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VALUE ADDING IN 3D CAD MODELS FOR ENVIRONMENTAL ASSESSMENT OF BUILDINGS

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ABSTRACT

Environmental assessment of buildings at an early stage of design development rather than after the design has been established is an essential requirement for achieving a building with the lowest impact. One of the sources of design information is the CAD drawings or models, particularly 3D CAD models, which contain much of the dimensional information and some properties of products to be used in construction of a building. Combining such information with databases of the environmental properties of materials and performance evaluation of alternative designs can provide measures of expected performance to satisfy clients' demand for decision-making information as early, and as efficiently, a possible.

The reported experiences of what clients (users) want from a computer application are reviewed and considered in relation to the ability to acquire a great amount of detail from 3D CAD models which has to be presented in the simplest of ways for the user to quickly grasp the implications of a proposed design. Practical aspects are discussed using examples drawn from recent experiences in creating LCADesign, a system which integrates the assessment of the eco-efficiency of commercial buildings into the design process.

Keywords: 3D CAD, life cycle assessment, commercial buildings

1. INTRODUCTION

Typically environmental impacts of buildings are long-term impacts with building design lifetimes of many decades and therefore minimising impact at the design stage is essential. A tool to automatically generate assessment of environmental impacts from 3D CAD models requires fully integrated procedures capable of delivering:

- repeatable evidence based calculations from absolute values of individual building components aggregated upwards from individual components,
- users selections of a variety of performance measures, and
- comparative ratings of buildings and components based on evaluation of detailed environmental impacts for identifiable trade-offs.

Successful implementation of a tool capable of performing the above tasks involves not only the development of computer software and related databases but paying considerable attention to the needs of the potential users. The technological advances made in producing a unique and versatile tool potentially form a paradigm shift in assessing the environmental impacts of buildings but only if the implementation addresses the problems faced by those who currently assess the environmental impacts of building and their materials.

This paper outlines the limitations of existing tools and summarises user needs and comments about utilising a new approach to assessing the environmental impact of buildings.

2. LIMITATIONS OF EXISTING TOOLS

Tools such as LEED of US Green Building Council in 2000 (US Green Building Council, 2002), BREEAM and ENVEST of the UK Building Research Establishment in the 1990s (Baldwin et al, 1998 and Building Research Establishment, 2003), and GBTool of National Resource Canada in 1995 (Cole and Larsson, 1999) have been adopted widely to assess various measures of environmental impact of buildings. Recently, similar rating tools such as NABERS (Vale et al, 2001) and GreenStar (Green Building Council of Australia, 2003) have been launched in Australia. These tools can be used to assess environmental impacts over a buildings' life cycle, from materials used to a whole of life cycle approach. Furthermore, each of the individual assessment tools and rating schemes address different aspects of a building's environmental impacts. Their coverage also varies from building components to whole of building construction as illustrated in Figure 1, as an example, for some of the Australian tools and rating schemes (see environmental design guide by Foliente et al. (2004) for more tools comparison world-widely used).

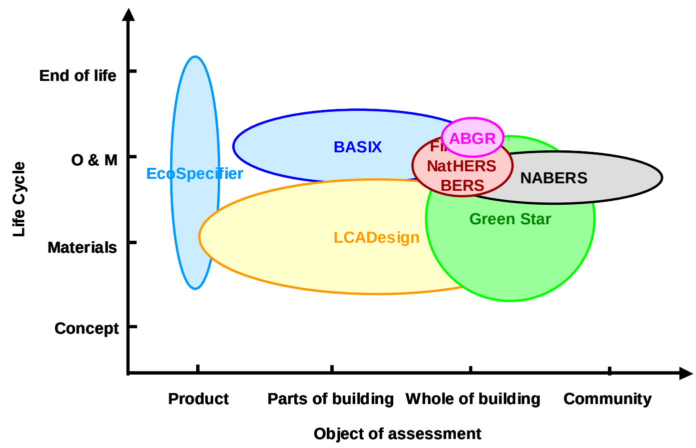

Figure 1 Classification of Australian tools and rating schemes for environmental assessment of buildings and related components

Most of the tools have limitations and weaknesses and in a recent review of such tools many common problem areas have been identified (Seo, 2002). They included having a narrow focus, lacking in-depth assessment, needing professional assessors, requiring time-consuming data input, considering minimal economic criteria and lacking transparency in weighting environmental indicators (Todd et al, 2001). No one model available in Australia completely satisfied all criteria considered in the study or is ever likely to cover all aspects.

The approaches vary greatly. For example, the limitations of the GBTool include it being a framework which is more time consuming than others as it requires users to use other tools to simulate energy performance, estimate embodied energy and emissions, thermal comfort and air quality, etc. It is used to assess pre-occupancy performance as well as occupied building performance. Cole and Larsson (1997) pointed out limitations of the LEED and BREEAM models include the difficulties in simplifying as they are not structured to handle different levels of assessment. Also they were not explicitly designed to handle regional-specific issues, i.e. national or regional variations.

Although some models included criteria such as commuting transport (GBTool, GreenStar and NABERS), almost all tools concentrated on assessment of a building. The exceptions were BEES and Eco-quantum which focused on building products. Seo (2002) suggested that it was important to extend models such as GBTool and LEED to cover community level assessments, as in GreenStar and NABERS, where broad coverage was a goal.

While all real-world design/assessment decisions consider economic aspects alongside other objective criteria, only BEES and LCAid address economic topics. Most models emphasise environmental loadings such as global warming, indoor air quality, energy consumption and resource depletion. As expected of rating tools, the checklists in these models are fixed so they cannot be modified by regional differences or users’ concerns.

Most models give all criteria inherently predetermined weightings partly because of the difficulty in assignment as in LEED or a transparent fixed weight that avoids assigning relative importance because of regional differences as in BREEAM and Ecoprofile. On the other hand, both GBTool and BEES employ flexible weighting methods so users can give due weight to criteria considering regional sensitivities or conditions (which may cause controversial problems as well).

All tools reviewed provided for environmental assessment over the building life cycle to some degree to assist users to become more familiar with such concepts. However the tools could be improved by addressing the following general shortcomings:

- Lack of clarity in what the tool can be used for (e.g. buildings, community, products, energy, eco-indicator, greenhouse gas emissions etc),
- Inability to assess comparisons of alternatives directly to inform choices,
- Need for especially educated assessor even for preliminary assessments,
- Time-consuming effort to obtain and input data,
- Lack of simple parameter settings to apply to Australia as a whole or regions,
- Non-availability of essential economic aspects, and
- Not showing weightings that can mislead for some applications.

3. AUTOMATED ENVIRONMENTAL ASSESSMENT

An automated environmental assessment system for commercial buildings has been developed to integrate a CAD-based tool with associated material-performance databases into an assessment system called *LCADesign* in an attempt to provide a system which is simple to operate despite its very detailed calculations. This unique combination of 3D CAD model, use of IFC export files and rules for estimating the quantities of materials in ill-defined 3D CAD objects, building material quantity estimation, drawing on a life cycle inventory of resource usage and environmental emissions for environmental indicators provides a facility to analyse in real time the environmental impacts of alternative commercial building designs. The system has been created with input from potential users who have a growing need for quick appraisal of the environmental design performance of constructed assets.

The key to being able to assess a proposed design is the modern 3D, object-oriented CAD files which contain a wealth of building information which is not commonly utilised to any great extent. *LCADesign* is a fully integrated approach to automatic eco-efficiency assessment of commercial buildings from the completion of the 3D CAD drawing of a building to viewing of the environmental impacts resulting from the construction of the building. *LCADesign* accesses the 3D CAD detail through Industry Foundation Classes (IFCs) (Wix and Liebich, 1997) - 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 materials, where necessary, are identified to calculate a complete list of the quantities of all materials such as concrete, steel, timber, plastic etc. This information is combined with the life cycle inventory database to estimate key internationally recognised environmental indicators such as Eco-indicator 99 and a range of additional readily understandable indicators such as greenhouse gas emissions, embodied energy and water and carbon (for considering the impact of any future carbon tax).

The building model database is populated from the CAD model via IFC files. An EXPRESS Data Manager (EDM) (Express Data Manager, 2002) system that was chosen to store and manage the specific building (or project) data provided facilities to import the IFC schema and IFC formatted data. The Australian Cost Management Manual (ACMM) (Australian Institute of Quantity Surveyors, 2001) was used to provide a building element classification - a descriptive hierarchical nomenclature that was familiar to many potential users of *LCADesign*. It also enabled a “drill down” capability by location to any single element assigned as a 3D CAD object in the model building.

The environmental data for all required building products was created in a Boustead (Boustead Consulting, 2002) Life Cycle Inventory model of resource use and emissions mainly per kilogram of building product. This Life Cycle Inventory database was refined to reflect Australian industry practice to related domestic and imported products and logistics, raw materials consumption and emissions generation and consequently to associated environmental impacts. Environmental results calculated in the Australian Life Cycle Inventory Model database to an international standard (ISO, 1998) are used to estimate impacts according to environmental indicator methodology of Eco-indicator 99.

4. ANALYSIS OF ENVIRONMENTAL IMPACTS

There are essentially two stages of an assessment:

- Creation of a 3D CAD model and tagging of each object, and
- Analysis of the environmental impacts of the model and variations.

The tagging is done by the 3D CAD modeller and is straight forward as many of the tags are the same (e.g windows, walls, doors etc) and are added simultaneously. In one building there were about 1500 3D CAD drawing objects which for initial analysis only required about 25 different tags to clearly define all the objects at material level. A typical view of a building model of a small commercial office building as drawn in ArchiCAD is shown in Figure 2.

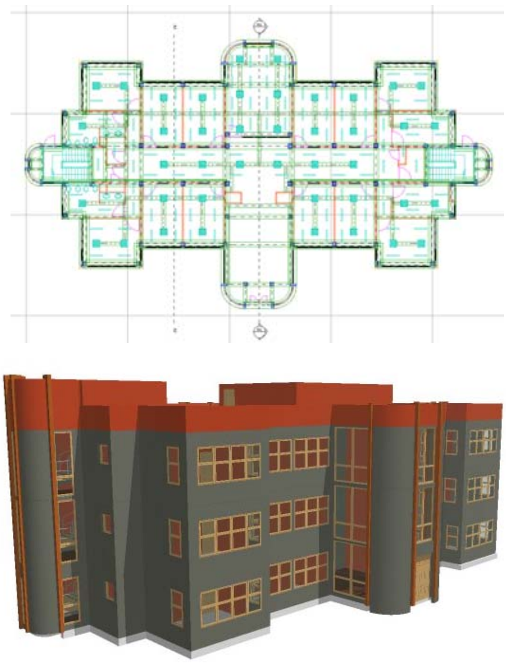

Figure 2 Views of the example building in ArchiCAD

With guidance from a Life Cycle Inventory expert the modeller could perform initial analyses, particularly if targets are given for a particular indicator or architecturally different models are required for comparing alternatives. *LCADesign* is most effectively used as a tool for the environmental analyst to consider the impact of alternatives from a basic design or significantly different designs.

LCADesign provides the environmental assessors with the capability to test variations (alternatives) on all the objects drawn in the 3D CAD model and investigate, in as much detail as required, the specific impacts or indicators of these variations. This is a role for an environmental expert who does not need any 3D CAD experience.

The most significant value-adding capability of an automatic assessment procedure is the ability to consider a wide range of alternatives while a design is being formulated rather than post-design as is almost always the case. There is a gap between macro level design intentions and the practical delivery of micro level specifications at a builder level. This is where *LCADesign* is designed to excel in that it can continually provide environmental indicators at both extremes of the design from whole building and life cycle views to individual components to compare the selected choices with other alternatives.

Typical output analysis charts are shown in is shown in Figure 3 and Figure 4. The first shows a radar chart for five measures: greenhouse gas emissions, carbon dioxide emissions, embodied energy, embodied water and cost for one alternative compared to another – the outer symmetrical pentagon is the original performance (at 100% of the benchmark) and the inner pentagon the improved measures resulting from an alternative. Similarly, in Figure 4, one alternative is compared with a benchmark building for four measures with the contributions from the major components of building being identified.

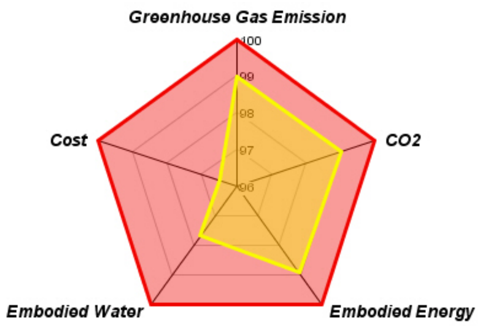

Figure 3 Chart of comparative environmental assessment of one design option against a base option

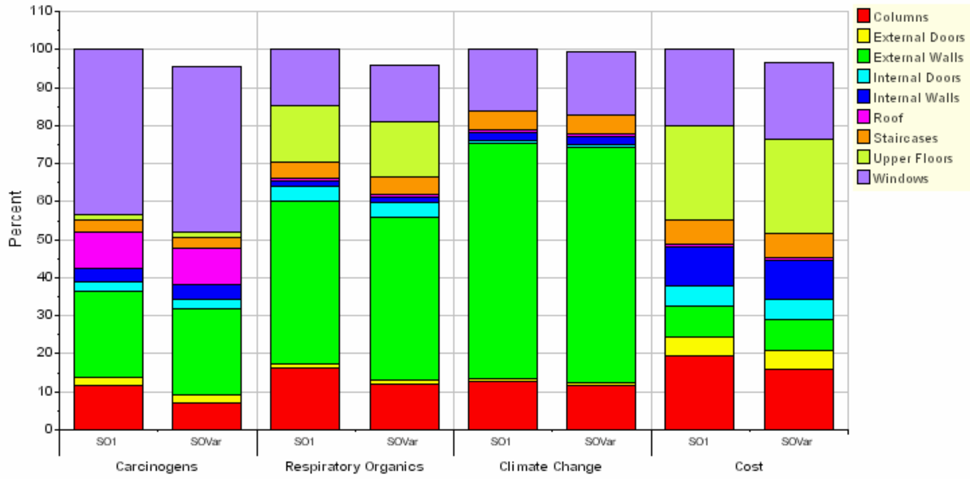

Figure 4 Chart of comparative environmental assessment of four design options measured in impacts per gross floor area showing breakdown by building element

From the perspective of the general user, *LCADesign* is the front end to the environmental analysis of commercial buildings. The "Analysis" is the basic "unit of work" of the system and provides the user interface into the results of the environmental analysis of one or more commercial building designs.

Benefits of an automated environmental assessment system Include:

- Environmental assessment direct from 3D CAD drawings,
- Choice of environmental impact and performance measures,
- Detailed design evaluation to assist in making choices, particularly on materials,
- Comparative ratings of environmental impacts of alternatives at all levels of design analysis, and
- Comprehensive graphical and tabular outputs specifically designed to convey to the user quantitative and comparative information on alternatives.

5. INDUSTRY NEEDS

A market survey in 2004 (CRC CI, 2004) indicated that the attitude to environmental assessment of buildings was changing in that most in the building design industry consider that recent years have seen a significant increase in amount of environmental issues in industry talk and exposure to the industry at large. This is also substantiated by regular comments on the expanding number of emerging rating schemes for buildings, the increasing number of seminars and conferences on environmental impacts of buildings and the beginnings of a formal group of rating specialists.

There is a lot of action with knowledge growing with positive attitudes to seeking improvements in the environmental impacts of buildings, but behaviour is slow to change. Implementation of environmental assessment appears to be very client-dependent and most building practices do not innovate until they are forced to (by clients and/or regulators) so even environmental tools such as *LCADesign* for decision making rather than ratings have only limited opportunities for application.

Comments on the integrated assessment approach were solicited from industry partners with the Cooperative Research Centre for Construction Innovation. While the number of industry partners are few, they are amongst the largest and most innovative of the players in the construction industry in Australia.

5.1 General

The lack of environmental tools and agreed procedures is often repeated with comments such as "Current analysis can be very crude but is the best available for reporting and often based on limited experience" indicating a demand exists but the tools to assist the required/ expected analysis are not available. Similarly, "A quantitative agreed procedure would provide more acceptable information for guidance on selection of materials quickly and in a standard form" implies speedy and credible information on which to make decisions relating to environmental impacts of selected building materials is in demand but not yet accessible. "LCADesign addresses the type of reporting which we are currently commonly asked to do" also suggests that the information being sought for reporting to those who make the final decisions can be provided by such a tool.

Questions about whether the constructed building is as intended raised the possibility of comparing "as built" with "as designed" with the former being a variation to audit post-construction. With comprehensive analysis being able to be done quickly, auditing procedures become feasible and are readily performed as long as the original computer files, materials database and rules are available at a later date.

As with the introduction of any new tool whose capabilities are substantial and a paradigm shift in relation to current practice, there is a strong need for education on the actual capabilities of a tool integrating 3D CAD models with a materials database so that users would know what to expect, e.g. which products or level of products can be analysed, the boundaries of application and outcomes, choice of generic building and construction products currently in the model, and any limitations.

5.2 Applications

The tasks and decision making to which Life Cycle Assessment of building materials can be applied in design stages of building and construction include the following:

- Identifying building materials which produce the minimum environmental impact,
- Comparisons of environmental impacts of products direct from the LCI database,
- Assessment of environmental impacts of building materials to make informed decisions on material selection as part of the design process,
- Very detailed analysis of materials used in standard designs (including a wide range of alternatives) which are constructed many times for institutional buildings e.g. schools,
- Suggesting which building materials might be improved from an environmental impact or specific emission point of view,
- Impact of materials (particularly finishes) on Indoor Air Quality which has become an important consideration in sustainability assessment,
- Cost effectiveness (indicative costs) to estimate payback times and judge which alternatives produce the best improvements per dollar spent, and
- Comparisons of alternative designs of components and/or sub-systems.

5.3 Useful features of LCADesign

LCADesign is intended to assess various environmental impacts from micro to macro level of building (e.g. building product comparison to whole building assessment). Some useful features of *LCADesign* include:

- Environmental assessment direct from 3D CAD,
- Assessing the environmental impacts of a whole building design in one step,
- Assessing the impact of different materials used in buildings,

- Assessing the impact of alternative designs and being able to compare the impacts using selected indicators from a comprehensive range,
- Drilling down on building components to identify source of differences between alternative designs, and
- Providing a unit rate of the indicator, e.g. per unit Gross Floor Area, because eco-indicator values do not mean anything by themselves and should be extended to other areas (e.g. net floor area) but must differentiate between office and car parking.

5.4 Stakeholder needs

Stakeholder needs for built environment analysis extend beyond the capabilities of *LCADesign*. Built environment analysis tool applications, attributes, features and functionality cover assessment and reporting over the building life cycle to support asset, project, design, product, construction and building processes. Gap analysis of previous/new reviews showed the extent that needs were being met over the building life cycle and found deficiencies in current tools and applications and found many lacked:

- Support for stakeholder decision making,
- Whole of life considerations integrated from investment /planning,
- Consideration of policy development and pre/post-occupancy assessment, and
- Functionality focussing on service delivery measures rather than physical dimensions.

Design performance appraisal requires consideration of environmental performance criteria and best practice performance benchmarks/end points, communication of environmental principals/policy for strategic decision-making as well as interactivity with supporting frameworks, guidelines and checklists. *LCADesign* has been depicted as a forerunner and significant contributor to stakeholder needs in that it provides:

- Objective detailed and comparative assessment rather than subjective assessments,
- Real time detailed design appraisals and evaluations with tool automatic take-off CAD,
- Generation of meaningful comprehensive graphics, tables and reports,
- Comparing alternatives at all level of design analysis, and
- Environmental assessment of building's development from cradle to construction.

5.5 Future developments

Future developments suggested by the first users, and based on demand from clients, included:

- An indoor air quality model to address an urgent common problem as much of the emissions occur from the materials chosen for the construction and fittings of the building but there is currently no usable prediction model,
- A whole life cycle assessment, not only for materials repair and replacement but also for estimating operating consumptions such as energy and water using detailed models,
- Estimation of recycled content as some rating schemes include recycled content of materials and identification reused proportion of renovation (if applicable),
- There is a development opportunity to enhance integrated packaging of *LCADesign* to provide user-friendly comprehensive flexible tools and appropriate features for:

- Communication in planning and strategic decision-making towards better environmental outcomes of buildings,
- Documentation and interactivity with frameworks, guidelines and checklists, and
- Plug ins to facilitate future deliverables/attributes in a development timeline.

6. SUMMARY

It is recognized that *LCADesign* is a huge step forward in environmental assessment of buildings and its real potential is yet to be ascertained. As a quantitative agreed procedure it provides more acceptable information for guidance on selection of materials quickly and in a standard form than has previously been available. *LCADesign* does give an ability to provide quantitative results using agreed indicators (e.g. Eco-indicator 99, greenhouse gas emissions) to substantiate decisions which are currently either tediously done poorly or based on experience.

Almost all of the comments were of a constructive nature to provide feedback on what should be done or expected of an environmental assessment tool with the suggestions on future developments implying that *LCADesign* has a future with other capabilities added as and when they can be implemented.

7. ACKNOWLEDGEMENT

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