LCADesign: An integrated approach to automatic eco-efficiency assessment of commercial buildings

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SUMMARY

Buildings consume resources and energy, contribute to pollution of our air, water and soil, impact the health and well-being of populations and constitute an important part of the built environment in which we live. The ability to assess their design with a view to reducing that impact automatically from their 3D CAD representations enables building design professionals to make informed decisions on the environmental impact of building structures. Contemporary 3D object-oriented CAD files contain a wealth of building information. LCADesign has been designed as a fully integrated approach for automated eco-efficiency assessment of commercial buildings direct from 3D CAD. LCADesign accesses the 3D CAD detail through Industry Foundation Classes (IFCs) - the international standard file format for defining architectural and constructional CAD graphic data as 3D real-world objects - to permit construction professionals to interrogate these intelligent drawing objects for analysis of the performance of a design. The automated take-off provides quantities of all building components whose specific production processes, logistics and raw material inputs, where necessary, are identified to calculate a complete list of quantities for all products such as concrete, steel, timber, plastic etc and combines this information with the life cycle inventory database, to estimate key internationally recognised environmental indicators such as CML, EPS and Eco-indicator 99. This paper outlines the key modules of LCADesign and their role in delivering an automated eco-efficiency assessment for commercial buildings.

INTRODUCTION

There has been an increase in public awareness that buildings consume significant resources and energy over their lifetime, that they generate pollution of air, water and soil but that they are also an essential part of the world in which we live. The Council of Australian Governments' (1992) National Strategy for Ecologically Sustainable Development calls for effective responses. Many throughout the world are struggling to develop efficient and effective tools for managing their buildings. Tools such as LEED of US Green Building Council in 2000 (US GBC, 2001), BREEAM of UK Building Research Establishment in 1990 (Baldwin et al, 1998), GBTool of National Resource Canada in 1995 (Cole and Larsson, 1999) etc., are used extensively. These tools assess environmental impacts of buildings during their life cycle, each from a different perspective, and thus help users to gain familiarity with assessment procedures. Most of the tools have limitations (Cole and Larsson, 1997; Todd et al., 2001; National Resources Canada, 2001) in that they are:

- not structured to handle different levels of assessment due to difficulties in simplification,
- not explicitly designed to handle regional-specific issues, i.e. the systems were not originally designed to accommodate national or regional specificity,
- not inclusive of explicit weighting because of a lack of consensus on appropriate weights,
- not inclusive of social concerns, a sustainable criteria suggested by Cole and Larsson (2000) for sustainable building assessment, i.e. tools only emphasize environmental loadings such as global warming, indoor air quality, energy and resource consumption.

There is a growing awareness by Australian government and industry of the need for systems and tools for use in life cycle assessment and costing in design and procurement of built assets, documented in Baldwin and Yates (1996), Woods and Jones (1996), Levin (1997), Queensland Department of Public Works (2000) and Barton et al (2002). This is particularly so in the context of energy and greenhouse gas emissions as well as water consumption but is also extending to other environmental aspects. This is a global challenge. Seo (2002) reviewed environmental assessment tools which have been developed and identified areas which limit the effectiveness and sustainable criteria of the models:

- Restriction of tools to specific aspects – a more comprehensive assessment model, extended to include building or community level, is needed.
- Lack of ability for in-depth and elaborate assessment (i.e. they do not have the ability to check different alternative criteria at the same time).
- Need of a specially educated assessor and thus unable be used by different/ other parties.
- Time-consuming and demanding data input (i.e. the GBTool requires the use of other tools for input data) - a user-oriented model will provide a more convenient model.
- Lack of consideration of economic criteria – only a few include cost effectiveness.
- Lack of a transparent weighting system - some models use equal or fixed weighting which may lead to misconstrued results.

Environmental impacts of buildings occur at all scales: *global* (ozone depleting chemicals, global warming from fossil fuel combustion, resource depletion); *local* (urban sprawl, environmental degradation of air, water, soil); and *indoor* (indoor air pollution, hazardous materials, workplace safety). The ability to assess environmental impact automatically from 3D CAD drawings enables building design professionals to make timely and informed decisions. These impacts are long term since buildings are constructed with design lifetimes of many decades and so the minimisation of environmental impacts at the design stage is an optimal approach. At an International level, ISO (ISO 2002) have also been attempting to classify the various approaches to environmental assessment of buildings (Figure 1).

Intended users and beneficiaries	Intended phase		
	Strategic planning and Schematic design	Detailed design and construction	Operation including repair and maintenance
Clients Asset owners Facility managers Quality managers Providers Suppliers	**Methods for sustainable asset management** Quality management Communication between management and providers **e.g. ESSAM & ESD Office Fitout Guideline[1]**		
Clients Designers Constructors Suppliers	**Methods for environmentally conscious design** Comparison of possible design alternatives Assessment against stated target values Communication between client and designers **e.g. LCADesign**		
Owners, investors occupants Facility managers, building operators Developers Real estate brokers		**Methods for rating of existing building from environmental aspect** Communication between stakeholders for investment to existing building **e.g. LEED[2]**	
Owners Designers Building managers and operators Occupants			**Methods for sustainable operation** Communication between stakeholders for building assessment **e.g. NABERS[3]**

[1] Queensland Department of Public Works (2000)   [2] US Green Building Council (2001)   [3] Vale et al (2001)

Figure 1   Intended users and life cycle stages of LCA tools (based on ISO 2002)

There is growing evidence that a combined life cycle assessment and economic costing tool can deliver both environmental and economic benefits for all sections of the building life cycle (via tradeoffs in product selection and design optimisation). This paper outlines key modules of LCADesign and their role in delivering an automated eco-efficiency assessment for commercial buildings.

LCADESIGN

LCADesign has been developed to satisfy the needs of "environmentally conscious design". The principal objective is to develop a building assessment tool (LCADesign) that includes databases and decision-support tools accepted by government and industry as the preferred environmental performance appraisal tool for commercial buildings. Specifically, the objectives are to:

- Create life cycle assessment databases required for specific manufactured building products (e.g. CO_2 emissions; air toxics emissions etc); and to
- Develop a product selection decision-support system interface to IFC complaint CAD software for environmental and cost assessment of commercial building designs.

The resultant software tool enables industry to optimise decisions on the environmental impact of buildings by providing a uniform level of information and to access environmental and cost information for different product combinations and designs. It will meet a growing need from designers and regulators for real-time performance appraisal of designs.

A comparison of the features of the LCADesign environmental assessment tool and the capabilities of existing tools are shown in Table 1. LCADesign is designed to be a significant advancement on current tools.

Table 1   Environmental appraisal tool features

Characteristic	LCADesign Automated Eco-Efficiency Design Tool for Commercial Buildings	Environmental Ratings Systems for Commercial Buildings*
Quantification	Absolute values	Relative values (usually ordinal scaling)
	Evidence based calculation (repeatable)	Evidence interpretation required (individual assessment)
	Calculated from building components	Calculated from aggregate building description
	Includes full life cycle	Includes some life cycle allowances
	Includes costing	No costing included
	Aggregates upwards from components	Available at building level only
Assessment	Objective (no personal judgment required)	Subjective (mixture of personal judgment and some objective measures)
	Comparative ratings star rating levels	Comparative ratings at star rating level
	Evaluation at detailed environmental impacts level	A few have detailed evaluation
	Comparison of performance of components	Little comparison of performance of components
	Accepted for standards, codes, performance based tests	Accepted for overall assessments
	Variety of performance measures	Usually single measure or rating only
	Weighting of components transparent to user	Inherently assumed weighting of components
Tools	Data direct from CAD	Data entered from collated information
	Evaluation based on comprehensive databases	Evaluation done by guided individual judgment
	Full evaluation at sketch design stage	Fully applicable at sketch design stage
	Full evaluation at detailed design stage	Little additional use at detailed design stage
	Process can be verified at every level	Process can be verified assuming subjective assessments
	Tradeoffs easily accomplished	Tradeoffs usually done manually
	Extensive calculations only possible with tool	Can be assessed by questionnaire

* e.g. LEED, BREEAM, NABERS

3D object-oriented CAD files contain a wealth of building information. LCADesign is a fully integrated approach to automatic eco-efficiency assessment of commercial buildings. LCADesign accesses 3D CAD detail through Industry Foundation Classes (IFCs) - the international standard file format for defining architectural and constructional CAD graphic data as 3D real-world objects - allowing professionals to interrogate these intelligent drawing objects and asses the performance of a design. The automated take-off provides quantities of all building components whose specifications are identified, combined with a complete list of product quantities in all qualities of concrete, steel, timber, plastic etc and results calculated in an Australian life cycle inventory database to estimate impacts according to recognised environmental indicators such as CML, EPS and Eco-indicator 99.

LIFE CYCLE ASSESSMENT (LCA)

Life cycle assessment, as defined by ISO 14040, is a method to assess the impact on the environment of a product (including buildings) from "cradle to grave", i.e. from acquiring raw materials for product manufacture to its disposal at the end of its useful life (ISO 1998). This includes components that are replaced in part or in whole over the life of a building, depending on the usage patterns, refurbishment or occupancy. A full life cycle assessment includes all resource depletion, emissions and impacts of pollutants released to air, water and soil during creation, operation and disposal. Consequently, a comprehensive database of resource and emissions data for a wide range of processes is required for such assessment.

The environmental impacts, in general, are categorised according to their effect on ecosystems, human health, and natural resources (SETAC, 1993). Environmental impact indicators provide a set of objective data useful to assess environmental effects of product use and the extent that each aspect of the intended product contributes to environmental impacts.

The indicators are also used to monitor improvement trends in performance as changes are made to the intended product. The impact categories express the environment impacts as quantities, so that processes and products can easily be compared. Well known international indicators include CML, EPS and Eco-indicator 99, each of which has a different focus and use. What is common is a demand for vast detail about resource consumption and emission generation at every process in product manufacture. In the case of LCADesign, the final product is an entire building.

INTEGRATED APROACH OF LCADesign

An automated assessment procedure requires a fully integrated approach. There are four steps (block arrows in Figure 2) in proceeding from the information contained in the 3D CAD to the results that the user needs to enable comparisons between alternatives.
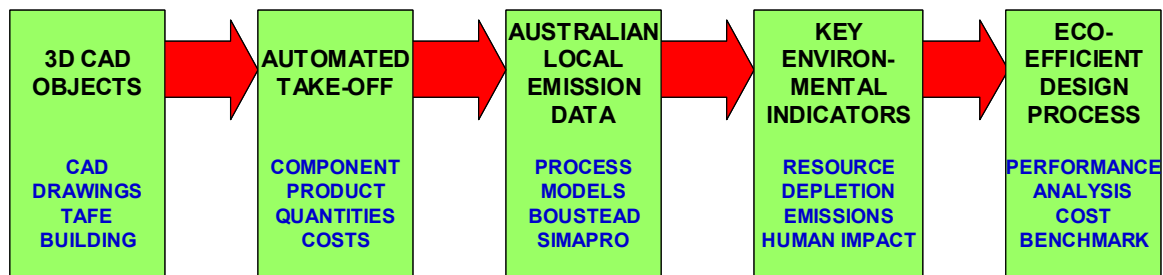

Figure 2   LCADesign information flow

The *first step* is to extract information (including dimensions, location, building products, etc) from 3D CAD to provide component quantities. At this stage the costs can also be established from a cost database.

The *second step* is to determine product specifications. Some product specifications relate directly to drawing components with some only identified from a range of intermediates in manufacturing. A generic database and set of reasoning rules for component composition are used to calculate quantities of resources and emissions for each product.

The *third step* is to calculate the various environmental indicators from the fuel, energy and raw material and emission information and any other aggregated quantitative measures.

The *final step* is to provide tools for viewing information and providing "drill down" facilities to reveal where the "hot spots" are in terms of product or location in the design.

IFCS

One of the great disadvantages of environmental assessment procedures for buildings, or indeed any system, is the need to quantify and enter data about a building. This is very time consuming and updating data and tracking changes can be onerous and error prone. Exploiting existing information sources is vital for general adoption of life cycle assessment. Some of the current generation of CAD systems offer a possible avenue for this data transfer. Traditionally, CAD drawings have been simple line representations of a building with no associated information as to what the lines represent, i.e. walls, windows, roofs, etc. However, object orientated CAD systems do contain such information and provide the opportunity to develop automated analysis software.

The Industry Foundation Classes (IFCs) currently being developed and implemented world-wide for information exchange from proprietary CAD systems is the future of data transfer platforms (Wix and Leibich, 1997). The IFCs are a set of electronic specifications representing objects that occur in constructed facilities (including real things such as doors, walls, fans, etc. and abstract concepts such as space, organisation, process etc.). These specifications represent a data structure supporting an electronic project model useful in sharing data across applications and are adopted for LCADesign.

Each specification is called a 'class'. The word 'class' is used to describe a range of things that have common characteristics. For instance, every door has the characteristics of opening to allow entry to a space; every window has the characteristic of transparency so that it can be seen through. Door and window are names of classes and these classes are termed Industry Foundation Classes or IFCs. A major advantage of utilising IFC technology is that it allows analysis of drawings produced from any IFC compliant system. Many major CAD vendors are moving towards IFC compliance. Identification of every object in a CAD drawing by class allows analytical software calculating building measures such as environmental performance to obtain almost all desired characteristics directly from a CAD drawing.

PHYSICAL ATTRIBUTES OF BUILDING OBJECTS

The building model database is populated from the CAD model via an IFC file. The EXPRESS Data Manager (EDM) system was chosen to store and manage the specific building (or project) data because facilities exist to import the IFC schema and IFC formatted data into an EDM model. The components of any specific building are stored as objects within the hierarchy specified by the IFC schema. The EDM system's *main feature is to manage information independently of any proprietary application. This is achieved through many international standards for industrial data now being developed and most importantly following the same methodology from ISO TC184/SC4 and the ISO 10303 (STEP) standard. These standards focus on computer sensible object models* (EXPRESS Data Manager 2002).

The environmental model of a building has a degree of incompleteness dependant upon the depth of information in the databases. Some attributes may be known to a lesser level of detail and therefore will be reported at a courser or more aggregated level. The environmental model is stored in the EDM model of the building integral with the data transferred from 3D CAD.

DATABASE CONTENT

Several sources of data have to be accessed by the assessment tool and the tool also needs facilities to directly manage some of this data. Figure 3 shows that a single database can be used for the storage of these various sources of data. Currently, the full implementation is still in progress to replace the original relational database management system used to manage the building and environmental impact data. The building quantity data are extracted from the 3D CAD model via an IFC file and imported into the relational database. Work has only begun in formalising the "Default Reasoning Rules" (described later in this paper) required to relate building elements with product composition. Currently this is being included with the building quantity data.
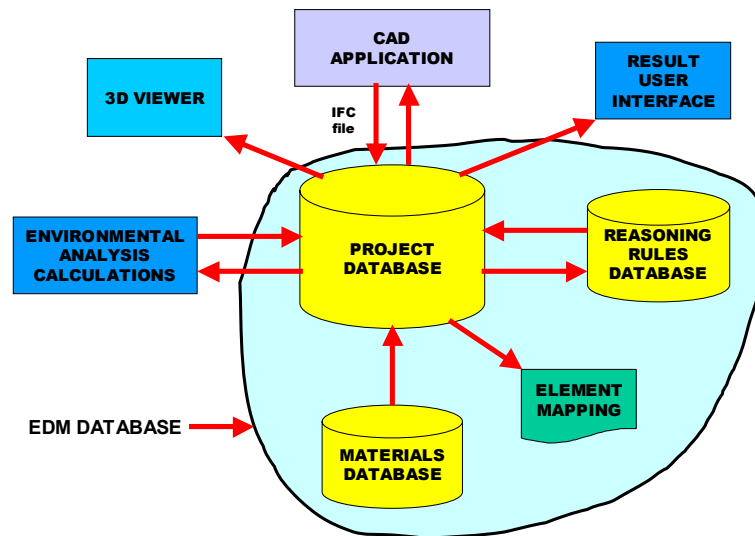

Figure 3   Outline of data information flows

The Australian Cost Management Manual (ACMM) (Australian Institute of Quantity Surveyors, 2001) provides a building element classification to enable "drill down" by building location and provides a descriptive hierarchical nomenclature familiar to many potential users of LCADesign. ACMM Element ("ACMME") codes are assigned to the 3D CAD objects.

The environmental data for building products is based on the Boustead model (briefly described later in this paper) of processes in mining, manufacturing, transporting, and assembling products. This Life Cycle Inventory (LCI) data (with resource use and emissions mainly per kilogram) inherent in the database is being refined for Australian industry practice. This relates the products and logistics, to the raw materials consumed and emissions generated and consequently to the associated environmental impacts.

MANAGEMENT OF THE BUILDING AND ENVIRONMENTAL DATA

LCADesign will provide facilities to manage all data required for environmental analysis. The LCADesign system exclusively manages the Default Reasoning Rules, ACMME mapping, and environmental assessment method definitions (CML, EPS, EcoIndicator 99, etc) and imports and manages LCI data (including the material to substance mapping). In the case of the physical building model, the LCADesign system "reads" the physical building data from the EDM database. The schemas are being designed in the EXPRESS language to describe EDM database storage for environmental assessment methods and impacts, ACMME information, default reasoning rules and LCI data.

BUILDING PRODUCT DATABASE

The inventory database contains resource consumption and emissions generation data in a hierarchy of industrial processes and "intermediates" with an ability to compile these attributes at any node in the hierarchy based upon unit mass factors. Product attributes such as density are used to convert unit operations to that of equivalent functional units. The inventory consists of all processes in acquiring, processing, and delivering various qualities of products for building construction. An extract is shown in Table 2 for structural concrete. Emissions are calculated in the Boustead Model 4.4 (Boustead Consulting Ltd., 2002) after identifying and logging unit operations for all processes in manufacturing a building product. The energy, fuel, raw material and emissions inventory so generated is calculated, compiled and transposed to the product database.

Table 2 Concrete Product Inventory Extract

Cement for Mortar	Concrete -15MPa	Concrete -40MPa	Concrete Masonry 100mm
Cement Sheet 4.5mm	Concrete -20MPa	Concrete -50MPa	Concrete Masonry 200mm
Cement Sheet 6.0mm	Concrete -25MPa	Concrete -80MPa	Precast Concrete
Cement Sheet 7.5mm	Concrete -30MPa		Cement Render

The Boustead Model has been developed over the last 30 years with such data for various products through modelling their process of manufacture, from raw material extraction, manufacturing, use and final disposal. Details of direct and indirect feeds into the entire process are accounted for allowing for a highly complex web of processes that together form a particular product. The various emissions data are aggregated for the entire process flow to derive gross totals for that product. Figure 4 shows a typical process flow for dry process bagged cement used for mortar.
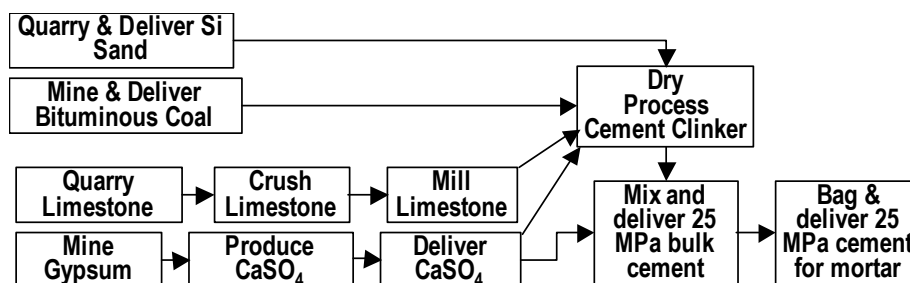

Figure 4 Process map for cement mortar

Table 3 shows an example from a list of resources and emissions to air, water and soil. Many items have small or negligible quantities in common building products but for an entire commercial building the sum can be significant.

Table 3 Materials database selected contents

Raw Material 30 Items eg.	Emission to air 43 Items eg.	Emission to water 44 Items eg.	Solid Waste 16 Items eg.
Bauxite	CO_2	Ammonia	Ash
Coal	Hydrocarbons	Cadmium (Cd)	Industrial waste
Limestone	Methane	Fluoride	Solid waste
Gypsum	N_2O	Phosphate (PO_4^{3-})	Slags/ash

DEFAULT REASONING RULES

Default reasoning rules link the product's inventory of resource consumption and emission generation calculated in and exported from the Boustead model 4.4 database. Thus all default reasoning rules are specified in terms of "known" component products (i.e. as specified in the IFC schema) and "known" manufacturing processes (i.e. made in processes in the model database) in order to gain a comprehensive environmental inventory of the building. The default reasoning rules have a recursive nature to allow for the varying level of detail throughout the stages of building design and specification. To maintain consistency all design detail is obtained from a single building model source (i.e. the EDM model) producing a 3D CAD model to a greater level of detail than is traditionally the case. To cope with the varying level of detail through the subsequent stages of building design, the default reasoning rules are always defined down to the finest level of detail specified by the building product inventory. This is achieved by specifying a rule in terms of applicable rules at the next finer level of detail until the rules at the "leaf nodes" are specified in terms of some specific product (or products) only.

EXAMPLE

An example building has been selected to test both the ability to create IFC files and to assess environmental impact through LCADesign. The Engineering Science Building (Roy Wallace Building) at the Southbank Institute of TAFE in Brisbane is a five level development of about 8000 m^2 that includes basement parking, child-care centre, tiered lecture theatre, laboratories, lecture rooms and offices. This building is complex, with a wide range of facilities despite its relatively small size. With all the characteristics of a commercial office building including lifts, air conditioning, etc, it was an excellent choice as a test building. A CAD view is shown in Figure 5 and an example environmental analysis of two design options in Figure 6.
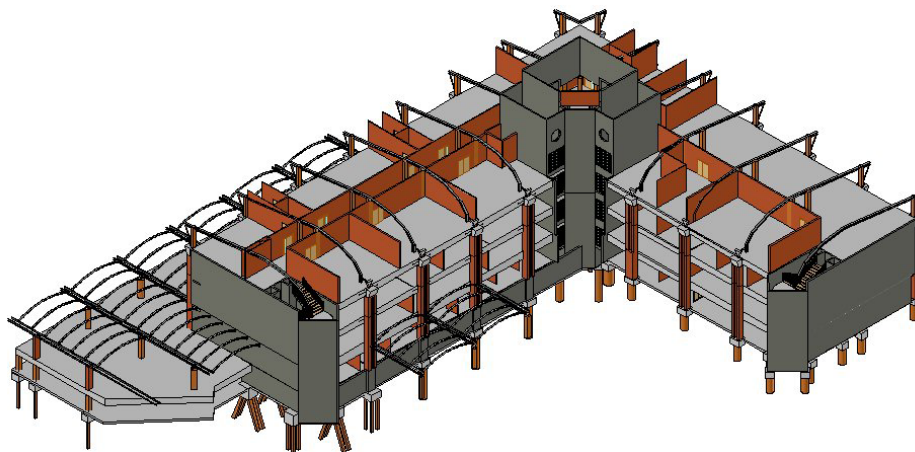

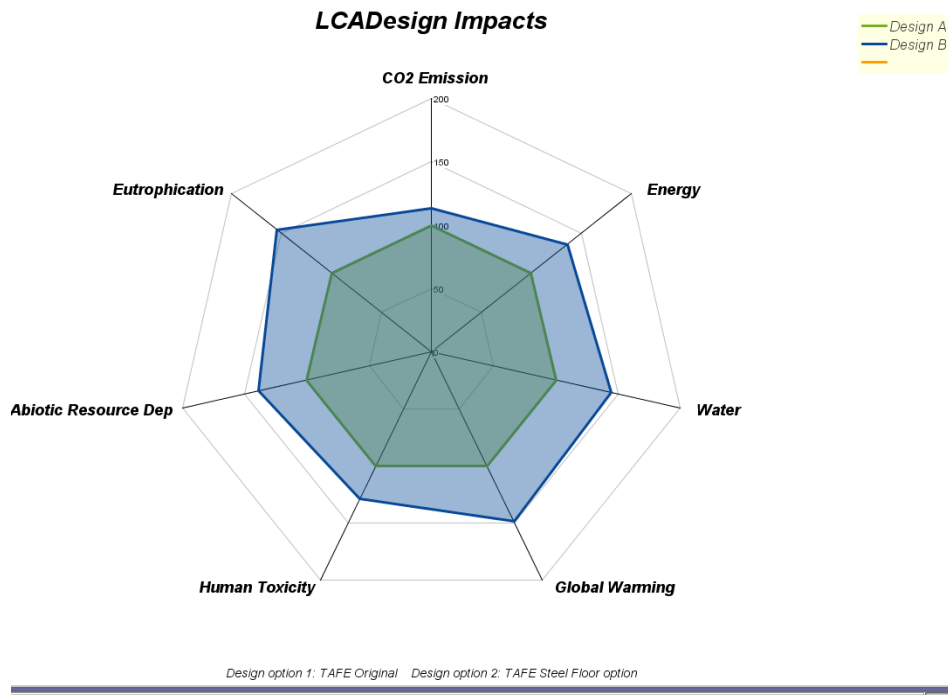**Figure 5**   A view of the Roy Wallace building in ArchiCAD

Figure 6   An example figure of an environmental result from the test building

CONCLUSIONS

The paper outlined the key modules of LCADesign and their role in delivering an automated eco-efficiency assessment for commercial buildings.   The ability to assess designs automatically from drawings to reduce environmental and economic cost impacts will enable building design professionals to make informed decisions on such impacts of building structures.

LCADesign exploits the wealth of information in contemporary 3D object-oriented CAD files directly for a fully integrated and automated assessment. It accesses the CAD detail through Industry Foundation Classes to permit professionals to interrogate drawing objects. The development of LCADesign direct from 3D CAD is a complex undertaking to integrate a wide range of key modules from a database accommodating IFC definitions, product life cycle inventories and environmental impacts.

The automated take-off provides quantities of building components based upon inventories from a database of processes, logistics and raw materials acquisition in Australia. Complete life cycle inventories for specified quantities of building products etc is the platform to provide reports from LCADesign based on internationally recognised environmental indicators.

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REFERENCES

Australian Institute of Quantity Surveyors (2001) Australin Cost management Manual, Vol. 2, Australian Institute of Quantity Surveyors, Canberra, 189p.

Baldwin, R. and Yates, A. (1996) An Environmental Assessment Method For Building, *Proceeding of the International CIB Conference,* RMIT, Melbourne, Australia.

Baldwin, R., Yates, A., Howard, N. and Raw, S. (1998) *BREEAM 98 for Offices*, Building Research Establishment, UK.

Barton, R., Jones, D. and Gilbert, D. (2002) Strategic asset management incorporating ecologically sustainable development*, Facility Management*, Henry Stewart, London.

Boustead Consulting Ltd. (2002) The Boustead Model 4.4 for window, Boustead Consulting Ltd.

Cole, R. J. and Larsson, N. (1997) Green building challenge '98, *Proceedings of CIB Second International Conference on Buildings and Environment*, Paris, June 9-12, Vol. 1, 19-29.

Cole, R. J. and Larsson, N. (1999) GBC'98 and GBTool: Background, *Building Research and Information*, 27(4/5), 221-229.

Cole, R. J. and Larsson, N. K. (2000) Green Building Challenge: Lesson Learned from GBC '98 and GBC 2000, *Proceedings of International Conference on Sustainable Building 2000*, 22-25 October, Maastricht, The Netherlands, 213-215.

Council of Australian Governments (1992) *National Strategy for Ecologically Sustainable Development,* Department of Industry, Science and Tourism. Canberra, Australia.

EXPRESS Data Manager (2002) On line help.

ISO (1998) ISO/CD 14042.3: Life Cycle Assessment - Impact Assessment.

ISO (2002) ICO TC59, ISO AW121931 Buildings and constructed assets – Sustainability in building constructions – Framework for assessment of environmental performance of buildings.

Levin, H. (1997) Systematic evaluation and assessment of buildings environmental performance, *Proceedings of Conference: CGI-97 Directions Forum:,* Brisbane, Australia.

National Resources Canada (2001) Limitation of GBTool, NRC Buildings Group (http://buildingsgroup.nrcan.gc.ca/Projects_e/GBTool.html).

Queensland Department of Public Works (2000) *ESD Fitout Guideline for Office Accommodation*, Brisbane, Australia. http://www.build.qld.gov.au/aps/aps01.htm#esd.

Seo, S. (2002) *International review of environmental assessment tools and databases*, Report 2001-006-3-.02, Cooperative Research Centre for Construction Innovation, Brisbane.

SETAC (1993) *A Conceptual Framework for Life cycle assessment,* Society of Environmental Toxicology and Chemistry, Pensacola, FL.

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.

US Green Building Council (2001) *LEED^{TM} Rating System Version 2.0 Draft*, March, US Green Building Council, San Francisco, CA.

Vale, R, Vale, B. and Fay, R. (2001) The National Australian Buildings Environmental Rating Scheme, Environment Australia, http://www.ea.gov.au/industry/waste/construction/pubs/final-draft.pdf.

Wix, J. and Liebich, T. (1997) Industry Foundation Classes architecture and development guidelines, *IT Support for Construction Process Re-Engineering*, Proceedings of CIB Workshop W078 and TG10 Cairns, Australia, July 9-11 1997, pp.419-431, (CIB Proceedings: publication 208).

Woods, G. and Jones, D G, (1996) *Using Life Cycle Analysis to Understand Environmental Impacts* Proceedings of International Conference on Design for the Environment:, RMIT, Sydney.