A review of LCADesign

Report 2001-006-B-22

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Research Program B
Sustainable Built Assets

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Environmental Assessment Systems for Commercial Buildings

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PREFACE

The Cooperative Research Centre for Construction Innovation (CRC CI) is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, the CRC CI is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. The CRC CI is a seven year project funded by a Commonwealth grant and industry, research and other government support. More than 150 researchers and an alliance of 19 leading partner organisations are involved in and support the activities of the CRC CI.

There are three research areas:

- Program A - *Business and Industry Development*
- Program B - *Sustainable Built Assets*
- Program C - *Delivery and Management of Built Assets*

Underpinning these research programs is an *Information Communication Technology* (ICT) Platform.

Each project involves at least two industry partners and two research partners to ensure collaboration and industry focus is optimised throughout the research and implementation phases. The complementary blend of industry partners ensures a real-life environment whereby research can be easily tested and results quickly disseminated.

The major project in the **Sustainable Built Assets** core area is an Automated Environmental Assessment System for Commercial Buildings incorporating a CAD-based tool and associated material-performance databases. These are being combined to facilitate real-time environmental appraisal of commercial building design from concept stage to detailed specification to meet a growing need from designers and regulators for real-time appraisal of design performance of constructed assets.

In the current marketplace for the design and construction industry it is impossible for organisations to spend significant resources examining the environmental impacts of different products and evaluating the performance of different components and systems. This project will enable industry to make these types of assessments by providing a uniform level of information, and tools to access the information on environmental measures for different products and designs in real time.

The research described in this report was carried out by the following research team:

Program Leader	Peter Newton
Project Leader	Selwyn Tucker
Industry Team Member	Delwyn Jones
CSIRO Team Members	Seongwon Seo, Michael Ambrose, David Johnston
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EXECUTIVE SUMMARY

Objective

The review addresses two distinct sets of issues:

1. specific functionality, interface, and calculation problems that presumably can be fixed or improved; and
2. the more fundamental question of whether the system is close to being ready for 'commercial prime time' in the North American market.

Findings

Many of our comments relate to the first set of issues, especially sections B and C. Sections D and E deal with the second set. Overall, we feel that LCADesign represents a very impressive step forward in the ongoing quest to link CAD with LCA tools and, more importantly, to link the world of architectural practice and that of environmental research. From that perspective, it deserves continued financial support as a research project.

However, if the decision is whether or not to continue the development program from a purely commercial perspective, we are less bullish. In terms of the North American market, there are no regulatory or other drivers to press design teams to use a tool of this nature. There is certainly interest in this area, but the tools must be very easy to use with little or no training. Understanding the results is as important in this regard as knowing how to apply the tool. Our comments are fairly negative when it comes to that aspect. Our opinion might change to some degree when the 'fixes' are made and the functionality improved. However, as discussed in more detail in the following sections, we feel that the multi-step process — CAD to IFC to LCADesign — could pose a serious problem in terms of market acceptance. The CAD to IFC part is impossible for us to judge with the information provided, and we can't even begin to answer the question about the ease of using the software to import designs, but it appears cumbersome from what we do know.

There does appear to be a developing North American market for 3D CAD, with a recent survey indicating that about 50% of the firms use some form of 3D modeling for about 75% of their projects. However, this does not mean that full 3D CAD is always being used. Our information suggests that AutoDesk accounts for about 75 to 80% of the 3D CAD market, and they are very cautious about any links that do not serve a latent demand. Finally, other system that link CAD to energy simulation are using XML data transfer protocols rather than IFC files, and it is our understanding that the market served by AutoDesk tends in that direction right now. This is a subject that is outside our area of expertise, so please take these comments as suggestions for more intensive market research rather than as definitive findings.

Note: This report presents an amalgam of findings of Wayne Trusty and Nils Larsson. The following observations are based on work carried out on 3 different systems: a Mac G4 Virtual PC running XP Pro; an 800 MHz Sony Vaio with 512 RAM running XP Pro; and a Toshiba Pentium 4 with 512 RAM running XP Home. We did not have access to IFC files other than the two files provided by CSIRO.

Nils Larsson, iiSBE

Wayne Trusty, Athena

September 15, 2004.

Appendix A contains the specifications for the review and Appendix B contains comments on the review by the LCADesign development team.

A. OVERVIEW OBSERVATIONS AND CONCLUSIONS

Our review addresses two distinct sets of issues:

3. specific functionality, interface, and calculation problems that presumably can be fixed or improved; and
4. the more fundamental question of whether the system is close to being ready for 'commercial prime time' in the North American market (it is difficult for us to address market acceptance issues outside of NA).

Many of our comments relate to the first set of issues, especially sections B and C. Sections D and E deal with the second set. Overall, we feel that LCADesign represents a very impressive step forward in the ongoing quest to link CAD with LCA tools and, more importantly, to link the world of architectural practice and that of environmental research. From that perspective, it deserves continued financial support as a research project.

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B. SPECIFIC USER NOTES

1. In a test on the Mac Virtual PC running XP Pro, it took one hour to calculate from the small office building IFC with the area set at 10000m2; 12 minutes on a Sony Vaio with 512 RAM running XP Pro; 6 minutes on a Toshiba Pentium 4 with 512 RAM running XP Home. A couple of people suggest that even 6 minutes is still far too long, especially as a first step. Other calculations, after no more than 6 reasoning rule changes, take about 3 minutes. With about 9 additional RR changes, calculation time is 3.5 to 4 minutes. In comparison, a consulting engineer tells us that it would be unusual to wait more than 30 seconds for an energy simulation calculation.
2. When we increased the area of the Small Office IFC file to 10,000 m2 in a new design to see what would happen, the changes were not obvious. The new design calculation time was 12 minutes as noted above, but the building remained a two-storey structure, the View still showed a small building, and the quantities implied by the reasoning rules did not seem to reflect the vastly larger size. It appears that you should either disable the ability to change the area from that of an original IFC file, or you should make it more meaningful.
3. We are not familiar with IFC categories, but assume that the Category structure itself is an independent overlay in the creation of an IFC file. In other words, we assume it is not universal but may reflect a standard (Australian) category structure for quantity surveying. The question is whether all users, even within one country, will have the same nomenclature and therefore be able to consistently interpret a set of reasoning rules. We find some strange elements included, such as Swimming Pools in Substructure, and items such as Chapels and Libraries under Outbuildings (Site Works). Especially for the latter examples, which are buildings in their own right, we don't really see any logic in including them as part of Site Works.
4. The Details screen shows product information, but the title "Type" is unexplained, and there is no indication of quantities or a bill of materials. We assume the quantities must be available somewhere in the system so that embodied energy and emissions can be calculated, but they are not shown to the user. Does the system assume that the user has a separate quantities list as a take off from the original CAD? If so, would it not be better to reduce redundancy by having this information in a single source. Also, a bill of materials can be an important check for the user that the design is being read properly and that all materials are taken into account.
5. Because the software is generally slow in responding to commands, it is important that it show an hour glass, or other indicator that a command is being processed. The fact that processing is underway is clear in the case of calculation routines, but not for other simple commands like opening a different window. On more than one occasion it slapped our wrist for not being patient when we assumed that the command had not registered.
6. When you name a new variation, it goes into a calculation routine before you change any of the reasoning rules (RR). Why? You would expect the process of generating a duplicate RR column in the design window to be very simple and quick.
7. In the design details screen, there is a 0 for the summary EI99 measure for all reasoning rules. This is a critical feature that signals whether a RR change is worth making, or at least what the relative effect will be. We assume the feature is simply not operable yet, but that it will be fully functional.
8. On a 15" screen, with the design window fully expanded, the drop-down-menu triangle symbol for most RRs is not showing. Double clicking an RR brings up the list and the symbol (discovered by accident), at which point the symbol is of no value.

Similarly, you can't see the whole title on a column in chart data view, even with the window expanded. 3

9. There is something awkward happening when the user wants to go back to see RR change details for a variation. With the base project, you can open details in the menu at the top. But trying to do that for the variation brings up a dialogue asking the user to pick a design, even with the variation name highlighted. This seems odd given that the variation is itself a design. Double clicking the variation name does the job, but shouldn't the same menu work?

C. ANALYSIS AND RESULTS ISSUES

1. When picking measures for a design analysis, the tree cascade has to be opened through 3 identical levels before the user sees any details (e.g., global warming gases). Why?
2. When 6 RR changes were made, more or less randomly, there appeared to be no difference in the total EI results, although there were very slight differences in some components.
3. With another 9 RR changes, there was a much larger difference in the EI99 scores, but there is no unit shown on the scale, so how significant is the difference? External walls was one of the RR changes and it doesn't show up at all on the stacked bar. Any very narrow component of the stacked bar is difficult to get at through drill down because it is hard to click on very narrow bands. For example, the roof does not show in the stack bars at all for the base case.
4. A shift back to the design details showed that the external wall change was from a concrete block wall to some sort of sandwich panel. Is the user supposed to assume or know that the items in the pick list are structurally equivalent (as opposed, for example, to a wall element that is for infill not structural use)?
5. An examination of chart data reveals that the sandwich panel is showing as 0.00, a result that continues no matter what measure is chosen.
6. In the case of the upper flows element, the variation has a much higher impact than the base, and it was therefore selected for drill down. To understand what change resulted in such a large difference, the user has to again switch to design details because the labels don't show enough information about the RR options. It turns out that the shift was from concrete to steel beams — a change that we would expect to be very evident from the labels alone.
7. When the measure was changed to show just greenhouse gas, the base case result for concrete upper floors totally disappears. A look at the chart data shows a negative number? Drilling down to CO2 process emissions only, shows the concrete is much better than the steel, which is exactly contrary to other comparative studies. One expects the concrete to shower higher process CO2 emissions and, indeed, that is the result one gets if the external concrete block walls are switched to the steel sandwich option. In short, there appear to be some fundamental calculation problems or problems in the base LCI data itself.
8. Chart data does not show totals for cost, embodied energy or other measures.
9. With cost, embodied energy and carbon selected as measures, the radar chart scale seems to show only MJ of embodied energy as a scale, something that actually has to be figured out by going to the 2D split chart because the radar chart does not indicate the units. The regular 2D chart uses the same measure (MJ of embodied energy) as the scale for the whole chart including cost. If the use of just one set of units reflects some sort of normalization, it is not clear.
10. In the chart data table, why does the internal wall in the variation have 0 cost? The same appears to be true for external walls.
11. If the user wants to see the full data set for any product or sub-assembly (i.e., all air and water emissions, etc.) it appears necessary to individually select all of the measures (which could result in duplication because some emissions appear in more than one EI category). This is very cumbersome and well beyond what most architects would be willing to do, let alone researchers.
12. What does 'IAQ unit operation' mean for indoor air quality?

D. THE ROLE OF ECO-INDICATOR99

One of our main reservations about the system relates to the interpretation of results. Data outputs are self-evidently clear, but the scalar values provided are not. For example, in Analysis Results, values on the X-axis are either percent (presumably of the base building, although this is not explained) or numeric values without units (presumably, but not definitely, Eco-Indicator points).

Much of this issue relates to the role of EcoIndicator99 (EI99). The User Guide explains that CDM (mid-point) or EI99 (end-point) values are options, but it does not go on to explain the meaning of the EI99 results, either in terms of things like DALY units or with regard to the meaning of the aggregate scale. Thus, a user who may have only a partial understanding of environmental issues, comes to the end of an impressive process only to wonder what the results mean. We therefore suggest that the User Guide should be beefed up in this regard, and that more supporting information be provided in the system itself when results are displayed.

There are also some somewhat more fundamental problems with respect to the use of the Eco- Indicator99 approach.

1. EI99 is explicitly developed for European applications, and the amount of modification required to validly apply it to other regions (material data, ecological damage etc.) is unclear. For example, would it be possible to easily shift to the TRACI system developed by the U.S. EPA and now being widely adopted in North America?
2. The EI99 system relies on the weighting of three “damage categories” to produce EI99 point scores: Human Health, Ecosystem Quality and Resources. In the LCADesign system, the unit of measure for Resources is MJ, which we found puzzling until we looked at the EI99 web site definition of Resources: *Under this category we include the surplus energy needed in the future to extract lower quality mineral and fossil resources. The depletion of agricultural and bulk resources as sand and gravel is considered under land use.* It appears that only the first part of this scope is included in LCADesign. Moreover, the measure is a proxy for resource depletion, which is not an easily understood concept for those outside the field, and is certainly not obvious from the use of the MJ unit without explanation.
3. In the human health category, the DALY system is used as a measure. This approach is undoubtedly useful in identifying building inputs or outputs that might affect people’s life spans, and within a purely LCA perspective, is a legitimate approach. However, in the broader arena of design support tools more subtle factors such as noise or illumination are also critical. We recognize that such factors are outside the purview of LCA, nevertheless caution that designers who might be interested in LCADesign as a support tool could be turned off the system because it does not reflect any of the positive attributes of their design. The essentially negative (disability and death) nature of the DALY approach compounds that problem. These comments are not meant to imply that the DALY approach is useless; only that it is not sufficient to cover the concerns of designers. The problem could be solved by linking LCADesign to a broader assessment tool, such as BREEAM, LEED or GBTool.
4. The other concern we have with the DALY unit of measure is that it is really geared to toxicologists and LCA practitioners, and does not so readily speak to architects, engineers, or the building developers who ultimately pay the bills and therefore have to be sold on the merits of using specific tools or techniques. We are rapidly reaching a point where design teams and their clients can talk with

some sense of understanding about global warming potential, ozone depletion and primary embodied energy, but they may be a long way from a similar level of comfort with a measure such as the DALY.

E. DOING A BUILDING ASSESSMENT

1. North American architects and design teams generally are not willing to spend a lot of additional time and money doing analyses unless required for LEED or for other reasons (in contrast to energy simulation, for example). Ideally, a tool should be usable in real time in a design meeting, probably after a base case has been entered to set the stage for real time analysis. Calculation times and general functionality are therefore key factors in terms of market acceptance of a tool for building assessment. LCADesign seems slow and somewhat awkward in terms of a user's ability to easily navigate through an assessment. Added to this is the time required to create an IFC (unknown to us), especially since a new IFC is required for any changes other than picking options from the RR lists. Our experience indicates that changes to dimensions, live loads, stud spacing, the number of windows, etc., can be just as important in the design process and should somehow be accommodated at the LCADesign level rather than forcing the user back to the CAD and the generation of a new IFC.
2. When is the software to be used in the design process? If at the conceptual stage, then it may be too detailed in terms of the reasoning rules. At that stage, the user should not have to change every column to assess the effects of a general material change (say from steel to concrete). If it is to be used only at a more detailed stage of design, then it misses the opportunity to influence critical early design decisions.
3. Without a print capability, there is no easily accessible place to look at the RRs when working on an analysis. The only option is to go back and forth between the design details and analysis screens. The problem is compounded by the fact that terminology does not link elements at various levels. For example, at a high analysis level one sees results for 'upper floors', but the drill-down results heading is something like 'in situ slab and beam construction'. If the user is doing extensive analysis on a series of changes, it is hard to remember exactly which RR is being referenced. The drill down heading should at least tie to the element headings (e.g., upper floor in situ concrete column and beam).
4. As noted previously, material quantities are not given anywhere, which means that an important piece of information is missing, even though the data is presumably in the system so that impacts can be calculated. In the Athena software, we find that the bill of materials is a useful diagnostic tool. And the original PPT description of LCADesign indicated that quantities would be available. Has it just not yet been implemented?
5. The first analysis screen that comes up for a new design and/or variations has stacked bar charts that show the variation of the total design from 100% for the base case. But it is quite difficult to see which assemblies or elements have changed, and by how much, especially if you make many RR changes. To properly understand where changes are occurring, the user has to go to analysis and drill down, which requires a shift to the analysis mode. So why have that initial results screen at all? And if there is going to be an initial screen to give a quick look at results, why not have it be an entry into analysis with drill down capability? This kind of comment goes to the issue of being able to use the software in real time situations, during a design charrette for example.
6. The RRs are difficult to understand because they are at a very detailed specification level as noted earlier. It appears that every column, etc, is being treated as a separate line in the RRs and presumably relates back to an individual object in the CAD. These elements (e.g., columns) seem to show in the view

schematic, which is itself not very useful given its size. Will the user always have a key of some sort that relates the IFC file back to the CAD? It seems logical that a typical user would not make a change to just one column or beam, but to all comparable columns and beams, especially if it is a major material change from steel to concrete, for example. It is therefore cumbersome to require that the user go through the same pick list several times. The simple office has up to about 4 RR for certain elements, but what if it was a 30 storey office building with columns and beams on every floor

F. LCI DATA ISSUES

The terms of reference for this review posed a number of questions about the use of use of life cycle inventory (LCI) data in assessing the environmental impacts of buildings, including the procedures used to develop the data, the scope of the database, opportunities for spin-off applications of the database, etc. We are not in a position to respond to these questions because none of the database details are available. One only sees relatively raw data at the lowest drill down level for a building element. Nor have we been provided any separate information on how the data was developed or about the underlying LCI datasets.

In general, we believe the use of LCI data for environmental assessment of buildings is essential if we are to get beyond prescriptive measures (e.g. % of recycled content) of the kind found in most assessment systems. The LCADesign introductory material talks in terms of ”automated take-offs” providing complete quantity lists that can be combined with the LCI database, but none of this detail is available to us. This is the basic approach used in the Athena software and other similar systems, so we have no doubt about its validity. But we are not in a position to assess how this is done in LCADesign given the material provided.

One comment we can make relates to the nature of LCI data that is being used. As noted previously, the RRs seem to be very detailed — almost at the level of brand-specific products. This implies an enormous database that would require considerable manufacturer cooperation as well as substantial resources for continuous up-dating and expansion. The alternative is generic data, which in our view is more relevant in any event at the conceptual design stage (brandspecific data comes into play more at the specification and procurement stages). The question for LCADesign is at what stage is it intended to be used, with the answer dictating the approach to database development (see point E2, above).

With regard to database spin-offs, which we assume refers to sales, we believe the trend will be more and more toward basic national LCI databases that are provided either free or at nominal cost. The US LCI Database Project is an example (see www.nrel.gov/lci).

G. CLOSING COMMENTS

The ideal, from a customer perspective, would be to have a single system that accepts sketch and data inputs and produces outputs relating to a wide range of issues (energy, environmental impacts, indoor environmental performance, material quantities, cost, visual appearance etc.; all at increasing levels of detail as the design process unfolds. While LCADesign goes some distance towards the achievement of this goal, it appears to leave out critical elements even if the focus is strictly on LCA. For example, it would be very helpful to have a sketch input tool similar to the one provided in the LT4 energy simulation system (the sketch model currently in the LCADesign system serves little useful purpose that we can see). A full bill of materials as part of the Analysis outputs also seems essential, so that quantities can be plugged into a costing program.

We assume that you have thought of the issue of how to replace the material LCI data with data appropriate for other regions. This really relates to how much of an export market you are aiming for, and what data are available in other regions. This may not be a simple exercise of replacing one set of data with another. As an example of potential complexity, the Athena datasets are designed so that all energy combustion and pre-combustion flows are in separate files. The LCIs for products deal with process emissions, energy use by type, and transportation use by mode. The separate energy combustion and pre-combustion datasets are then addressed for the full calculation. In short, an Athena LCI will not necessarily simply replace another LCI if the placeholder for the data is designed for a full roll-up of all effects.

Finally, we have highlighted our concern that EI99 focuses on a limited range of negative issues. This may be useful and necessary to demonstrate conformance to government regulations, but does not address the desire of architects to show their clients that their designs make a positive contribution to clients' and occupants' happiness, comfort and productivity, especially in areas of lighting, acoustics, durability, adaptability and functionality. Again, the present approach is necessary but not sufficient for a design support tool. A link with another broader assessment tool might allow the user to have access to both the measurable LCADesign outputs, but also to other outputs that are considered important in the "business end" of design practices

Appendix A - LCADesign evaluation

LCADesign

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) - 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 and combines this information with the life cycle inventory database, to estimate internationally recognised environmental indicators, principally Eco-indicator 99.

The LCADesign software and Life Cycle Inventory database are both currently in prototype versions with updates and improvements continuing as capabilities are extended, suggestions are implemented and bugs are fixed.

Evaluation

Evaluation at this point in the development of LCADesign is thus aimed at the general principles from approach to the assessment and user understanding of what is being assessed to practical issues such as being able to compare alternatives: While identification of any problems with use of the software would be appreciated, the focus should be on the capability of a designer to use LCADesign to assist in design improvement in environmental impacts of materials.

Issues to be addressed cover:

- Overall concept of utilising 3D CAD models as the basis of automatic assessment.
- Approach used in the LCADesign software to analyse the environmental impact of material used in building.
- Ease of comprehension of what the LCADesign software does.
- Use of Life Cycle Inventory data in assessing the environmental impact of building materials.
- Usefulness of LCADesign for assessing the environmental impact of building materials.
- Process of obtaining useful comparative information on alternatives.
- Choice of environmental assessment indicators (measures).
- Use of Reasoning Rules to calculate detailed materials quantities.
- Use of substituting alternative Reasoning Rules as a method of creating variations to the original 3D CAD model.
- Appropriateness of charts (graphs).
- Ease of using the software to import designs, create variations and undertake analysis of alternatives.

- Additional features which would further assist in making better decisions on materials used in buildings.
- Procedures undertaken to develop the Life Cycle Inventory database.
- Scope of the Life Cycle Inventory database.
- Procedure for maintaining the Life Cycle Inventory database.
- Current state of the LCADesign software.
- Potential for use of the LCADesign approach at the sketch design stage.
- Opportunities for spin-off applications, particularly the Life Cycle Inventory database.
- Importance of having a cost (Dollar) attribute to the usefulness of LCADesign
- 3D CAD models as a barrier to implementation of environmental assessment tools in the North American market.
- Potential for LCADesign to be applied to Life Cycle Inventory databases from other regions or countries.
- Current or planned legislation which would make it attractive to use IFC files or whole building materials assessment
- Comments on the skill level requirements of the users of LCADesign and who in the cycle - architects or engineers etc - would be the users of LCADesign
- An indication of the level of importance of life-cycle assessment through the *operational* phase of a building(LCADesign currently assesses only *as built*)

Materials provided

The materials to be provided will include:

- LCADesign software on CD for installation on a Personal Computer
- Instructions for use and operation of LCADesign
- Papers on LCADesign
- Selected reports and Powerpoint presentations which will provide details of LCADesign

Report content

The written report should address the issues listed above and make suggestions and recommendations on improvements to LCADesign.

Appendix B - Comments

A. Overview observations and conclusions

The feedback received from Nils Larsson and Wayne Trusty which documents their review of LCADesign is extremely useful for the continued development of the LCADesign system.

The reviewers have assessed LCADesign in terms of its usefulness and relevance to building design professionals and have endeavoured to give constructive feedback on how LCADesign could fit into the building design process.

Nils Larsson and Wayne Trusty have reiterated the first impressions of most other reviewers in that they acknowledge that "…LCADesign represents a very impressive step forward in the ongoing quest to link CAD with LCA tools…". However, in terms of their overall comments it is clear that much more thought is required, specifically in establishing the target design process (or processes) where LCADesign will be of greatest benefit to the procurement of eco-efficient buildings. The reviewers state that currently there are few drivers for the use of such a tool and therefore LCADesign must be very easy to use with little or no training. To this end, once the target is clearly established future development would be focused on usability and performance enhancement.

B. Specific user notes

1. The performance of LCADesign reported on the PC platforms is as expected and the development team acknowledge that this would not be acceptable in a production environment. Work has been done to investigate how the performance may be improved and possible solutions involve redesign of the underlying database and calculation algorithms. It may be possible, for instance, to show preliminary results to the user prior to the full calculation being complete. The time taken for calculation of variations (changes to Reasoning Rules) can also be reduced in future versions. The performance of LCADesign on the Mac G4 should not be taken as any indication of how LCADesign would run on the Mac OS platform. The overhead of the Virtual PC emulator and then Windows XP Pro on top of that is large. The problem in supporting Mac OS is that EDM is not available for that platform yet. There is a version of EDM for UNIX which may run on Mac OS 10.3 but this has not been tested. Apart from the platform dependencies of EDM, LCADesign only requires the Java Virtual Machine (JVM 1.4 or later) and hence, in theory, runs on any platform that supports the JVM. An earlier version of LCADesign using SQL Server 2000 as the database management system ran very well on an iMac with Mac OS 10.2 (better, in fact, than any PC we had in the office at that time).

2. Changing the floor area value of a design would have negligible effect on the performance. The "Floor Area" field is merely a divisor (or normalizer?) for the results, so further clarification of this feature is required in LCADesign and does not change the area of the design in any way. The floor area of a design is not derived from the design itself (although it may be possible to do this by summing the areas of all slabs) but in the current version of the prototype it was decided to allow the user to enter the floor area manually. This has advantages in that the total floor area of the design is not usually the same as the "rentable" floor area or Gross Floor Area (GFA). By allowing the user to enter a value the results can then be shown relative to a meaningful functional unit. It is intended that this functionality be enhanced to allow the user to see the results by other functional units such as "per occupant" or "per cubicle???".

3. The Australian Cost Management Manual (ACMM) system of building element nomenclature was chosen for the building element hierarchy and could be customized for regional requirements. The choice of building element

nomenclature has knock-on effects through the Reasoning Rules and the 3D CAD object tagging system and while detailed links would have to be made, the structure is readily changed. However it is a necessity for a production version of LCADesign especially for interoperability with quantity surveying and specification systems. There are certainly some aspects of the ACMM nomenclature that leave a bit to be desired, but it is in use in the Australian building industry and is non-proprietary.

4. An explanation of “Type” is needed in the Guide or help system. Currently, only one all-in-one “Type” of Reasoning Rule (e.g. Structural or Fitout) has been implemented. A very good point is made about the quantities. The calculated quantities should be exposed for the user to check and use in other tools and is essentially a matter of providing more output options.
5. Earlier versions of the prototype made use of the hour-glass cursor. Some problems were encountered in the refreshing of the normal pointer when tasks were complete so it was removed for fixing at a later date. Some additional progress bars could be implemented where appropriate.
6. When the user starts a new variation there is a delay caused by the copying of the base design information in EDM. This is necessary so that quantities and impact assessment calculations do not have to be re-done. This turned out to be slower than expected and will be improved in future versions.
7. The unit scores of Reasoning Rules are not yet implemented. It is intended that the user will see the EcoIndicator99 score for the original and the variation rules and will have some idea of the relative impact. As will be described later it is also intended that the user will be able to select a preferred score or measure instead of EI99.
8. It is very unlikely that the screen size or resolution has anything to do with this issue. The method of making a variation to the Reasoning Rules does not appear to have been fully understood. This is a fault of the user guide and the LCADesign user interface could be more intuitive. A user can view details of a rule by clicking once on it. The user can make a variation to the rules by double-clicking on a rule and then the user will be presented with the drop-down list of alternatives. If the user does not make a selection from the drop-down, and clicks somewhere else, the drop-down box will close but the drop-down arrow will remain so that the list may be opened again. This arrow is always visible in this case no matter what screen size or resolution is being used. If the user opens the drop-down and makes a selection, the selection will be accepted and the drop-down arrow will disappear. If the user wishes to change the selection a double-click the rule will again be presented with the list of alternatives. The problem reported with column titles in “Chart Data” view could not be replicated as stated, but the user can change the column widths and amend the order of the columns. It may be useful add a function to be able to hide the columns with 0.0 entries.
9. Yes this would be a bug; the menu should work in the same way as double-clicking the variation in the “Designs Folder” tree. To open a Variation the user must use the “Variation” menu. To open a Design the user must use the “Design” menu. It sounds like the reviewers were trying to open a Variation with the “Design” menu, hence the software prompted with “Please select a Design.”.

C. Analysis and results issues

1. The “Measures” hierarchy follows the LCIA methodology of “Method”, “Damage”, “Impact”, and “Stressor”. For impacts that don’t fit into this hierarchy such as “Greenhouse Gas Emission” which only has “Impact” and “Stressor” amounts it was decided to add layers for “Method” and “Damage” with weighting factors of 1.0 so as to fit in with the LCIA hierarchy. This does lead to confusion and extra work to find a measure. Something needs to be done with this situation to clarify the user interface.
2. The EI99 score is rounded to an integer and the changes were probably of significance smaller than the fractional amount of the score.
3. The unit of the chart shown in a Variation is percent – that is, percent difference to the original design. If a category is very small and cannot be easily seen on the chart the user can click on its legend item to drill-down on it.
4. LCADesign is NOT a structural design package and it cannot account for variations that result in structurally inept designs. The user (or design team) must have enough knowledge to know when changes are required to the dimensions and configuration of building elements. A Variation works from the same IFC (i.e.3D CAD model) as the original Design and therefore all dimensions are the same. If a steel column is varied to be a concrete column the dimensions of the building element will not change. Therefore it would be likely that the concrete column will be undersized because it will still have the dimensions of the steel column. All users of LCADesign MUST be made aware of this fact. However, it may be reasonable to make a change of this type to get an indication of the differences in impacts between alternative products. More work should be done on this issue, in close contact with our industry partners.
5. It is likely that there are some problems with the Reasoning Rules for “Sandwich Panel…” which are resulting in 0.00 impacts. It is likely that a dimension required by the rules is not available from the IFC model. This shortcoming with use of IFC files has been identified and later versions overcome the problem.
6. It is intended to provide more depth to the drill-down facility. Currently it only goes to the bottom of the ACMM building element hierarchy, which is very limited for the type of analysis suggested. If this is done then the user could drill-down through “Upper Floors” to materials (e.g. “Concrete” and “Steel”) or to trades (e.g. “Structural Concrete” and “Structural Steel”).
7. Yes, a negative measure value is usually a problem (except maybe for Biomass energy in timber). This is likely to be a problem with lack of a dimension (mentioned above) for a component of a Reasoning Rule or even the underlying LCI data.
8. The problem could not be replicated. When “Cost” is selected as a measure it appeared on the chart and in the data table as expected.
9. A Radar chart is always comparative. The user should make one of the designs a “Benchmark Design” (on the Designs “tab”) so that the units are always in percent relative to the benchmark design. If a benchmark design is not specified then the Radar just shows the actual values. The only problem with showing actual values is that if one is very large (as would be the case for “Embodied Energy”) the other measures would be hard to see on the chart. Perhaps a radar chart should always select the first design to be the benchmark if the user has not specified one. Normalization is done as per the EI99 method but there is no normalization for any other methods.
10. It is likely that there has been a problem with getting the building element dimensions for the Reasoning Rules. There needs to be some way to flag this to the user, but also this should not happen and work needs to be done with IFC 2x2 and ArchiCAD to cover more dimensional information in the IFC model.

11. Some of our research and industry partners do indeed investigate specific emissions so flexibility was permitted at the expense of simplicity. It is intended that a user will be able to specify their own "Measure" made up of any of the available stressors. It is also intended to allow the user to save an analysis as a template so that they do not have to specify all the measures every time.
12. The "IAQ unit operation" is just a placeholder for real stressors that will contribute to the Indoor Air Quality measures. This has not been done yet, similarly for "Ecological Footprint", and "Biodiversity Loss"; each of which is a pointer to additional indicators being developed and should be removed in distributed versions.

D. The role of EcoIndicator99

LCADesign is initial version. The output units of indicators in LCADesign can be quite different (Table 1). For example, the final output for EI 99 is shown as a weighted single impact value (as points; Pts). But when users click the sub-impact category (damage) such as human health, ecosystem quality and resources then these three damage impacts are currently shown as characterized impact. Thus, to harmonize the units, the three damage impacts (human health, ecosystem quality, resources) should be shown as weighted indicators (means the same unit as "Pts" - Table 1) to deliver similar information to users.

Table 1 Output units for each indicator

Indicator	**Unit**
EcoIndicator 99	Pts (Points)
Human Health	Pts (Points)
Ecosystem Quality	Pts (Points)
Resources	Pts (Points)
Carcinogens	DALY
Respiratory Organics	DALY
Respiratory Inorganics	DALY
Climate change	DALY
Ozone layer depletion	DALY
Ecotoxicity	PDF m^2yr
Acidification/eutrophication	PDF m^2yr
Minerals	MJ surplus
Fossil fuels	MJ surplus
Each of substances (or emissions for each of the impact categories)	Mg (or ug)
Embodied energy	MJ
Embodied water	Litre (or Mega Litre)
CO2	Kg-C (or Kg-CO2)
Carbon	Kg-C
Cost	A$
Greenhouse gas emission	Kg CO2 eq.
Indoor Air Quality	-
Ecological Footprint	gha (global hectare)
Biodiversity	-

Environmental performance of building can be measured by aggregated characteristics from multiple environmental issues. One of the indicators for LCADesign is Life Cycle Impact Assessment (LCIA) results which quantify the importance of environmental stressors tabulated in a life cycle inventory (LCI) and to aggregate the stressors to a small number of category indicators and/or a final figure of merit. The LCIA method is divided into two types (midpoint and endpoint approaches) depending on the point in the environmental mechanism at which the category indicators are defined. The Midpoint approach (environmental theme oriented) converts the LCI results into a number of themes, which was developed in previous SETAC work. The endpoint approach focuses on the damages caused by the inventory results and organises impacts according to protection areas (human health, ecosystem etc.).

There are a number of methods for LCIA used in the world; CML, Eco-Indicator 95/99, EPS, EDIP, etc. Of these methods, CML and Eco-Indicator 99 (EI99) methods are selected for midpoint and endpoint approaches as one of the environmental indicators in LCADesign. Of both approaches, indicator units for the EI99 method might be difficult to understand for users who are not familiar with LCIA methodology.

It is difficult to find the right balance between simplified measures and detailed impacts to allow flexibility to suit all users' requirements and specific interests. One of the biggest problems is the lack of established standards in impact assessment and regional differences. For example, Australian industry and government is more sensitive to sustainable water use than in other parts of the world.

1. There are a number of methods available for LCIA and used in the world, including CML, EDIP, EPS, Eco-Indicator 99, IMPACT 2002+ etc. Although these methods are developed especially for European countries, there are no fundamental reasons that would restrict the applicability to other regions such as Australia, North America, or other Asian countries. However, as pointed out by reviewers, they will require modification to apply them correctly to other regions. Currently in Australia, there is only limited development of methods for quantifying the most relevant environmental impacts and there is no thorough methodology available to compare these impacts. Designers or building decision makers are not environmental specialists and they never will be. They will not expect to be consulted by environmental experts in every case, and therefore, they need a simple, yet reliable tool to measure the environmental consequences of their design decisions.

   LCADesign presents a number of indicators such as "Embodied energy", "Embodied water", "Embodied carbon dioxide", "Ecological Footprint", "Indoor air quality" and "Biodiversity" which might be more concerned by building designers or building decision makers. Besides these indicators, LCADesign presents LCIA indicators such as EI 99, since building designers or decision makers are frequently required to deliver their decision with consideration of the multitude of environmental problems together rather than single issue assessments (such as energy analysis, global warming analysis or risk analysis etc).

   We know TRACI is developed for quantifying the environmental impacts (as midpoint approach) for North America and is consistent with the EPA Risk Assessment Guidelines, US policies and regulations. LCADesign can easily add it on the indicator list with simple addition of environmental indicator database. That is one of merit of LCADesign which means it is very flexible to adapt for different countries just adding by the adequate indicator methods. Earlier versions of LCADesign included CML and EPS2000 as well as EcoIndicator99 to provide choice in assessment measures.

2. There are different groups of resources such as;
   - mineral resources (metals etc),
   - bulk materials (sand etc),
   - energy resources (fossil fuels),
   - flow resources (solar energy etc),
   - environmental resources (water, air and soil), and
   - biotic resources (wood etc).

   These are partially overlapped with the other damage categories in EI99. For example, environmental resources are considered in the damages of Human Health and Ecosystem Quality. Bulk materials and biotic resources are covered by the effects on land use. This is because bulk resources are abundantly available for the near future in most regions. EI 99 assumes that the surplus energy will not increase. Otherwise, the real problem in many countries for bulk resources is the land conversion problem. Thus, this is considered in the impact

land-use. The rest of group of resources, mineral resources and energy resources are only considered in EI 99 as damage for Resources.

In LCIA with EI99, the uses of minerals and fossil fuels for a product are typical entries in LCI, because of a widespread belief that reducing the earth's endowment with non-renewable resources is an environmental damage. However, no satisfactory assessment system for these items seems to be available, with the consequence, that these entries do not influence the result of the interpretation of LCA results. That is, unlike the damage categories Human Health and Ecosystem Quality, there has not been found a more or less accepted unit to express damage to Resources. Thus, in EI99, the unit of resources damage category is set the "surplus energy in MJ per kg extracted material". T his is the expected increase of extraction energy per kg extracted material, when mankind has extracted an amount that is n times the cumulative extracted materials since the beginning of extraction until 1990. A value of 5 is chosen for n. As the surplus energy is dependent on the choice of n, the absolute value of the surplus energy has no real meaning. Surplus energy is used to add the damages from extracting different resources.

Although, as described by reviewers, the measure for damage of Resource might be a proxy and a number of LCA practitioners in the world are using the unit. But building designers or decision makers, who are not familiar to environmental assessment or LCA methodology may find it difficult to understand this unit. The User Guide should have more explanatory information.

3. As described by the reviewers, human health is only part of EI 99 indicators. LCADesign presents a number of indicators, which is mostly satisfied of minimum list of environmental performance issues to be included in an environmental assessment of a building. These indicators supported by LCADesign include "LCIA results (by midpoint (CML method) and endpoint (EI 99 method))", "Embodied energy", "Embodied water", "Embodied carbon dioxide", "Ecological Footprint", "Indoor air quality" and "Biodiversity" are of more concern to building designers or building decision makers.

   Other indicators such as noise, illumination or others are also critical indicators for buildings. The indicators of LCADesign include all of these indicators described by reviewers (Table 2). Human Health is part of the EI99 method and Is not meant to be the only measure by which a decision is made. There is no single measure so LCADesign provides a range of indicators.

4. Some of indicators such as DALY for damage of Human Health are focused to the LCA practitioners or toxicologists not building designers or decision makers related to building. Designers or decision makers for building do not have as much knowledge of LCIA as environmentalists do. Conversely, environmentalists have less knowledge of buildings or building materials. That's the reason why assessment tools such as LCADesign are necessary for building. In addition, that is also a reason why LCADesign suggests a number of environmental indicators to them. As described above, LCADesign suggests various environmental indicators depending on their purpose and intent. Thus, as pointed out by the reviewers, the User Guide should provide more information on environmental indicator units (such as DALY, PDF m2/yr, etc.).

Table 2 LCADesign Indicator list

Indicator			**Current Status***	**Minimum list by ISO**
LCIA result-Midpoint	Abiotic Resource Depletion		S	Resource productivity
	Global Warming		S	Energy efficient operation
	Ozone Layer Depletion		S	Pollution
	Human Toxicity		S	
	Freshwater Aquatic Ecotoxicity		S	
	Marine Aquatic Ecotoxicity		S	
	Terrestrial Ecotoxicity		S	
	Photochemical Oxidation		S	
	Acidification		S	
	Eutrophication		S	
LCIA result-Endpoint	Carcinogens	Human health	D	
	Respiratory organics		D	
	Respiratory inorganics		D	
	Climate change		D	Energy efficient operation
	Ozone layer depletion		D	Pollution
	Ecotoxicity	Ecosystem quality	D	
	Acidification/eutrophication		D	
	Minerals	Resources	D	Resource productivity
	Fossil fuels		D	
Others	Embodied energy		D	Operational energy Thermal load Natural energy utilization Building systems' efficiency Energy efficient operation
	Embodied CO2		D	
	Embodied water		D	Water consumption
	Ecological footprint		N/F	Resource productivity
	Biodiversity		N/F	-
	Indoor Air Quality		N/F	Thermal comfort Lighting Air quality Noise & acoustics
Economics	Life cycle cost		D	-

S: Soon, N/F: Near Future, D: Done

E. Doing a Building Assessment

1. The performance of LCADesign is definitely an issue and will be addressed. The current version is still only a prototype. A “Sketch” or “Concept” design tool should be developed as a front end for LCADesign so that basic parameters can be entered and a concept can be assessed prior to spending time on a full 3D CAD model. Such a tool could build an IFC model in the background, dimensionally but not spatially correct, for LCADesign to use in the same way as full 3D designs exported to IFC. This would be of great benefit at the earliest stage of design and could even incorporate many facilities of other “Check list” type building assessment tools. It is envisaged that aggregated versions of the Reasoning Rules be applied at Sketch Design stage but to achieve an effective macro view, the detail of LCADesign is needed first. Some simple (typical) Rules can be developed for application at an earlier stage and have been anticipated in the underlying structure of LCADesign. The basics of a simple structural engineering tool, where the user could modify floor loadings, sounds ambitious but some rudimentary facilities could be possible to the level of accuracy required.

2. When a tool such a LCADesign is most effective in the decision process is an issue and must be carefully considered. Since the most benefit can be achieved at the earliest stage of design more work could be done in targeting LCADesign to the conceptual stage (see above) with the current approach following on for a more detailed analysis. It is intended that higher level Reasoning Rules could be used to hide the detail at the early stages of design.

3. Reporting and printing facilities are on the agenda for future development work. Again, there needs to be more work done to integrate the ACMM nomenclature, Reasoning Rule names and Product names. The combination of these three hierarchies in the Reasoning Rules does require more information to be clearly available to the user. These hierarchies are important in providing quick access to the required Rules and knowing where you are is important.

4. It is a good idea to somehow expose the material quantities to the user. They are indeed calculated and stored and could be very useful for the user to check and export. This could also increase confidence in the results. Implementation is mostly in deciding on the form of display.

5. The first chart that is seen after a Design calculation is intended to give the user a quick view of the assessment. It was intended that the user could change the configuration of this default view, but this has not yet been implemented. Perhaps this could link to an Analysis automatically. The tab title of “Analysis” in the Design view could be misleading and perhaps should be changed to “Results” or similar. The first chart after a Variation is made shows how it compares to the base Design, by percentage – an instant view of whether the variation is an improvement on the original design.

6. The rows on the “Details” (RR) table of Designs and Variations are collections of building elements. The first three columns, “General Group, Element, Sub-element”, are the ACMM levels. The fourth column, “Type”, is not used yet but is ready for giving multiple RRs to elements such as Structural (‘S’) and Finish (‘F’) rules. The fifth column, “Base Reasoning Rules”, is the RR given to the element in the 3D CAD tool. Each row in the table covers a collection of building elements that have the attributes given in columns 1 to 5. For example, all 18 column elements in the Small Office building are covered by one row in the table. A variation to the RR in that row will change all 18 columns in the design.

F. LCI Data Issues

Generic data at a national level is used in the current LCI although more detailed information on products is available but not across all products so for consistency, only generic LCI values are used. Specific products can be readily developed and incorporated in the Reasoning Rules where individual products need to be compared. At this stage, only products which are different in some clearly identifiable manner are being included. The LCADesign concept provides for great flexibility at all levels.

G. Closing Comments

As noted above, a sketch design tool would be a great advantage for ease of use in the early design stages. The sketch design tool could create an IFC model behind the scenes and unknown to the user. It would not be necessary for this model to be spatially correct for an assessment to be done.

Exposing the bill of quantities should be done. Later on perhaps the CRC CI Estimator could be integrated into LCADesign.

The issues of using other LCI data has been catered for but not yet implemented in detail. A priority is to accept data from SimaPro. One problem is the lack of an accepted industry standard LCI data format. ISO 14048 has been used so far.

Selection of environmental impact measures is very important for acceptance and must be customizable. This will need to make allowance for regional differences, but should also have a global intent.