Automating the Extraction of Quantities

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Abstract

The Automated Estimator and LCADesign are two early examples of nD modelling software which both rely on the extraction of quantities from CAD models to support their further processing. The issues of building information modelling (BIM), quantity takeoff for different purposes and automating quantity takeoff are discussed by comparing the aims and use of the two programs. The technical features of the two programs are also described.

The technical issues around the use of 3D models is described together with implementation issues and comments about the implementation of the IFC specifications. Some user issues that emerged through the development process are described, with a summary of the generic research tasks which are necessary to fully support the use of BIM and nD modelling.

Introduction

Building material quantities need to be extracted from building designs for a range of purposes including:

- Estimating cost

- Environmental assessment

- Ordering of materials

- Thermal modelling.

The partners within the Cooperative Research Centre for Construction Innovation (CRC CI) are involved in a number of projects that require the extraction of quantities for various purposes. This paper focuses on two of the deliverables from these projects. The first project, the Automated Estimator, has been examining the issues around extracting quantities for estimating purposes. The second project, LCADesign used quantity takeoff to support assessment of the environmental impacts of buildings.

Both deliverables are intended for use by industry partners to the CRC CI so they have to meet industry needs. The most important of these is the requirement to fit within their current processes with minimal change. Since IFCs (Industry Foundation Classes) (IAI, 2003) are used as the method for data extraction and exchange this requires the partners involved in design processes to use one of the IFC compatible CAD systems. As part of this process, modelling guidelines have been developed to reduce ambiguities and problems in the exchange of IFC based information.

The generation of Bills of Quantities is a fairly standardised process within those countries that have followed the English tradition of building construction. Environmental assessment is not standardised so that it is expected that methods of quantifying, analysing and presenting information on environmental parameters will change rapidly as this area develops.

Each process starts with a three dimensional object-based model of the proposed building project encoded in the IFC format. At the current stages of development

both systems also require a detailed model of the building as would be prepared to tender stage in the traditional design/tender/construct procurement process. This was an explicit decision since it was felt that the detailed information required to undertake these processes in their entirety was needed before examining earlier stages of the procurement process and the information available through alternative procurement methods. It is intended to adapt both systems to handle earlier stages within the design process now that the requirements at the documentation stage are understood. This targeting at the design process distinguishes this work from Graphisoft Estimator 2005 (Graphisoft, 2005) which is based on the creation of an as-to-be-constructed CAD model of the project. The emphasis by Graphisoft Estimator on a model that encodes the proposed construction method is appropriate for some forms of procurement such as design-and-construct, while the Automated Estimator is appropriate where a number of contractors are bidding competitively using a single, more generic model.

The intention in these projects was to minimize changes required to existing processes within the participating industry partners while providing the maximum benefit to the users. This constrained the work on Bills of Quantities, where there are already established precedents. The environmental assessment work was much less constrained since the existing processes within the industry partners were built around the use of spreadsheets within informal processes.

BIM Preparation

The construction industry is still in the process of moving from 2D CAD processes to 3D CAD. The advantages of moving from 2D to 3D processes are well documented, the costs less so. A clear distinction must be made between modelling in three dimensions (geometry only) and 3D object-based CAD. Three dimensional object-based CAD provides additional semantics that are necessary to

support the processes described in this paper. The term Building Information Model (BIM) is emerging as the preferred title for CAD and other software systems that support 3D object-based processes.

As with any computer-based process, the results are only as reliable as the input data.

As part of the commitment to minimize the changes in process required of users, the documentation for a range of building projects, as documented, has been and continue to be examined. The intention is to build up a library of projects where various modelling methods can be examined. The industry partners have also been asked to provide the project data as it exists at frequent intervals through the design/documentation process to provide a history of the development of the various models. An interesting issue that emerged with obtaining histories of models was the unwillingness of CAD operators to release models that they considered incomplete. They felt that it was a reflection on their technical competence if other people saw unfinished models. The implications of this attitude on future, more powerful, integrated design systems is another area worthy of study.

The models provided have ranged significantly in size of project, extensiveness, quality and intent. Some of the models that were used were developed explicitly for these projects. These included a 5 storey education building and a single storey laboratory building developed by the project team to build an understanding of the modelling issues and to ensure that reliable data was available for testing. Another existing building is being modelled by an industry partner to build their understanding of the modelling process before they start to use it in their normal processes. Another industry partner started to move to 3D modelling for structural design concurrently with the start of the project. Savings in time and cost of

approximately 30% were identified across the board for the use of 3D object modelling for a single discipline view. The majority of smaller models were provided from "design" models that were prepared during the sketch design process to show the client what they were getting. These were obviously not complete and required additional work to make them usable. The two dimensional drawings that were prepared for tender purposes were used to complete the models as far as practicable.
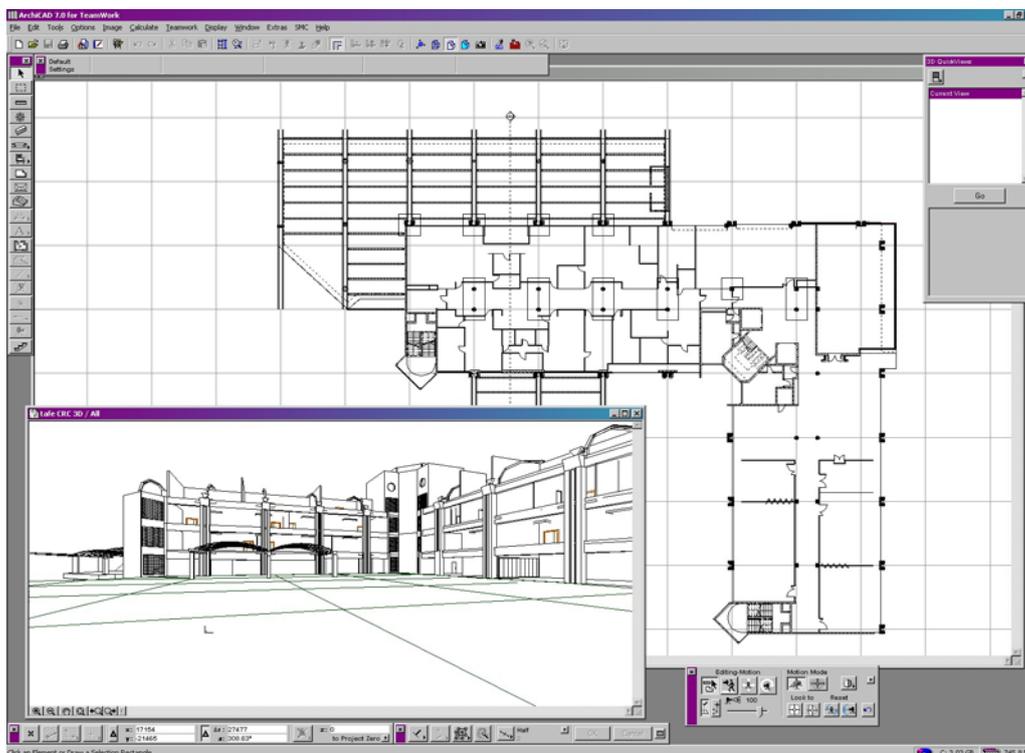

Figure 1: South Bank TAFE model explicitly prepared for the project

After commencement of the project the industry partners adapted their documentation process to suit the generation of BIM as far as they thought possible without impacting significantly on their delivery activities and time. A number of issues arose out of this process:

- Some CAD systems do not support the concept of stories. It is possible to automatically generate storey information but this still requires careful checking by the users.

- Users would often want to achieve a particular visual effect, with either hatch patterns or colours, that meant that the resulting IFC output data was incorrect. The representation of materials, finishes and colours in CAD systems generally needs more thought.

- The generation of library objects by users within CAD systems often requires more technical knowledge than the users are prepared to invest. One user used the column and beam tools to drawn window frames because the available library objects did not match his intentions.

- The successful use of the 3D architectural CAD systems often requires full technical specialists who continually revise the work of the users to ensure that repeat components are added into libraries. For example, the Eureka Tower project, in Melbourne Australia, (Khemlani, 2004) had two full time ArchiCAD specialists working on the CAD model to ensure that the full 88 stories of the project could be modelled within current software and hardware limitations. The emergence of a new type of specialist often does not fit well into existing organisational structures.

- Users will often use a tool inappropriately. An example is the use of the column tool to add piers below the foundations of a building.

- CAD system documentation often recommends practices that lead to confusing semantics in the exported models, for example, using the slab tool/command to draw furniture.

Many of these issues will be resolved as CAD systems become semantically richer. The challenge for the CAD vendors is to increase the richness without increasing complexity.

Issues with Quantity Takeoff

As expected, attempting to automate the quantity takeoff process leads to some insights in the nature of the data itself. The rules that have been developed need to deal with building components that are explicitly represented in the model and also with components that are not explicitly represented but can be inferred. A third category is components that are not represented in the model and can not be inferred. These obviously present a problem that can not be resolved in taking models purely from CAD.

The components that are represented explicitly need to be processed in two ways. Some components, such as door furniture, just need to be counted. This requires a simple query against the database. Other components need to be identified, have the length, area, volume or mass determined and then aggregate the data. Discrete solid components, such as skirtings, floor finishes and concrete walls all fit in this group. The Australian Standard Method of Measurement (ASSM) () requires that the length of some components be included in the item description. Generally, this applies to larger prefabricated components that are brought on to site, such as structural steel. A typical description is "*150UC30 Plain column (.. @ ...m, .. @ ...m long)*", where "*150UC30*" is the manufacturer's designation of a hot rolled steel section and the bracketed figures give the number of and length of the members in the model. In this case, the presented quantity is in tonnes, so the weight per metre of the member is required. Obviously knowledge of the manufacturer's products is required. This means that the generation of item descriptions has to be a four stage

process – identify the relevant components, extract the required quantity, generate the item description and then count the number of occurrences.

The issue of information that is not available and can not be inferred is covered in subsequent sections.

Comparison of the Two Systems

This section provides an overview of the two systems and their differences to give a context for the more detailed subsequent discussion.

Since the two projects were supported by industry partners and these industry partners expect to be able to use the deliverables in their daily processes, a pragmatic approach was taken on model generation and CAD usage requirements. Current commercially available CAD software was used to generate the CAD models and the output produced by the current versions of the IFC export utilities was used.

The Automated Estimator team developed the system so that no additional user input is required before processing. However, since no standardised list of item descriptions will ever capture every possible permutation a post processing system was developed to allow user rectification of problems. The LCADesign team had to be able to estimate the amount of some materials that would never be explicitly modelled in CAD. This lead to the development of a "tagging" extension to ArchiCAD (which could be adapted to suit other major CAD software) as a pre-processor. This is described in more detail later.

The projects that developed the Automated Estimator and LCADesign both started at the same time, but the work on the Automated Estimator finished a year earlier and was funded for an additional stage. This meant that the Automated Estimator

team were able to review their work at the completion of the first stage and update it to reflect changes in the Industry Foundation Classes (IFC) specification and software that supported the revised specification. In their current versions Automated Estimator supports IFC 2x2 while LCADesign supports IFC 2.0. The changes in the IFC model from version 2.0 to 2x and the subsequent revisions was substantial. The major issue affecting these two programs was the introduction of the "library" mechanism in IFC 2x, where the repeated use of a building component could be captured by referencing the shared definition from multiple instances. This is not a criticism of the IFC model – this was a known issue that was one of the motivations for the IFC 2x development. Since IFC 2.0 models define each instance individually LCADesign either had to process every object or to pre-process and attempt to recognise repeated elements. Since the processing time of recognising elements was expected to be the same or more than the calculation of the life cycle assessment results the "process everything" approach was taken. The time taken to identify identical elements in the model is a direct result of the modelling approach used in the IFCs.

The Automated Estimator software only processes and displays one model at a time. This is consistent with the use of BoQs. LCADesign allows the results of multiple models to be compared on the various graphs. This introduced complexities in the programming required but was necessary since the major aim of the software was to allow designers to compare alternative designs. This also allows different buildings to be benchmarked against each other.

Issue	Automated Estimator	LCADesign
Model generation	Minimise changes to CAD process by users	Minimise changes to CAD process by users
Additional User Activity	Post processing to handle unusual cases	Tagging of CAD data within the CAD software
IFC Version Supported	IFC 2x2	IFC 2.0

Library usage in model	Part of the model	Not available
Scope	Structural trades – concrete, steel, reinforcement, etc	All trades
Exception handling	Post processing with Viewer and drag-and-drop	Pre-processing with comprehensive range of tags
Encoding effort	Heavy reliance on queries means great care is required in defining them to avoid overlaps	Combination of tagging and rules simplifies generation and maintenance
Comparison of models	Not supported	View results from multiple models on some graphs

Table 1: Software Comparison

Quantity Takeoff and Bills of Quantities

The use of Bills of Quantities (the Bill) within the English tradition dates back to the late 18th-early 19th centuries (Ferry, Brandon & Ferry, 1999). Contractors bidding for work realised that the process of extracting the necessary quantities, prior to the assignment of unit rates of cost, could be shared by the contractors all paying a portion of the cost and distributing the result. Over time, the client became responsible for paying for the generation of the Bill of Quantities and a distinct profession of Quantity Surveyor emerged. Documents, called standard methods of measurement, were also developed to provide more consistency through providing guidelines on how the Bill of Quantities should be structured, which items should be measured, how they should be measured and what units should be used.

The usual process a Quantity Surveyor will currently follow is to lay the drawings for the project out on a desk next to computer based Bill generation software. Standard lists of items are drawn from a database and the appropriate measurements are made by hand against the drawings, with the individual measurements being accrued within the software. As each measurement is taken

the Quantity Surveyor will mark off the measurement on the drawing using an appropriately coloured pen.

If an appropriate unit rate of cost does not exist in the database, the Quantity Surveyor will also build up a unit rate for the item from first principles.

While it is not a core issue of this paper, it is useful to note that the use of Bills is declining in Australia for various reasons:

- Clients wish to reduce their apparent cost of design and tendering;

- Use of alternative forms of project procurement other than "design/tender/construct";

- Time required after completion of the documentation to complete the Bill;

- Increasing complexity of projects and the increased range of products used, with the consequent complexity of standard methods of measurement and the possible lag between the emergence of a new product or process and a standard method for measuring it;

- Legal and risk issues;

amongst others. This had led to the interesting position that one firm of Quantity Surveyors (now repositioning themselves as Cost Consultants) may be taking off Bills for several tenders who are pricing the same contract. Obviously, strict separation between the processes must be maintained.

The advantage of each tenderer paying for the preparation of their own Bill is that the result can then be customized to suite their preferred working methods, plant, etc. An analysis of the cost/benefits of shared Bills versus customised Bills for various types and complexities of projects would be a useful exercise.

When work on the Automated Estimator was first started the intention was to only provide the Bill of Materials interface. However, it was soon realised that the software programmers needed some method to check the results from analyses and that on completion of the project professional quantity surveyors and estimators would also require a visual check on the information. The use of marked up sets of drawings as visual checks within the current quantity takeoff process suggested that providing a viewer that was linked to the Bill of Quantities was an appropriate addition to the development work. The Viewer has subsequently been used as a visual interface into several other CRC CI projects.

Automating Quantity Extraction

As stated above the initial intention with the Automated Estimator was to provide a "traditional" BoQ user interface to meet the requirement of minimal change to existing processes. However, it was soon realised that importing data directly from CAD into a BoQ bypassed the existing process of marking off drawings to record what had been measured. After some consideration it was decided to implement a Viewer application that could be used to confirm that the measuring process had produced correct results. A simple application to define and edit the measurement rules was also written. All of the programs are written in Java so that they could be run as either stand-alone or over a web-based service as applets. The data they use is stored in an Express (ISO, 1994) compliant database, Express Data Manager (EPM Technology, 2004). Figure 2 shows the software architecture of the system.
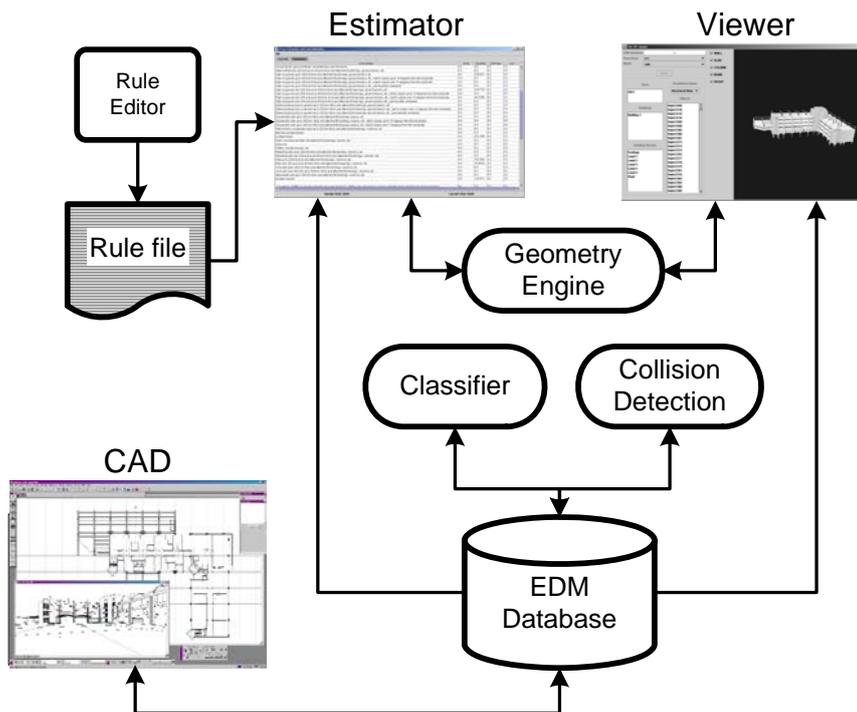
Figure 3: Automated Estimator Software Architecture

The core of the system is the EDM database. This commercial database is able to read any Express schema and provides both file based and API access. The usual method of input is through reading a file, although Graphisoft are developing a capability for ArchiCAD to directly export to EDM version 4.7. However, this is still being tested. EDM was chosen due to its ability to store multiple repositories, representing different projects, and multiple models within one repository, allowing different versions of the one project to be stored simultaneously. These versions can be sequential in time or can be mappings of the same model onto different schema versions. The ability to define mappings between Express schema and to store Express-X rules are also useful, in this and other related projects.

The other input to an estimating session is the estimating rules stored in rule files. Each rule file contains a separate trade breakdown which is automatically shown in a separate tab within the Estimator window. Rule files contain an XML representation for each item that will appear in the Bill of Quantities (BoQ) window.

It consists of the human interpretable text that will be displayed in the window, a matching database query for the database, the units of measurement and a unit rate of cost. A simple Rule Editor was written that simplifies the generation of Rules files.

The process of generating an estimate can be initiated from either the Estimator or the Viewer (figure 4). In either case, the Rule files are loaded and read into the tabbed interfaces in the Estimator user interface. The collision detection agent is then run to ensure that there are no illegal overlaps in geometric bounds. The classifier parses the instances in the database and checks that they are defined within expected constraints. This is used to automatically convert some standard IFC instances from a supported class to another. For example, ifcColumns that are below the lowest slab are automatically converted into footing piers and instances of ifcSlab that are supported on a pier and are smaller than a preset size are converted to footing pads. Once the above agents are run the estimating rules are run. The relevant queries for each item in the BoQ are then called. The first stage of the query returns all of the relevant instances. These are then processed through iterators to extract the quantity stored against the query (length, area, volume, mass, no. of). If the length, area or volume is not stored these are calculated on the fly. The mass of structural steel and reinforcement products is stored in a separate database to allow calculation of masses.

The Estimator program provides the BoQ interface and allows new models to be loaded into the database. The user interface consists of tabbed panes, one for each of the trades. As mentioned previously, the trades are implicitly defined by the number and names of the Rules files.

If the Estimator is the first program started the user will either load a new project, add a new model to an existing project or analyse a previously loaded model.

When a model has been analysed, the display shows the item description, the units of measurement, the measured quantity and the cost of this element. The total estimate for this trade and the total estimate for all measured items are shown at the bottom of the window. This is the format with which industry is familiar.

The powerful features of the Estimator lie in its integration with the viewer. For each of the operations below, the viewer is started or brought to the foreground and all of the selected components are shown in the Viewer window, with everything else made semi-transparent. The user can query the results by:

- Selecting an item in the BoQ and requesting a list of all building components measured. From this list, individual components can be selected, or the entire list;

- Requesting display of all components measured in a trade;

- Requesting display of all components not measured in a trade;

- Requesting display of all measured components;

- Requesting display of all components that are not measured.

The last item above is possibly the most important. Components that are not measured are informally called "rogue" items. They do not match any of the predefined item descriptions and a new description has to be written. This is not perceived as a shortfall in this system – as long as designers show some imagination there will be a need for new item descriptions.

The other operations above will potentially identify mis-measurements. In an ideal world, new queries would be written and the BoQ regenerated. However, the facility as been added to allow users to drag-and-drop components from one item into another if an error is found.
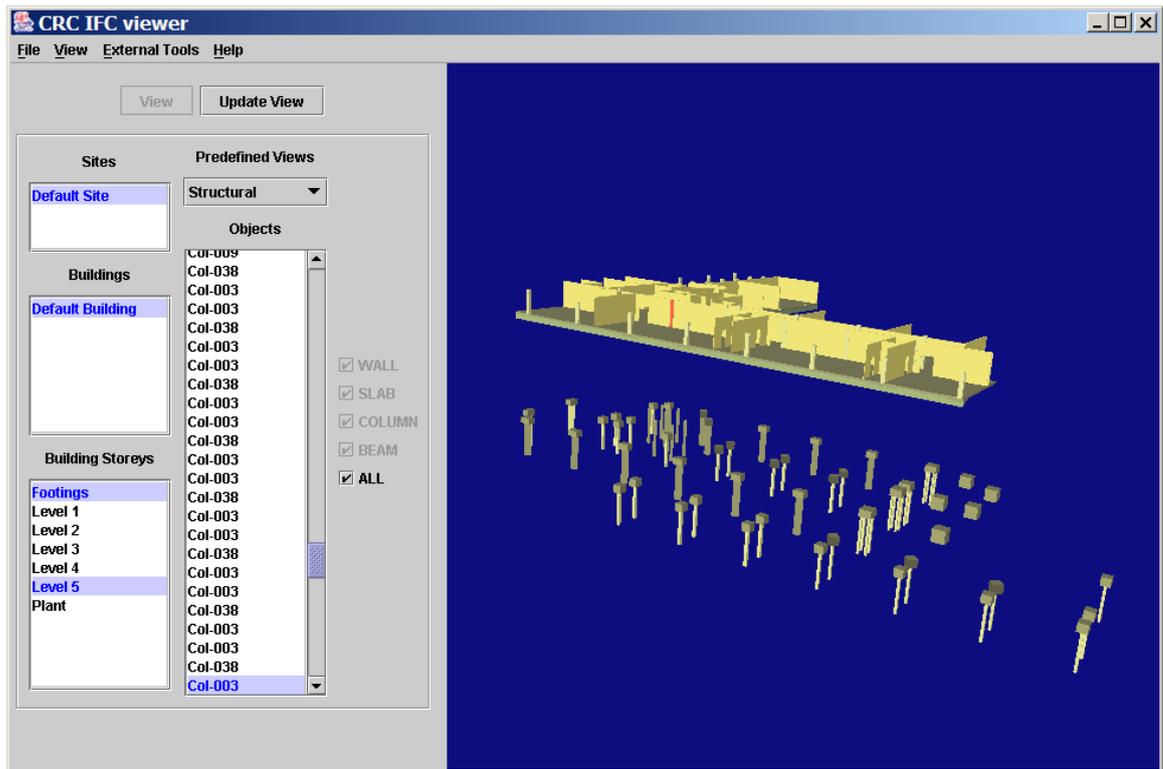
Figure 5: Viewer showing display of partial model

As described above, the Viewer can act as a passive partner to the Estimator. It can also act as the starting point for a user session. The Viewer allows the selection of individual floors and filtering of views by component type (based on the IFC entity names). It also allows selection of a component and querying of its properties. Most importantly, the Viewer can be used to audit the results through selecting a building component and requesting the display of all items in which it is measured. This brings the Estimator to the foreground with a separate window containing the relevant item descriptions and the trades under which they appear. The user can then check that a component is measured under all expected items and that it is not measured where it should not be. Thus the Viewer acts as a quality check on the results.

Quantity Takeoff and Environmental Assessment

Use of LCADesign (Life Cycle Analysis of Design) enables building design professionals to make informed decisions on the environmental impact of commercial buildings by providing detailed environmental measures for different materials, products and designs, automatically from their 3D CAD drawings. It meets a growing need from designers and regulators for real-time appraisal of design performance of built assets against a set of sustainability criteria. A fully integrated approach to automatic eco-efficiency assessment of commercial buildings works off a complete 3D CAD building model and allows the viewing of environmental impacts resulting from the combination of design and choice of materials used in construction. To perform such an analysis, each and every component must be represented in the 3D CAD model, just as a Bill of Quantities requires all components but the requirements of the information, other than dimensions, differ significantly.

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). Thus the focus is on the amount of each individual material for which quantities are the essential first importance scaling factor. Each material has different environmental impacts per unit mass so density and environmental inventory data are subsequent importance scaling factors.

Using an Environmental Assessment Tool

The most significant value-adding capability of an automatic environmental 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. The alternatives may consist of an entirely different structural designs in the early design stages but mostly the alternatives consists of using different claddings, windows, doors, floor coverings, ceilings, etc. The outcome of an analysis is a large number of designs mostly with the same quantities but different material properties.

Inferring All Required Information inform the Model

The life cycle inventory database of building products includes details of resource consumption and environmental emissions generated during the manufacture of building materials, including embodied pollution and water as well as energy. The individual environmental indicators are nested under three major categories of impact: resource depletion, degradation of the physical environment, and harm to human population. Each sub-category has a number of sub-sub-categories. Environmental assessors require the facilities to drill down into the source of environmental impacts by material category, individual material, building assembly or component. The result is a capability to analyse the environmental impact of a building, or any of its components, using a multitude of indicators – potentially a few hundred, each of which may be considered a dimension – thus creating a multi-dimensional view of environmental impacts where the n in nD could be regarded as being in the hundreds.

Since 3D CAD objects do not contain all the required data and are inconsistent in the available attributes, reasoning rules provide the link between the components

in the building model database and the resource usage and emissions of the materials. The reasoning rules use the dimensional parameters from 3D CAD and convert them to a unit matching that of the Life Cycle Inventory Product to enable life cycle environmental analysis. Reasoning rules combine all relevant materials from the Life Cycle Inventory to create a real building component or product, e.g. a 3D CAD representation of a window has little other than the name to identify it (say) as aluminium framed so the reasoning rules must contain relationships (mainly formulas) to calculate the quantities of all the *materials* in the window, e.g. aluminium, glass, sealant, fixings, etc from the one set of dimensions. The amount of material in the frame is calculated from the perimeter of the window and the typical cross-section of the extrusion while the amount of glass uses the area and the typical glass thickness for the particular window type. Thus, while the rules are scalable for size, needing only one rule, different window types require additional rules. The 3D CAD object must be tagged with the relevant reasoning rules as part of the creation of eth 3D CAD model. The Life Cycle Inventory covers commonly available products for use in the reasoning rules and is currently limited to typical building elements such as wall, slab, and ceiling systems. Future versions are expected to include additional reasoning rules which will encompass higher aggregate level analysis like default complete floor types and even whole buildings.

LCADesign

A software tool, LCADesign, has been developed to enable industry to make decisions on building environmental impacts based on a uniform level of information and access to environmental for different products and designs. The principal aim 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 as shown in Figure 6
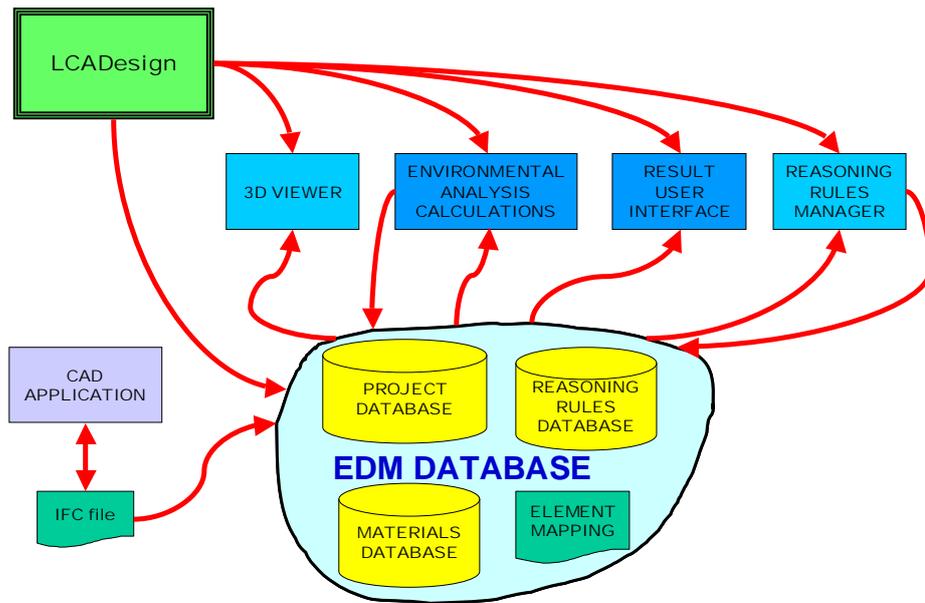
Figure 6   **Schematic diagram of LCADesign components**

The essential steps in the process involve:

1. Creating a 3D CAD model of a building,

2. Using the dimensional information in the 3D CAD model to automatically estimate quantities of all materials in the building,

3. 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,

4. Calculating a series of environmental indicators based on Life Cycle Analysis, and

5. 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.

To achieve this integration, information has to 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. Unlike almost all other environmental assessment tools in existence, an integrated tool can evaluate alternatives while a design evolves and not, as is typically done, as a post-design evaluation to check whether a required benchmark has been achieved.

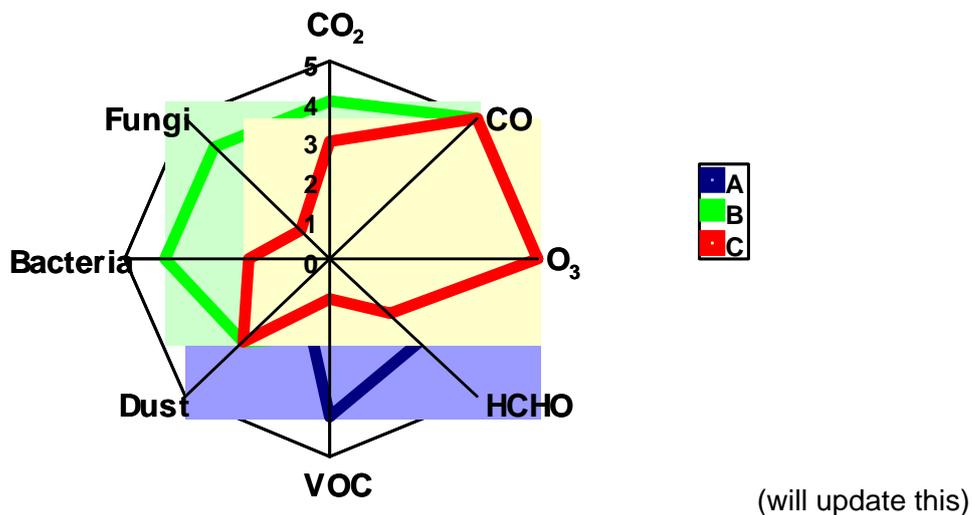A typical analysis comparing alternative designs is shown in Figure 7.

(will update this)

Figure 7   **Typical comparison analysis of alternatives**

Comparison of LCA and standard BoQ Requirements

Extraction of quantities from a 3D CAD model are similar to standard Bills of Quantities in that they both require:

- Accurate dimensional data for the object

- Identification of what the 3D CAD object represents in the model

- Additional information, e.g. costs or environmental measures, which is the focus of analyses

- Aggregate measures derivable from the dimensions in the model for comparison of alternatives, e.g. floor area to calculate unit rates

- A hierarchical nomenclature for aggregation and analysis of all components

The differences are:

- The measures and indicators used

- The need to specifically identify the *materials* in the environmental assessments of every object because of the more detailed level of analysis

- The need for the standard Bill of Quantities to include non-material items which impact on costs, such as overheads

The robustness of the environmental assessment to accept tagging of any element means that any model can be analysed. Information that is not in the model can be inferred using default values. For example, in the model aluminium windows may be defined. For environmental assessment, the areas of glass, length of neoprene gaskets, etc must be calculated. These are calculated using the reasoning rules from the gross parameters of the window itself.

Potential of 3D Models

The range of software supporting the production and use of IFC data that is now available indicates the faith that the developers have in the uptake of the IFCs by industry. However, users, or potential users, often complain that they need particular tools before they will consider using the IFCs in their daily work. Herein lies the classic "chicken and egg" situation – until there is a wide range of software that supports IFC exchange, most users are not motivated to use it. Until there are

sufficient numbers of users, it is not economic for a wide range of software to support IFC exchange. However, the push by companies such as Graphisoft to use the IFCs as a core part of their business strategy promises to eventually resolve this problem.

Comments on the IFC Specifications and Implementations

There is no doubt that the IFC model is large and flexible. The availability of the IfcProxy entities means that any desired object can be exchanged. The use of property sets also allows a great deal of flexibility in the passing of attributes and values. However, with this flexibility also comes the possibility for confusion. The varying interpretation of the specification by the various CAD vendors makes the development of downstream software more difficult than it should be. Rigorous testing against a range of output files from the generating systems is necessary to increase the robustness of the downstream software.

The extensive use of objectified relationships is confusing to programmers. In IFC R2x2 there are 41 instantiable relationship entities. Some of these could be handled directly from the relevant entities. This use of objectified relationships also means that two accesses are required to trace a relationship from one instance to another. This is not a major consideration with file based exchange since the IFC data is converted into the internal model of the receiving software. However, this will impact on the performance of BIM servers if they provide an IFC interface.

The major issue faced by downstream software developers is the inconsistencies between the output from the various architectural CAD vendors. Some IFC files have no area or volume information, even though CAD systems should be well placed to provide this data. Even more problematic is that some systems do not even support the IfcBuildingStorey concept. No matter how many storeys in the

model, they are all referenced from a single instance of IfcBuildingStorey. While it is possible to automatically determine storeys in most instances tis sould not be necessary.

It is hoped that as the use of BIMs becomes more widespread that the CAD vendors will adapt their user interfaces to support some of these concepts. The move away from generic CAD platforms, such as AutoCAD and Microstation, towards vertical solutions such as Revit and Triforma Architecural/Structural etc is an indication that such a shift is underway.

User Attitudes

While the projects that developed the Automated Estimator and LCADesign were not intended to cover user attitudes, these became apparent when the industry partners were asked to provide CAD models.

The attitudes of the senior staff were often more accepting than those of the staff who use CAD and analysis software on a day to day basis. Senior management acknowledge that BIM is coming and want to position their organisations to benefit from its introduction. They are also searching form methods to gain commercial advantage from the change. This is expected to include increased cross-disciplinary collaboration. One area where management have major concerns is in the potential changes in legal liability if the re-use of models becomes more common. Who made the first mistake?

Both management and project staff are nervous about the impacts of change, but some project staff appear unwilling to change, either because they do not yet see the benefit to themselves or because they are quite happy continuing in their current path.

One issue that surprised the researchers was they concerns that project staff had in supplying weekly updates of the project files. They felt a sense of professional pride in always providing a consistent product. This was not what the researchers wanted. The researchers wanted to study how the models were built up over time. The more serious consideration is what impact this sort of attitude will have when project servers become more common and partal model exchange is introduced.

Further Work

Besides the standard issues of making both the Automated Estimator and LCADesign more comprehensive and robust within their areas of application, there are a number of more general area where research is required:

- partial model exchange – allowing users to extract, manipulate and return portions of the model rather than an entire file;

- discipline views – defining the objects and attributes that are of interest to one particular discipline or in one explicit exchange scenario;

- discipline specific "assemblies" within a shared model, for example, a structural topology (stick) model and applies loads maintained in parallel with the architectural model;

- interactive versus batch processing – current commercial CAD systems update data in a batch when the user "saves" the data. Cad systems are now starting to support software events which can be used to trigger other actions. This may extend to the shared BIM in the longer term, but this will require a fundamental rethink on how CAD systems store and interact with data;

- Support for non-Cad data and analyses from CAD;

- Resolution of the human issues of trust and sharing of data.

Conclusion

With the lifecycle of the AEC industry being characterised by so many professionals and stakeholders, there are massive gains to be made by integrating all stakeholder requirements into a mutually equitable solution. However, collaboration is difficult due to the constraints and conflicts imposed by the number and variety of social, economic and legislative factors. Recent years have seen a major change in the approach to architectural design innovation and research. There has been a huge concentration, from both the academic and industrial communities, on the development of a single building/ product model and/ or on the expansion of 3D CAD modelling with other design attributes (such as process, cost, accessibility, crime etc). These are being referred to as nD models.

An nD model is an extension of the building information model that incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility, and thus enables true what-if analysis of design decisions. The information in the model is also linked, so that when design information is changed, for example, the cost of the project will also change to reflect the new design.

The Automated Estimator and LCADesign are two early examples of nD model based software because they both support the sharing of information and value-adding of information to the shared model

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