Selection of Sustainable Building Material using LCADesign Tool

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ABSTRACT
Manufacture, construction and use of buildings and building materials make a significant environmental impact internally, locally and globally. But it is not easy to deliver information to make adequate holistic decisions considering the whole life cycle of building. Decisions in sustainable building integrate a number of strategies during the design, construction and operation of building projects. Selection of sustainable building materials represents an important strategy in the design of a building.

The Australian Cooperative Research Centre for Construction Innovation (CRC CI) funded development of an evaluation tool, LCADesign, for automated building environmental life cycle assessment (LCA). LCADesign is built on an ICT software platform, acting as a hub, to integrate outputs of 3D object oriented CAD models, a national Life Cycle Inventory (LCI) environmental database and recognised Life Cycle Impact Assessment (LCIA) indicators to report comparative performance across building planning, design, quantity survey and checking applications.

This paper describes methodological approach for LCADesign and illustrates with an example for environmental life cycle assessment (LCA) for building materials.

KEYWORDS: Life cycle assessment, Building evaluation tool, Decision making

1. INTRODUCTION

Design decisions regarding the selection of less environmental impact building components need careful consideration during the building design process. Careful building design and materials selection can substantially reduce environmental impacts (Kim and Rigdon,1998; DEH, 2006). In order to assist building designers or developers in choosing more sustainable options, a number of tools have been developed in the past decade to assess the impact of choice of materials on energy consumption or other specific environmental impact of buildings. Most of the tools have limitations and weaknesses and in a review of such tools, many common problem areas have been identified (Seo, 2002). The weaknesses include 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).

Successful implementation of a tool capable of performing the required 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 (Watson and Jones, 2004). A useful approach to achieve high performance design is to assess materials and design features simultaneously to obtain a full picture of impacts of a building on environment at the design stage.

A new integrated eco-assessment tool, LCADesign, was developed to fulfil the above requirement by addressing the needs identified by the stakeholder requirements for building evaluations. This paper gives a brief overview of the tool, which enables building design professionals to make informed and fast decisions about a building or its products, as well as its application to a case study building to demonstrate how a tool such as LCADesign can be used in sustainable building design processes and material selection, to satisfy the requirements of building design professionals and commercial industry.

2. FRAMEWORK FOR LCADESIGN

2.1 Integrated approach

An integrated environmental evaluation tool, called LCADesign was developed funded by Cooperative Research Centre for Construction Innovation (CRC CI), Australia for automated building environmental life cycle assessment (LCA). LCADesign is an acronym for Life Cycle Assessment (LCA) with Computer Aided Design (CAD). It is built on an ICT software platform, to integrate outputs of 3D object oriented CAD models, a national Life Cycle Inventory (LCI) environmental database and recognised Life Cycle Impact Assessment (LCIA) indicators to report comparative performance across building planning, design, quantity survey and checking applications.

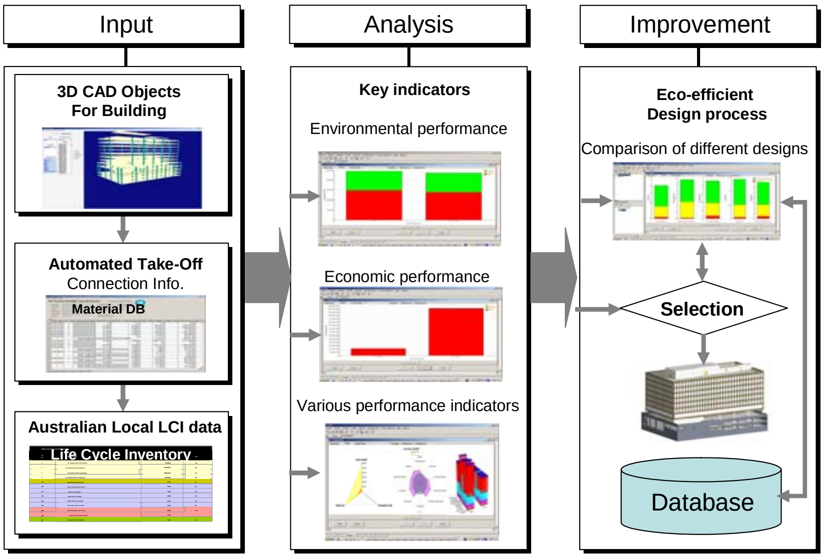

Figure 1 Essential steps for LCADesign tool

The principal aim of LCADesign is to integrate building environmental assessment in a 3D CAD model to avoid any manual transcription of data from one step to another in evaluation processes. A schematic diagram of LCADesign is shown in Figure 1. LCADesign is divided into three main parts which comprise the followings key steps:

- Input
    - Creating a 3D CAD model of a building,
    - Using the dimensional information in the 3D CAD model to automatically estimate quantities of all materials in the building,
- Analysis
    - Estimating all material and gross building environmental burdens by factoring each material quantity with results of their emissions generation and resource depletion from a comprehensive database of a wide range of building materials,

    - Calculating a series of environmental indicators based on Life Cycle Analysis, and
- Improvement
    - Providing facilities to undertake detailed analysis of alternative designs and benchmarking over time to facilitate designers' creation of buildings with least environmental impact considering their service delivery requirements.

Information for LCADesign flow seamlessly from the 3D CAD model to the evaluation stage without interruption or intervention from the designer or environmental assessor. Thus the designer can obtain almost instant feedback on whether the current building design under development is likely to produce a better environmental outcome.

LCADesign uses Life cycle assessment (LCA) methodology to assess the environmental impact of a product (including buildings) from raw material acquisition to product manufacture and replacement. 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.

Quantification of the environmental impacts of a product and the derivation of clear measures involves many complex tasks requiring applied physical chemistry and process engineering knowledge, numerous detailed observations and extensive data collection that must be transposed into simple measured units to compile model datasets. It involves the systematic ordering of many considerations in extensive detail for subsequent condensation into numerous types of calculations resulting in environmental indicators based on causal relationships contributing to key impacts.

The environmental indicators available in LCADesign comprise:

- Life cycle impact assessment (LCIA with Eco-indicator 99);
- Embodied energy (EE);
- Embodied water (EW);
- Carbon emissions (CE);
- Total greenhouse gas emissions (GHGs); and
- Recycled mass (RM).

With such indicators, builders, designers and building owners can view their building's environmental performance and make efforts to reduce its impact.

2.2 Benefits

From the perspective of the general user, a software tool is the front end to the environmental analysis of 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 LCADesign include:

- Automated environmental assessment direct from 3D CAD drawings;
- Choice of environmental impact and performance measures;
- Detailed design evaluation;
- Assessment of buildings at all levels of design analysis; and
- Comprehensive graphical and tabular outputs.

LCADesign provides environmental assessors with the capability to test alternative scenarios. This means that all the attributes of all the objects drawn in the 3D CAD model can be substituted and investigated, drilling down to identify the specific impacts or indicators of these variations. This is a role for an environmental expert who does not need any 3D CAD experience.

3. APPLICATION EXAMPLE

Melbourne City Council Building (CH1) was selected to show how LCADesign can be used. The building is about 35 years old and is being considered for refurbishment. This building has four floors of car park for 230 cars, a retail area of 400m^2, offices on seven floors each of

1070 m^2 per floor totalling 7490 m^2 and roof level plant room; in all 7668 m^2. The structure of this building comprises reinforced concrete slabs supported by primary and secondary beams and concrete encased steel columns for the car-parks and concrete encased steel columns and steel edge beams on the perimeter for the office floors.

The environmental impact of the materials used in the building was analysed for the example building using LCADesign. Eco-indicator-99 was chosen as the main environmental indicator. For the example building, the resulting impacts for the whole building using LCADesign are shown in Figure 2. .

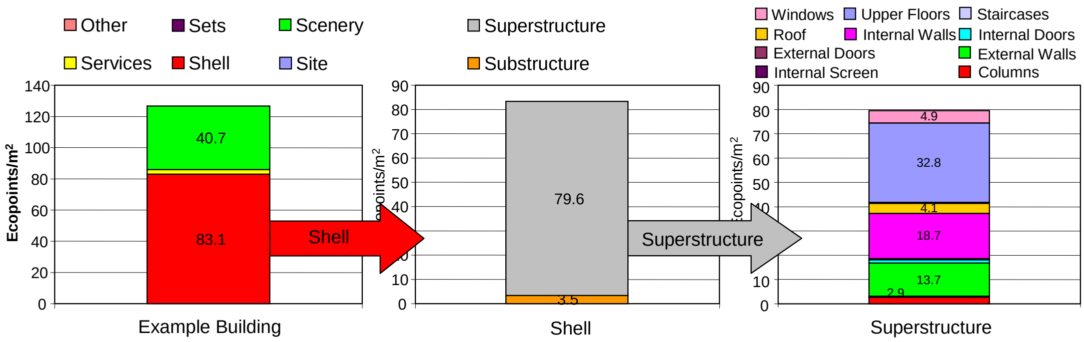

Figure 2. Environmental impact by layers and further breakdown for example building

As seen in the left hand side of Figure 2, the example building is classified into several layers of longevity of built components, which distinguishes several layers as shell, services, scenery, set, and site. Total environmental impact of the building was 127 ecopoints/m^2 for the Eco-indicator-99 indicator. Of the building layers, more than half the environmental impact was contributed by the shell part which was further divided into two parts as super-structure and sub-structure, with by far the largest contribution to the Eco-indicator value for the shell being the superstructure as might be expected. The superstructure component can be further broken down into elemental groups, consisting of several elements (columns, internal and external walls, internal and external doors, windows, staircases, roof etc), with the largest contributions being from upper floors (structure), followed by the internal walls and the external walls.

By becoming aware of which building materials and elements of a building have the lowest environmental impact, architects or building designers can encourage the marketing of sustainable buildings by specifying the more environmentally friendly products and redesigning buildings to reduce the largest element contributors. For example, in the example building, a small reduction in use of materials in the upper floor structure could reduce the overall impact by more than the whole contribution by the roof.

One of the possible options to reduce environmental impact can be considered as using recycled materials. However, recycling may not always be the most environmentally friendly option. Thus, building materials containing recycled contents should be evaluated in a manner consistent with a quantitative assessment of the overall environmental impacts.
Steel is the most commonly recycled building material, in large part because it can be easily separated from construction debris. In this example building, the potential for using recycled content was restricted mainly to reinforcement bars (up to 99% recycled) and 7% fly ash concrete which is popularly used in Australia.

Figure 3 shows the environmental impact comparison for the same building with alternative building materials which have recycled content in the superstructure part of the building. By replacing the non-recycled material components with those materials with recycled contents

(99% recycled reinforcement bars and 7% fly ash concrete) in the superstructure part, the total environmental impact was reduced by 19% to 103.1 ecopoints/m^2.

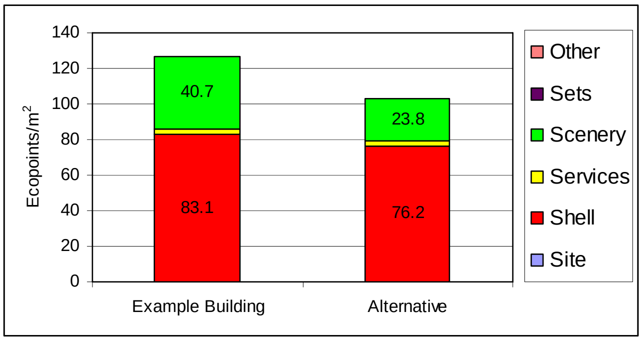

Figure 3. Comparison of Eco- indicator 99 for the example building and alternative

There are also different indicators which might be concerned by different purposes. These indicators comprise embodied energy, embodied water, and greenhouse gas emissions etc. The potential to calculate and use these indicators are a result of the detailed underlying life cycle inventory of building materials and can be selected according to the user's needs. Some of these indicators are shown in Figure 4 for the example building.

Five different indicators for both the example building and the same building constructed completely of lower environmental impact (alternative) materials (including recycled content) are shown in Figure 4 for the same superstructure part assessed in the earlier figures. The lower environmental impact materials were chosen as representative of what is now available a rather than those materials with the lowest environmental impact.

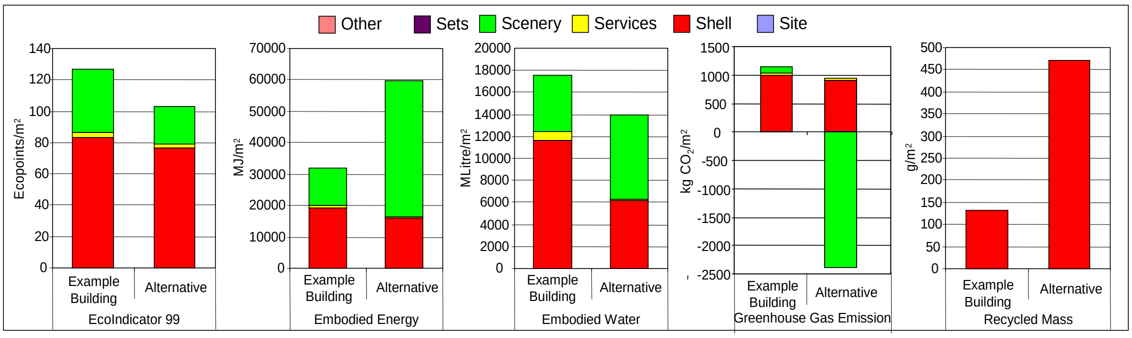

Figure 4. Comparison of the example building and the same constructed of lower environmental impact products for different indicators

The analysis of this example building suggests that a wide range of possible outputs illustrates how useful the breakdowns are in determining which components have benefited most from choosing less environmental impact materials and which have not.

Selection of sustainable building materials frequently requires difficult decisions since it is carried out considering a range of different environmental indicators. To deal with this difficulty effectively, an integrated evaluation tool, LCADesign that supports decision makers for building environmental performance has been developed and is a 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.

However, environmental considerations need not be the only factor when selecting building materials. The key consideration is the material's appropriateness for the intended function as well as the cost of their manufacture. As seen in Figure 4, embodied energy for alternative building was much higher than for the initial example building. This is because the wool carpet was used as finished flooring to reduce the environmental impact of the scenery part in the alternative building. Even though traditional wool carpeting is non-toxic and less hazardous for building occupants, the embodied energy is higher than existing one made from petroleum products (It is also a lower cost product).

While most of the environmental performance indicators do trend in the same direction for alternative products, care must betaken to ensure that the decisions are not made from a single viewpoint identified by using only one performance indicator. Thus, there will be other indicators such as costs and/or social aspects which might exist in conflict relationships when attempting to deliver the best decisions for sustainable buildings and/or building materials.

4. CONCLUSION

While considering various criteria that influence environmental sustainablility of building, Building material selection is more difficult. To deal with this difficulty effectively, LCADesign has been developed as an integrated eco-assessment tool to analyse, value and compare environmental impacts of design alternatives of the building and building material. The example building demonstrated that an integrated tool which utilises a Life Cycle Inventory of building materials enables design practitioners to make timely informed decisions on reducing environmental burdens of building materials as well as facilitating self-assessment from an environmental point of view at the design stage rather than at the post-construction stage. While a range of performance indicators are readily available in such a tool, use of a single focus performance indicator may mislead the designer in choosing the materials which produce the lowest environmental impact of the building as a whole.

5. ACKNOWLEDGEMENT

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