycles [5] and tools [25 to 50]
- Map stakeholder needs [7] and gaps in tool function considering existing tools applications [25 to 50];
- Consolidate a list of tool requirements for better performance and more holistic physical and temporal cover [7].

Previous reviews of such tools [25 to 51] were re-examined. The reviews included several independent studies on BEA tools from the architectural perspective [7 and 10]; CRC CI reports of BEA international tools and databases [14 & 16], as well as RMIT reports of international tools and databases [15]. In addition, the authors reviewed newer BEA tools [7] including the Environmental Estimating tool (ENVEST 2) [25]; Guideline for Ecologically Sustainable Office Fitout (GESOF) [26]; Ecologically Sustainable Asset Management Rating System (ESSAM) [6 and 52], Green Star Environmental Rating System For Buildings (Green Star) [27], and the National Australian Building Environment Rating Scheme (NABERS) [28].

4.0 BEA TOOLS AND LIFE CYCLE CONCEPTS

4.1 Traditional BEA Life Cycles and Tool Coverage

Reijnders and Van Roekel class BEA tools as mainly Guidelines, checklists, manuals, eco-labels, blueprints, scoring systems, computer based guidance, building component, LCA and eco preference lists [11]. There are accepted attributes that are considered useful for most tools and it is against these attributes as outlined in Table 1 that they must be compared. Such attributes proved useful in comparing BEA tool functionality against user applications.

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

Some tools Seo [14] and Foliente et al [16] reviewed aimed for holistic and some LCA type assessment. Seo reviewed tools considering level of assessment, coverage and weighting, data needs, design/building issues, end-use, impact assessment/scale and weighting including BEA impact criteria [14] as shown in Table 2 . The point made here is that all criteria concern physical flows over product and building life cycles in LCA boundaries such as shown, for example, in Figure 1. All tools reviewed by Seo were found to have sound coverage of criteria except air pollution in one tool, with one tool covering products, and one both buildings and products. All applied weightings based on judgement with variable transparency [14].

Table 2 BEA Impact Criteria (extracted adapted from Seo)

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

At the beginning of this review work for LCADesign such results seemed reasonable so what were stakeholders' issues and what should BEA tools really do? On revisiting the Seo [14], Foliente et al 16], and the RMIT [15] studies, the authors concluded that most of the BEA tools focussed on physical metrics 14] and lacked:

- Integration of whole-of-life considerations or support for stakeholder decision-making;
- Consideration of policy or principles particularly for a project's operational service delivery parameters, and
- Flexibility for a range of stakeholder outputs and comprehensive support for stakeholder decision-making [7].

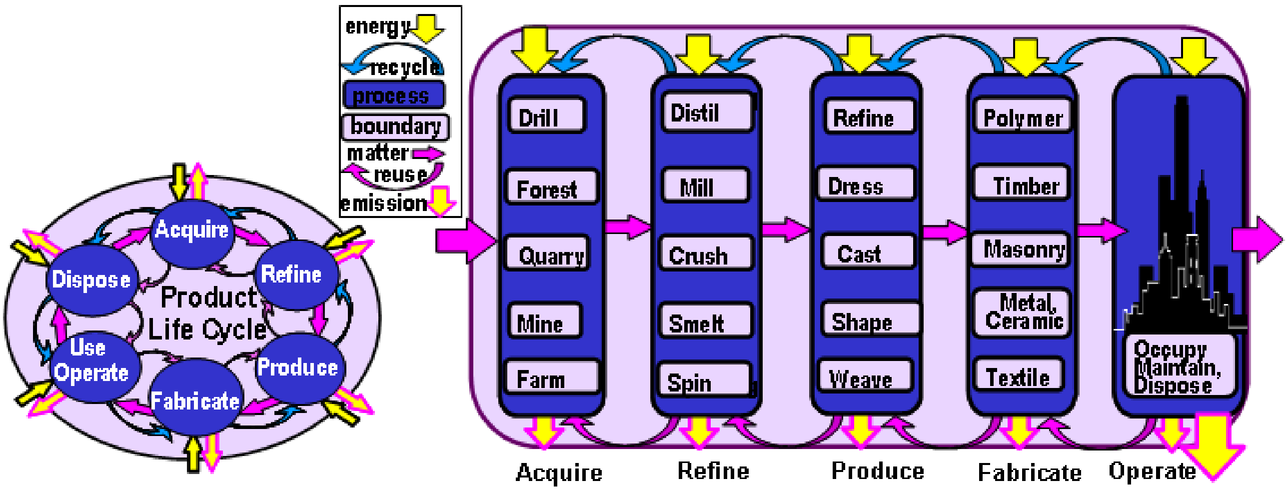

Figure 1 Physical Matter Flows over Product and Built Asset Life Cycles from Acquisition to Use and Disposal.

4.2 Reviewing Basic Tool Uses and Performance Attributes

So while tools need attributes as outlined in Table 1 the question was asked: What should BEA tools really do for stakeholders? Quality tools, for example, direct and facilitate clear communication, hopefully by structuring and streamlining information for the stakeholders [3]. Direction and communication is facilitated when a BEA tool clarifies definitions, aims, objectives, policy positions, strategies, and tactics and provide material for presentations and outcome reporting.

Stephen Watson defines tools as making a job easier or more efficient and argues BEA tools should bridge assessment and actions, professions, ideologies and divergent paradigms [11]. They must also encourage interaction and flexibility in the project delivery process while remaining comprehensive [8]. In addition, 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 [3].To this end 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 have been reported [3, 4]. Furthermore Cole [10 to 14], Sarja [1], Gilbert [15], Barton [6], Jones [5,] Lovins [16], Watson [11] 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].

4.3 Stakeholder Applications by Life Cycle

As previously noted, BEA tools were reviewed with particulars investigated including attributes, functionality and stakeholder reach; stakeholder needs for applications and features and functionality to meet such needs [5]. Stakeholders require tools with appropriate applications, both in the early stages and later project phases [8], essential to facilitate consideration of numerous up-and-down stream effects and implications of these over long asset life spans. As Watson points out; understanding of the building lifecycle varies significantly [11] but to make informed decisions, users need to know the implications from upstream and downstream operations [1-20].

A variety of needs is shown in Table 3 where, for example, investment tools are used to benchmark and communicate policy, whereas construction industry players use tools for scheduling and certification. But if BEA tools are to be holistically applicable they need to provide policy, benchmark and rating applications at the earliest investment processes of the building life cycle, as well as for all the other stakeholder application and phases noted in Table 3.

Table 3 Professional BEA by Application and Life Cycle Phase

Stakeholder	Professional Type	Communication	Documentation	Life Cycle Phase
Investor	Broker, Client, Agent	Feasibility Literature	Policy, Benchmarks	*Asset Investment*
Owner	Corporate, Community	Policy and Class	Classing System	*Acquisition*
Developer	Urban, Land, Builder	Bid Development, Estimate	Development Apps.	*Development*
Manager	Facility, Portfolio, Asset	Strategies/tactics, Standard	Management Systems	*Management in-use*
Planner	Portfolio, Asset	Guide, Benchmark	Guides, Benchmarks	*Strategic Planning*
Purchaser	Eco labelling, Costings	Brief/Tender Eco-Values	Bid Assessments	*Procurement*
Provider	Logistics, Marketing	Marketing Assessment	Campaigns	*Project Initiation*
Designer	Architecture/Landscape	Design, Model	Blueprints/Plans	*Design life cycle*
Consultant	Engineer, Research	Data, Efficiency/IAQ	Reports	*In-use, operations*
Surveyor	Quantity	Specification	Bills of Quantities	*Procurement*
Manufacturer	Environmental 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 in use*
Occupant	Tenant, Owner,	Tenancy Checklist	Checklists	*Pre Occupancy*

The investment phase is key because 'early-bird' timing is critical with prior allocation to master plan, infrastructure, orientation and budget limiting later opportunities. And as Lovins [16], Watson [11 and 12], Jones et al [5 and 13] and Watson et al all [2, 7 to 9,] all stress, by the time designs are developed it is too late to integrate most sustainability initiatives. Watson finds that 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 [11].

But as Table 4 shows only 32% of the BEA tools reviewed applied to planning, with 23% covering the four building life cycle phases of planning to disposal, 36% applied to three phases and 27% to one or two phases only. Seo also found tools limitations included time and resource intensive assessment and negligible economic and social criteria.

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 [50], Your Home [44], GESOF [26], BREEAM+ 3 BRE tools [25]	*	*	*	*
GreenStar [27], GBTool [35], CASBEE [33]	*	*	*	
Evergen [47], EPGB [46], BRE Profiles[25], BASIX [43], LCAid [49]		*	*	*
LEED [40], Ecoprofile [34], BEAT[31], Greencalc [37], EQUER [38.], Envest [25]		*	*	*
ATHENA [30], Green Globes [36], AccuRate [41], Firstrate [48], LISA [51]		*	*	
NBGR [29]	*		*	
BEES [32], Eco-Quantum [39], EcoSpecifier [45]		*		*
NABERS [28]			*	

A deeper review found that most older tools ignored buildings in-use, fitout, refurbishment and disposal phases and none applied in any depth to the earliest investment phase. It also found that, while NABERS focussed on extant buildings, the newer tools: ENVEST, GESOF, GreenStar together with ESSAM as a group had broader life cycle cover than the older tools [7]. One assertion put forward was that the newer tools were also possibly better suited to stakeholder needs for a range of applications and because of the property and construction language used.

Considering these findings, LCADesign team members set out to identify key strategies to achieve a better tool, which they considered began with consideration of integrated whole life coverage of building phases. They synthesised a comprehensive list of stakeholder application needs, an excerpt of which is shown in Table 3. They also conceptually synthesised a framework for application that exploits a 3D CAD integrative ICT software platform, comparable with that of LCADesign, as depicted in Figure 2. It was recognised that such an ICT platform could be the basis for a flexible, broad ranging support framework for BEA as well as BSA tools to coordinate and plug-in the disparate current tools as well as new ones, thereby enhancing their opportunity, applicability and usefulness to stakeholders [7].

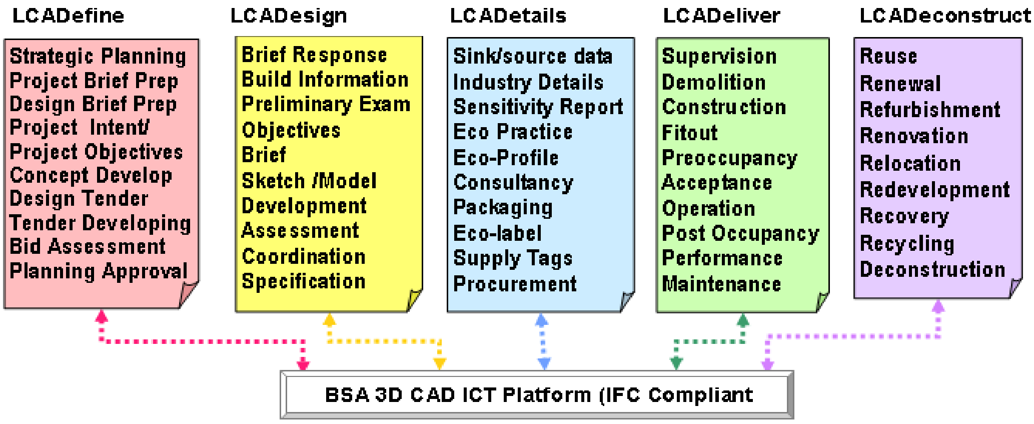

Figure 2 BEA Framework Skeleton, Modules and Basic Information Flow

Since the LCADesign project was originally focussed on Commercial Building, it was accepted that the philosophical foundation for development of any theoretical framework would need to be based on considerations of integrated and cyclical interior, shell and built environmental systems as ecological systems. It was also accepted that life cycle and systems thinking had lead to more objective strategic planning as it supported decision-making which led to more comprehensive outcomes. With this way of thinking economic and environmental assessment can be seen side-by-side rather than obscured by subjective assessment [4, 5, 6, and 20].

5.0 REDEFINING BUILDING LIFE CYCLE PHASES

5.1 Life Cycle Definition

While life cycle approaches, frameworks and systems were considered essential for and had to be inherent in development of any BSA framework, it was clear that LCA needed to be revisited as it only focussed on physical metrics. LCA needed to be formally further defined or re-defined in order for it to structure conceptual thinking to meet stakeholder decision-support needs. Re-thinking LCA and re-visiting Life Cycle Theory (LCT) was considered important and became useful in identifying key areas of need for stakeholder decision-making. The support of these key decision-making areas effectively supported the goal of moving toward sustainability[10, 11, 52].

A breakthrough in thinking by Steve Watson, in his thesis on environmental implementation strategies in the design process, distinguished the temporal design phases as separate to the physical building life cycle [11, 12]. This basic distinction offered a new perspective when reviewing existing BEA tools. Temporal activities could be distinguished from physical ones offering some freedom to restructure information according to different and diverse decision-making needs, physical flows as well as to stakeholder applications. Watson applies the terms to differentiate building 'physical' life cycles from actions over a 'temporal' life cycle in design and asset planning going to manage building processes [3]. His physical life cycle relates to sequencing material flows in forming 'objects" such as shown in Figure 3 and his temporal life cycle to of decision-making in Figure 4.

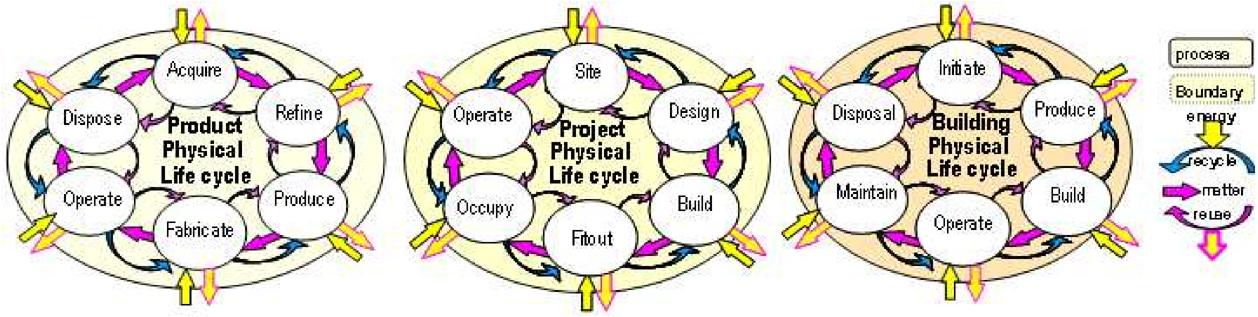

Figure 3. Flow Diagrams of Product and Building Physical Life Cycle Phases

Defining the temporal phase separately for decision-making enables keying for a distinct space in the building process and also distinguishes its locus for BEA tool developers. Stakeholders and their decision-making mechanisms can be given clear consideration aside from and before the quantitative analysis of physical flows takes place. Furthermore, before understanding of this concept, Jones et al [5, 6] Mitchell [10], and Watson et al [2, 7 to 10] had all developed separate models of particular procurement and overall asset and project life cycles within the built environment that the LCADesign team used to differentiate tool applications, assessment needs and decision-making tasks.

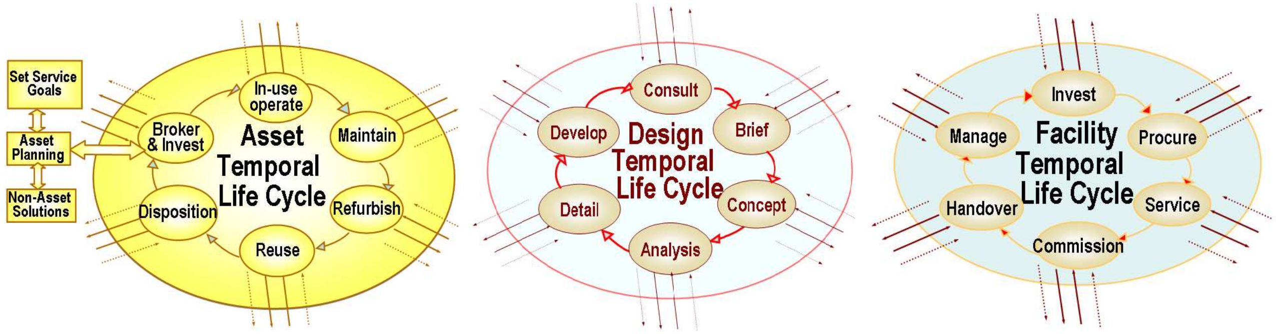

Figure 4. Flow Diagrams of Asset and Design Temporal Life Cycle Phases (adapted from Watson [11])

5.2 Building Life Cycles

The term 'building lifecycle' loosely covers the 'planning and design development process' and the 'building life cycle from inception through building life and disposition' [7, 8]. And as shown in Figure 5 , for example, end of building life strategies are increasingly a focus of urban renewal for CBD space as people seek to live closer in to avoid traffic.

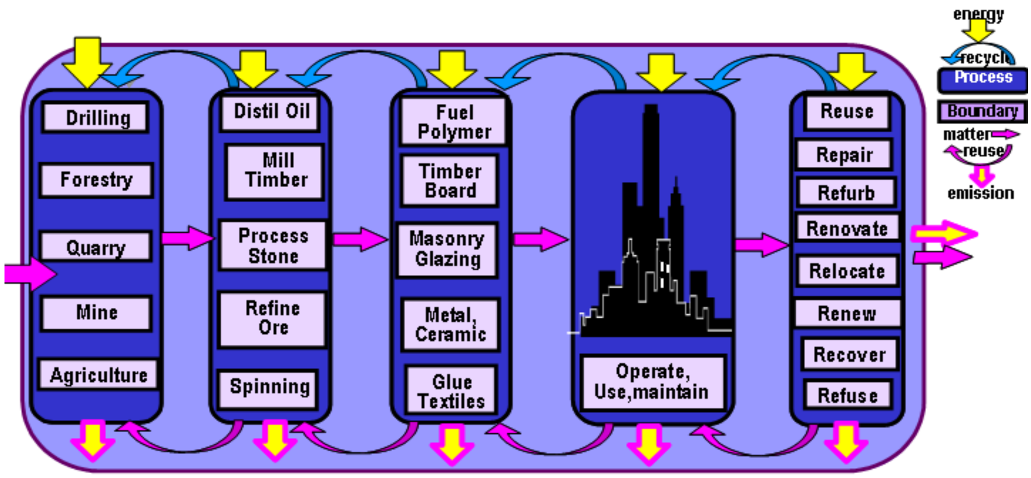

Figure 5 Operational Flows over the (a) Product Life Cycle and (b) Built Life Cycle

Also, as found by Watson et al [11], and illustrated in the American Institute of Architects' publication *The Environment Resource Guide* [50], historically BEA tools have drawn on LCA theory developed around heavy industry sectors, and to address greener consumer and marketing concerns. Because of this development history, 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. This is possibly because they apply to physical theory and metrics for material and energy flows in industrial operations and ignore such temporal theory or metrics for management decision flows on asset and facility operations [8]. The authors assert that with life cycle terminology such as physical and temporal phases undefined, key BEA elements/associations would remain undifferentiated and obscured.

6.0 WHOLE OF LIFE BSA FRAMEWORK

Accepting that BEA tool theory was developed around a primary industry sector picture of mines, factories and consumer goods rather than management of asset, facility, building, design, construction and in use processes, the authors sought to ensure that LCADesign effectively considered temporal decision flows. To do this they sought such considerations in existing LCA, LCT and other frameworks but found all wanting for commercial building applications.

In the absence of pre-existing commercial building BSA frameworks, the emerging life cycle theory discussed up to this point in this paper, was therefore applied to conceptualise a theoretical BSA framework in work that was attempting to determine how to:

- Incorporate all needs and applications while distinguishing between temporal and physical life cycles;
- Facilitate stakeholder communication and technical and linguistic coordination with other BEA tools;
- Act as a bridge between disparate stakeholders and application typologies that they currently use;
- 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 and embody BSA principals, policy, planning, and strategies throughout stakeholder applications and;
- Align 'docking ports' for proposed plug in tools to meet user needs for BEA operational assessment and criteria.

Essentially, the BSA framework was used to align temporal decision-making stages with physical operations over the building life from acquisition of material from the earth to disposition back to the earth. Examples of some differing phases are shown in concept diagrams of temporal design and physical building life cycles with physical flows depicted in Figure 1 and Figure 3 and temporal flows in Figure 2 and Figure 4. The new BSA framework, depicted in Figure 6 is shown as a software schema for an automated interactive BSA toolkit of the same name LCADevelop, leveraging function off an ICT platform to integrate LCA or other economic or community assessment of 3D CAD models.

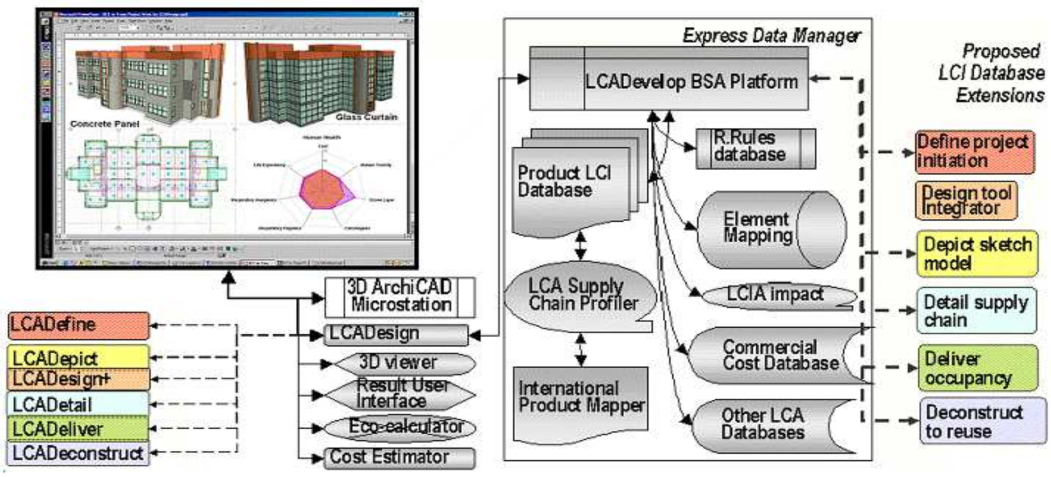

Figure 6. Schematic ICT Flow of Sets of BEA Tools in the LCADevelop Tool Kit.

A critical aspect of LCADevelop is the ICT platform (sharing the LCADesign concept) from which it leverages its function. 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. LCADevelop also provides a 'hub' for moves from encapsulating the common description of Building Environmental Assessment (BEA) to the broader but increasingly called-for move to Building Sustainability Assessment (BSA) of true costing incorporating economic and community (social and cultural) costs.

The BSA framework and tool kit name 'LCADevelop' was coined as it related to LCA, CAD and development, structured around processes occurring over the temporal property development life cycle stages as shown in Figure 2 as well as Figure 4, definition, depict, design, detailing, delivery and deconstruction. These stages were chosen as representative and essential for consideration of decisions and action towards ESD.

7.0 A TEMPORAL AND PHYSICAL BSA TOOL COVERAGE

The earliest intent of proposing 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. The BSA frame of reference for LCADevelop was developed as a consequence of reviewing existing theory, tools and stakeholder opinion and is also grounded on the authors' experience as well as knowledge assimilated during their research. It was initially put forward for ongoing wider examination as it:

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

The authors have proposed a frame of reference BEA toolbox such as shown in the ICT Schema in Figure 6, in Figure 2 to be considered as a platform on which further integration of plug-ins/supplements to existing tools in the right sequence and level of detail could avoid current issues with the often ad hoc, linguistically-confusing, separate tools. It is asserted that, for BEA in the short and for BSA in the long term, any such 'one stop shop' requires provisioning for:

- Enhanced definition of objectives, tender and bid evaluation for sustainable building;
- Performance assessment of the Building and Property Industry supply chain;
- Development of a national independent tool to assess impacts of construction products, and
- Applications for delivery processes from design to end of life recovery of physical elements

Used as a conceptual guide/map to the whole process of creating sustainable building, the BSA framework indicates that key support for sustainable building, described in Table 5 to 9, 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.

8.0 LCADEVELOP AND BSA FRAMEWORK MODULES

Theoretically the LCADefine module incorporates tools defining investment targets and setting of project objectives during strategic decision-making in concept development, investment planning and project initiation. It facilitates up-front acquisition of key data to better inform planning processes. Some LCADefine tool selections are listed in Table 5.

Table 5. LCADefine Tool Box Selections

Development Application	Attribute	Supplement
Asset Planning	Design Performance Appraisal Against ESD Criteria	ESSAM Guides, Checklists
Brief Development	Comparison Against Building Best Practice Benchmarks	Ratings, Benchmarks
Design Brief/Tender	Documentation/Templates For Early In Planning	ESD Brief/Bid Evaluator
Concept Development	BSA Throughout ESSAM Development Process Life	Guides & Checklists
Bid Assessment	Incorporating Economic Life Cycle Costing	CRC CI "Estimator"

As previously noted, and shown in Table 6, LCADesign also needs to link to, incorporate and integrate exemplar concept models and related BEA design tools probably via plug-ins of appropriate existing and new tools, to ensure:

- Technical/Linguistic coordination with other BEA tools;

- Documentation and interactivity with frameworks, guidelines and checklists;
- Additional life cycle components for analysis of operational demands for energy, water, resources and,
- Linkage to parametric models and economic cost estimation.

Table 6. LCADesign Tool Box Selections

Application	Attribute	Supplement
Design Brief Response	Audit/Assess Current Codes/Standards/Contracts	Codes, IAQ, Access Auditor
Building Information	Compare All Levels Design Analysis & Other Tools	Orient, Space, Light Plug-ins
Preliminary Examination	Design Against Sustainability Criteria And Exemplars	Benchmark, Code Checker
Setting Design Objectives	BEA Throughout Building & Design Process Life	Process Guides and Plug-ins
Sketch Design Modelling	Technical & Linguistic Coordination With Other Tools	NABERS, GreenStar, NGBR

LCADetails containing BEA tool selections, such as shown in Table 7, is a procurement module of supply-chain knowledge to acquire and disseminated various levels of information for and to building product suppliers LCA. It offers automated product profiling and supply as well as procurement guidance notes to improve tendering and the industry bottom line. This would service an industry that is under growing pressure to reduce its impact and also those stakeholders selecting building products on the basis of environmental impacts. It satisfies a core need for sustainability decision-making that is currently under-informed and especially compared to that available in other advanced countries.

Table 7. LCADetails Tool Box Selections

Application	Attribute	Supplement
Sink/source data	Sink/Source Data On State Of Domestics Sources/Sinks	Links to SOE/Resources
Supply Chain Details	Sensitivity Analysis For Improved Practice Opportunity	Service Consultants
Eco Practice	Eco-Profile Reports Of Industry Sectors Performance	Eco-Practice Notes & Reports
EcoProfiles/Labels	Industry Details Of Best /Typical/Poor Practice	Eco-profiles & Practices Notes
Supply Tags	Green Supply, Marketing And Eco Specification	EcoProfiles, Tags & Labels

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

Table 8. LCADeliver Tool Box Selections

Application	Attribute	Supplement
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 reuse, and recycling options to avoid demolition and waste.

Table 9 LCADeconstruct Tool Box Selections

Application	Attribute	Supplements
Reuse, Refurbishment	Automated Whole Life User BEA	Credit & Note Cascade for Reuse
Renewal, Recovery	Whole Of LCA & End Of Life Fate Choices	Credit Disassembly for Recovery
Renovation, Redevelop	Whole Of Life Coded Inventory Database	Credit Renewal & Redevelopment

9.0 BEA TOOLS CRITICAL IMPROVEMENT NEEDS

Finally the authors suggest stakeholder needs of BEA tools, as listed in Table 10 are largely unmet and support Watson's thesis that designers (as well as building stakeholders) need BEA tool features, for:

- Defining sustainability criteria/priorities/issues at all temporal steps in design and building development;
- Informing strategic decision-making throughout key temporal design, building and facility processes;
- Facilitating interaction with building design assessment during the design and building management process;
- Assessing design and building temporal processes, contiguity and gaps;

- Assessing investment and design objectives according to trade offs/strengths and weaknesses;
- Predicting and specifying building design performance and assessing performance in-use is as specified;
- Guiding and facilitating design and building project team work as well as (as well as building stakeholders), and
- Accessing detail as well as strategic and summary information in ready, appropriate formats [11].

Table 10 BEA Tool Outputs and Forms

Outputs	Sustainability End-Point Formats	Environmental Improvement Point Formats
Interactive support	Compare With Sustainable End-Points Measure With Recognised Eco Indicators	Compare With Improvement Points Measure With Recognised Ratings
Project Support	Strategically Targeted Decision Support Sustainability Planning Guidelines Pre & Post Occupancy Evaluation	Tactical Decision Support Checklists At Key Times Project Delivery To Acceptance For Improved Use
Generate templates or sections of documentation	Graphics Tables, Reports &Presentations Brief/Tender Development And Evaluation Development Application/Report Building Specifications/ Contracts	Communication Structures & Support Procurement/Performance Specifications Templates/Frameworks For Scheduling Templates/Frameworks For Handover Manual

CONCLUSIONS

The paper presented and discussed practical outcomes from life cycle theory embedded in an emergent BSA framework for integrated tools considering stakeholder decision-making needs. It discussed BEA tool applications considering:

- Relevant findings from a BEA tool scoping and review report that focused on life cycle issues;
- Background motivations for development of the physical LCA theory; and for a
- Redefined temporal life cycle theory in the context of the BSA framework; and their
- Relevance to stakeholders as decision-support towards sustainability.

It revealed some of what BEA tools lack in terms of providing adequate support for stakeholder decision-making. The many existing tools reviewed were found to focus on physical rather than stakeholder required metrics such as functionality measures for operational service delivery. Most overseas developed tools have 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 there were many gaps in current tool attributes/applications. Newer tools had increasing coverage by phase so these were found to potentially better fill stakeholder needs than earlier ones. There remains considerable potential to provide applications for managers, owners, purchasers, operators and occupants in most existing BEA tools here and overseas.

The theoretical BSA framework foreshadowed at least one step change, by exploitation of ICT platforms, with potential to create improved tools to meet stakeholders' BEA needs. Such platforms were considered as a practical vehicle for facilitating collection/connection from divergent sources for flexible and varied outputs covering many aspects, criteria, processes and life cycles. Key points that BEA tool developers should address in future 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 facilitate consistent decision-making.

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