INTEGRATING ECO-EFFICIENCY ASSESSMENT OF COMMERCIAL BUILDINGS INTO THE DESIGN PROCESS: LCADESIGN

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Abstract

The ability to assess a commercial building for its impact on the environment at the earliest stage of design is a goal which is achievable by integrating several approaches into a single procedure directly from the 3D CAD representation. Such an approach enables building design professionals to make informed decisions on the environmental impact of building and its alternatives during the design development stage instead of at the post-design stage where options become limited. The indicators of interest are those which relate to consumption of resources and energy, contributions to pollution of air, water and soil, and impacts on the health and well-being of people in the built environment as a result of constructing and operating buildings. 3D object-oriented CAD files contain a wealth of building information which can be interrogated for details required for analysis of the performance of a design. The quantities of all components in the building can be automatically obtained from the 3D CAD objects and their constituent materials identified to calculate a complete list of the amounts of all building products such as concrete, steel, timber, plastic etc. When this information is combined with a life cycle inventory database, key internationally recognised environmental indicators can be estimated. Such a fully integrated tool known as LCADesign has been created for automated eco-efficiency assessment of commercial buildings direct from 3D CAD. This paper outlines the key features of LCADesign and its application to environmental assessment of commercial buildings.

Keywords: Environmental assessment, commercial buildings, industry foundation classes, 3D CAD, life cycle inventory

1. Introduction

Sustainable building design is the gathering of a complex set of social, economic and environmental information and making decisions based upon that information to produce sustainable developments. In the current marketplace for the design and construction industry, it is very difficult for organizations to spend significant resources finding the environmental impacts of different products and evaluating the performance of different components and systems.

The need for integrating eco-efficiency assessment into the design process is partly driven by an increase in awareness that commercial buildings, in particular, consume

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significant resources and energy over their lifetime, that their construction generates pollution of air, water and soil but they are also an essential part of the world in which we live. Among others in the 1990s, the Council of Australian Governments' National Strategy for Ecologically Sustainable Development [1] called for effective responses to develop efficient and effective tools for managing their buildings.

Tools such as LEED of US Green Building Council in 2000 [2], BREEAM of UK Building Research Establishment in 1990 [3], GBTool of National Resource Canada in 1995 [4] etc., are widely available. These tools are used to 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 [5,6,7]. 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 [8,9,10,11,12].

In a recent review [13], specific problem areas identified included restricted focus, lack of in-depth assessment, need of a specially educated assessor, time-consuming and demanding data input, minimal consideration of economic criteria, and lack of a transparent weighting system for the environmental indicators. At an international level, ISO [14] 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	**Methods for sustainable asset management** Quality management Communication between management and providers **e.g. ESSAM & ESD Office Fitout Guideline[1]**		
Clients Asset owners Providers 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 environ mental 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]**

Based on ISO [14] [1] Queensland Department of Public Works [11], [2] US Green Building Council [2], [3] Vale et al [15]

Figure 1 Intended users and life cycle stages of LCA tools

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 impacts 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. This paper outlines key modules of LCADesign and their role in delivering an automated eco-efficiency assessment for commercial buildings.

2. LCADesign

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 accessing environmental and cost information for different product combinations and designs at a corresponding level of detail. It is aimed at meeting a growing need from designers and regulators for real-time performance appraisal of designs.

LCADesign is designed to be a significant advancement on current tools with the following capabilities: absolute values from repeatable evidence based calculation (including costing) of individual building components over a full life cycle aggregated upwards from components; variety of performance measures (with transparent weighting) of components and comparative ratings (star ratings) based on evaluation at detailed environmental impacts level which are acceptable for standards, codes, and performance based tests; tradeoffs easily accomplished using data direct from CAD and associated comprehensive databases for full evaluation at sketch and detailed design stages.

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 achieved through accessing 3D CAD detail via 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 assess 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 from an Australian life cycle inventory database to estimate impacts according to recognised environmental indicators such as CML and Eco-indicator 99.

3. Integrated approach of LCADesign

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

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 viewing information with "drill down" facilities to reveal where the "hot spots" are in terms of product or location in the design.

4. IFCs

Obtaining and entering data about a building into an assessment tool is very time consuming and a significant disadvantage of environmental assessment procedures for buildings. An obvious source of building information is a CAD drawing which traditionally has consisted of simple line representations of a building with no associated information as to what the lines represent, i.e. walls, windows, roofs, etc. Some of the current generation of CAD systems offer a quick effective solution for data transfer by being object orientated and do contain detailed associated information to provide the opportunity to develop automated analysis software.

The Industry Foundation Classes (IFCs) currently being developed and implemented world-wide for future information exchange from proprietary CAD systems [16] 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.

A major advantage of utilising IFC technology is analysis of drawings produced from any IFC compliant system. Identification of every object in a CAD drawing by IFCs allows analytical software calculating building measures such as environmental performance to obtain almost all desired characteristics directly from a CAD drawing.

The building model database is populated from the CAD model via an IFC file. The EXPRESS Data Manager (EDM) [17] 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 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 coarser or more aggregated level. The environmental model is stored in the EDM model of the building integral with the data transferred from 3D CAD.

5. 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. The building quantity data are extracted from the 3D CAD model via an IFC file and imported into the relational database. Default reasoning rules are required to relate building elements with product composition.

The Australian Cost Management Manual (ACMM) [18] 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 of processes in mining, manufacturing, transporting, and assembling products. This Life Cycle Inventory (LCI) database (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.

6. 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 [19]. 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 [20]. 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 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.

7. 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, e.g. concrete products such as cement for mortar, cement sheet 4.5mm, concrete-20Mpa, concrete masonry 200mm, precast concrete and cement render Emissions are calculated in the Boustead Model 4.4 [21] 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.

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 2 shows a typical process flow for dry process bagged cement used for mortar.

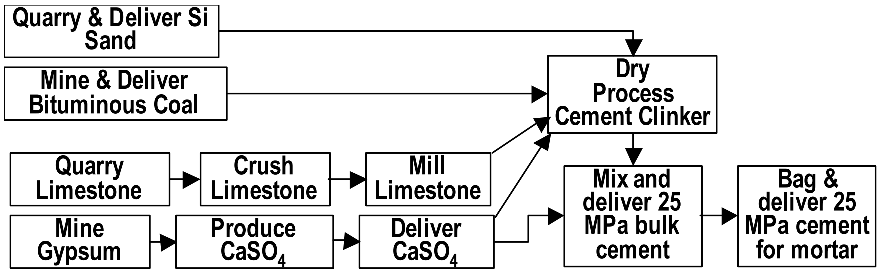

Figure 2 Process map for cement mortar

Table 1 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 1 Materials database selected contents

Raw Material 30 Items e.g.	**Emission to air 43 Items e.g.**	**Emission to water 44 Items e.g.**	**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

8. 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.

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 are specified in terms of some specific product (or products) only.

9. Example

An example building has been selected to test both the ability to create IFC files and to assess environmental impact through LCADesign. A small 3 storey office building of about 1500 m^2 was drawn in ArchiCAD. The walls are of precast concrete and the building is air-conditioned and has aluminium framed windows. This building has all the characteristics of a commercial office building except for the absence of lifts. A CAD view is shown in Figure 3 and an example environmental analysis of two design options in Figure 4.

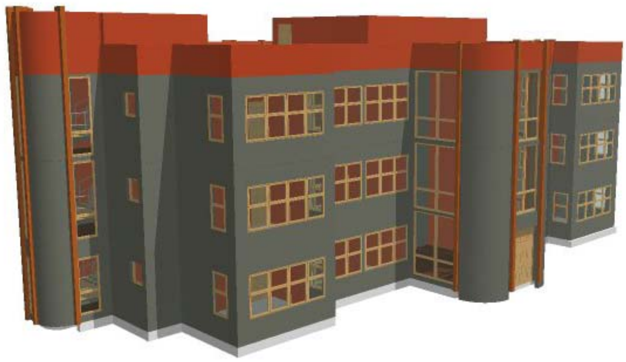

Figure 3 A view of the example building in ArchiCAD

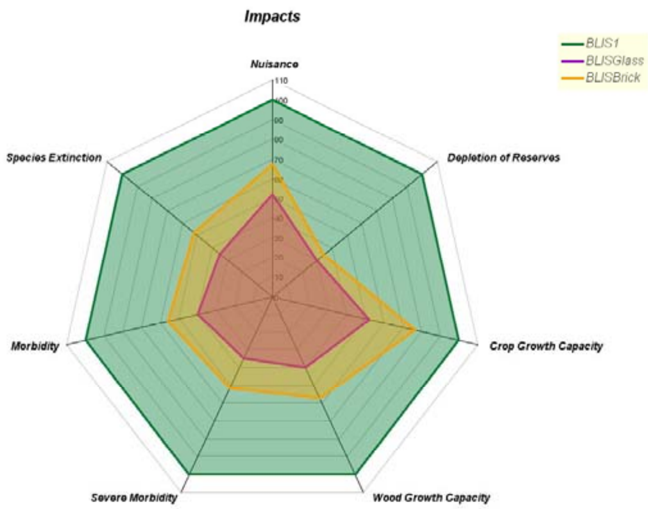

Figure 4 An example figure of an environmental result from the test building

10. 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.

11. Acknowledgement

LCADesign is being developed by the Cooperative Research Centre for Construction Innovation which is funded by the Australian Government's CRC Program.

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