Drogemuller, Robin M., Crawford, John and Egan, Stephen. *Linking early design decisions across multiple disciplines.* In : Conference on Product and Process Modelling in the Building and Construction Industry: ECPPM 2004, 8–10 September 2004, Istanbul, Turkey.

Linking Early Design Decisions Across Multiple Disciplines

Robin Drogemuller, John Crawford, Stephen Egan
CSIRO Division of Manufacturing and Infrastructure Engineering, Highett, Vic 3190, Australia
Robin.Drogemuller@csiro.au, JRCrawford@optusnet.com.au , Stephen.Egan@csiro.au

ABSTRACT: The early stages of the building design process are when the most far reaching decisions are made regarding the configuration of the proposed project. This paper examines methods of providing decision support to building designers across multiple disciplines during the early stage of design. The level of detail supported is at the massing study stage where the basic envelope of the project is being defined. The block outlines on the building envelope are sliced into floors. Within a floor the only spatial divisions supported are the "user" space and the building core. The building core includes vertical transportation systems, emergency egress and vertical duct runs. The current focus of the project described in the paper is multi-storey mixed use office/residential buildings with car parking. This is a common type of building in redevelopment projects within and adjacent to the central business districts of major Australian cities. The key design parameters for system selection across the major systems in multi-storey building projects - architectural, structural, HVAC, vertical transportation, electrical distribution, fire protection, hydraulics and cost – are examined. These have been identified through literature research and discussions with building designers from various disciplines. This information is being encoded in decision support tools. The decision support tools communicate through a shared database to ensure that the relevant information is shared across all of the disciplines. An internal data model has been developed to support the very early design phase and the high level system descriptions required. A mapping to IFC 2x2 has also been defined to ensure that this early information is available at later stages of the design process.

1 INTRODUCTION

Building projects follow the Pareto Principle or 80:20 rule, where 80% of the decisions affecting the project outcome are made during the first 20% of the project's life. Thus the decisions made early in the design process have the most far reaching consequences and should be made with an appropriate level of care. However, this stage of the design process is poorly supported by current CAD systems. The aim of the project described in this paper is to assess how well three major architectural CAD systems and a CAD system aimed at mechanical design, support the parametric description of building designs across multiple disciplines. While the results of the comparison are not yet complete, this paper describes the current status of the project and the deliverables to date. A side effect of the main deliverable is the implementation of a decision support system for the early stage of building design that interfaces with four different CAD systems. This demonstrates the benefits of interoperability in providing shared information services.

This is one of the projects supported by the Co-operative Research Centre for Construction Innovation (CRC CI) (CRC CI, 2004) as part of its charter to change the way that the AEC-FM industry operates. Some of the deliverables from previous projects have been adapted to suit the needs of early design problem solving.

2 IDENTIFYING KEY SYSTEMS

The starting point of the project was to identify the major building systems that should be considered during early design. Discussions with the industry partners and a literature review identified these key systems and the relevant parameters within the systems. Systems were only chosen if they had major implications for the shape and layout of the project.
The systems selected were:

- Architectural spatial layout
- Structural
- Environmental
- Fire protection
- Hydraulics

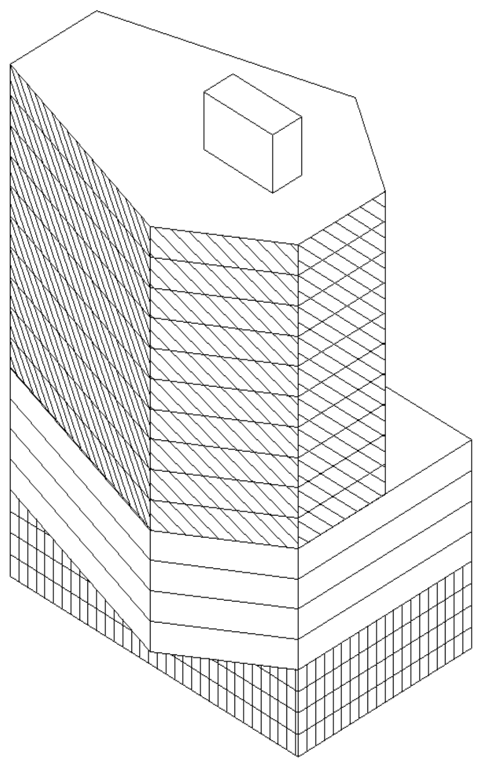

Figure 1: Massing Model with Storeys

Upper shaded floors are residential, middle floors are office space, lower levels are below ground car parking. Lift overrun on top represents the building core.

- Electrical
- Vertical transport
- HVAC
- Cost/budget

The types of projects and the level of detail used are illustrated in figure 1.

3 BUILDING SYSTEMS

Even at the early stages of design with which we were concerned each of the building systems is interdependent with the others. We were not able to identify any one view that could be modeled independently of the others. We were also not able to identify one system on which there were no dependent systems.

Each of the "design advisors" within the software has its own "view" of the shared information in the database. The development of the advisors has assisted in defining these specialist views at the early design stage.

An overarching parameter that applies to all building services systems is the "quality" or level of service that the building will provide. Normally the rental return on a building will be closely linked with the quality. In Australia and, presumably, in other countries, there is a list of requirements for the various "grades" of office accommodation which make the requirements very explicit. The rental charged on space is then negotiated with this standard as the starting point.

3.1 *Architectural Spatial Layout*

The way that spaces can be laid out depends on the type of space and how flexible it needs to be over the proposed life span of the building. The types of "user" space that are handled in this system are residences, office accommodation and car parking. All of the space types have a scaling factor applied to allow for shared communication space. For example, the area of residential units is scaled up by a factor that caters for corridors and lobbies that are shared on a floor. This factor is user configurable to allow adjustment for different layouts and requirements.

Residences are treated as a single space representing the entire unit. The parameters that are used cover the number of bedrooms and the "standard" of accommodation based on local real estate categories. Connection points for the plumbing are also required to assess whether a vented stack is required or not. Constraints on the minimum width of the space are applied and some adjacency to an external wall, for views and ventilation, is required. The requirements for services are applied to the unit as a whole since they do not vary much within a residential unit.

The office accommodation is much simpler to handle from a geometrical perspective since most office accommodation is designed to be flexible. There are no inbuilt constraints on shape or adjacency to external walls although these can be added. There is an increased requirement for detail on the building services. Briefing documents from completed projects were used to define a standard template for space data. The space data is aggregated under user control to provide the appropriate level of granularity for the particular design requirements.

The information stored for office spaces includes:

- Location/access requirements – public or private space, access to other spaces. Etc
- Occupancy – number of people
- General surface finishes
- Environmental control – HVAC, naturally ventilated, etc
- Hydraulic requirements – water supply and drainage
- Sanitary fixtures
- Electric power and lighting requirements, including heat generating equipment
- Communication system requirements
- Security requirements
- Special fixtures – any non-standard fixtures or fixtures that will affect the provision of building services

Not all of this information is currently used but it was considered important to maintain continuity of information from the briefing stage through this very early design stage.

As van Leeuwen & van Zupthen (1994) recognised, even at this stage the functional requirement/technical solution concept of GARM (Gielingh, 1988) is useful. The requirement of X m^2 of general office space is met by the physical solution of floors 3 – 7 of the proposed building.

3.2 *Structural System*

The current modeling and implementation of the structural system is fairly crude. It relies on lookup tables to estimate the size of columns and beams for reinforced concrete and steel framed construction. The inputs required to estimate member sizes are the spacing of columns in both directions and the storey height between floors. It is assumed that the building core provides sufficient stiffness for the structure.

While this is a crude solution it gives satisfactory results for this stage of the design process. Future work is planned to improve the scope of this module by refining the available structural systems and adding alternative structural systems.

3.3 *Environmental System*

The environmental analysis system is provided by a modified version of LCADesign (Tucker *et al*, 2003). An automated take-off module provides the quantities of all building components. The specific production processes, logistics and raw material inputs are identified to calculate a complete list of quantities for all products such as concrete, steel, timber, plastic etc. This information is then combines with the life cycle inventory database, to estimate key internationally recognised environmental indicators such as CML, EPS and Eco-indicator 99. The original version of LCADesign requires a detailed breakdown of the quantities of the materials in the building. The revised version uses default reasoning to infer the likely material breakdowns of the project given system level descriptions of the building. For example, if a reinforced concrete structural frame has been chosen, the structural module gives the number and size of columns and beams on a floor and the thickness of slabs. This provides all of the information necessary to calculate the volume of concrete and to estimate the amount of reinforcing steel required. The area of formwork required can be estimated to a reasonable level of accuracy from the floor area of the slab multiplied by a scaling factor plus the surface area of the columns. This information can then be aggregated with the information from other systems to provide whole of building results.

The required inputs are the geometry of the building and indications of the overall physical building system configurations. The outputs are graphs that allow assessment and comparison of the building performance.

3.4 *Hydraulics*

The hydraulics system is concerned about two issues – identifying needs for water storage within the building and passing this information on to other components and ensuring that vertical service ducts are appropriately located within the building envelope.

The population of the building provides the necessary information for the estimation of tank sizes. The output is a requirement for a tank size in floor area and headroom.

3.5 *Fire Protection*

Fire protection systems are pervasive in modern multi-storey buildings. Local building regulations will often mandate the type of system that must be used for buildings of various heights, occupancies and areas.

The applicable input parameters in Australia are the building height, area and occupancy type. The outputs are whether an automatic sprinkler system is required and if so, the capacity of any storage tanks, whether a fire control centre is required and whether diesel/electric booster pumps are required. Assessment for smoke protections systems could be added in the future.

3.6 *Electrical*

The major impact of the electrical system in the early stages of design is in deciding if a substation is necessary in the project and if so, where it should be located. Obviously, on large sites this may not be a major constraint, but on smaller, highly developed sites this can be a major decision.

Whether a substation will be needed can be identified by taking the area of the building and applying a load density appropriate for the particular usage(s). Electrical loads from the other building services systems, especially HVAC also need to be factored in. This gives the total estimated load, which can be used as a basis for discussion with the local supply authority. If a substation is required the size can be given in a simple lookup table based on the total electrical load.

Other spaces which may be needed include:

- Switch room
- Battery room
- Emergency generator

However, at the level of detail at which we are working these can normally be added to the substation.

3.7 *Vertical Transport*

The choice of vertical transportation system depends heavily on the height of a building, the usage, the population and the standard of the building. Slower installations may be appropriate in smaller buildings or where the standard is lower.

Once a system is selected, the number of floors served, the population of these floors, maximum waiting times and usage patterns all provide input into the number of lifts and the capacity and speed of the lift cars.

3.8 *HVAC*

The HVAC system is often the most expensive services system and has significant impacts on the spatial configuration of a building. One of the first considerations is whether to have a centralized system that services many floors or to have a separate system on each floor. Either choice has its advantages and disadvantages.

If a centralised system is chosen then the location and size of the vertical air conditioning ducts is significant.

The most important factor is the number of occupants, which is normally estimated from the usage type and the floor area. The required values of airflow, heating and cooling load can then be looked up. Obviously the external environment also plays a role in HVAC loads so a load factor can be applied for locations where explicit data is not available. If data on the external envelope of the building is also available then the estimates can be made more accurate. This is an appropriate time to assess various alternative external envelopes and HVAC system selections to ensure that the most appropriate choice is made.

Once the overall loads have been determined and a system selected the plant room requirements can then be estimated.

When the plant room location(s) has been selected and loads per floor calculated the duct sizes for the vertical ducts (if necessary) can be calculated and vertical duct positions determined. This then allows the horizontal duct sizes to be determined. If necessary the floor-to-floor height may need to be adjusted before going through the loop again.

3.9 *Cost/Budget*

The cost implications of the project are obviously determined by the decisions made for all of the other systems. However, projects have financial constraints so cost implications can provide a significant constraint on the selection of the other building services systems. The use of cost planning methods to control project budgets through the design/construction process and also when trading off between systems is well understood (ie. Ferry & Brandon, 2002). Currently an overall budget is entered as a cost constraint. The cost module uses user defined rules and unit rates to calculate a cost estimate based on elemental data extracted from the shared model.

Where necessary information is not directly available it is derived using inference rules.

The quantities are shared with the life cycle assessment module through a shared quantity calculation module that writes the calculated quantities back into the shared database. In some instances different quantities are required across the life cycle assessment and cost modules due to differing classifications of building systems and elements.

3.10 *Server Database*

The server database uses the EDM Express server (EPM Technology, 2004). This provides single writer/multiple reader capabilities that comply with the ISO 10303 standard. A connection manager has been implemented as an interface to the EDM server to handle the event notification required to keep all of the co-operating components synchronized.

The EDM Server can store multiple projects by storing them in separate repositories. Within each repository there can also be multiple models. This provides a useful mechanism if there is a need to store different versions of the one project model for comparative analysis. Separate models are necessary if two alternatives differ in more ways than just substituting one material for another within a building component. For example, if a steel frame was being compared with a concrete frame it may be necessary to use different column and beam spacings to produce efficient structural designs for each construction type. Trying to track such alternatives within a single model is difficult. It is easier to clone the entire database and then vary one of the copies to suit the new alternative.

3.11 *CAD Customisation*

The CAD customisation provides the interface between the inbuilt facilities offered by the CAD software and the information stored in the shared database. The implementation consists of three functions:

- User interface elements that provide access to the information and services that underlie the entire system;

- Data import facilities that read the information in the shared database and convert it to the internal structures necessary for manipulation within the CAD system; and
- Data export facilities which map the internal information on to the schema used in the shared database.

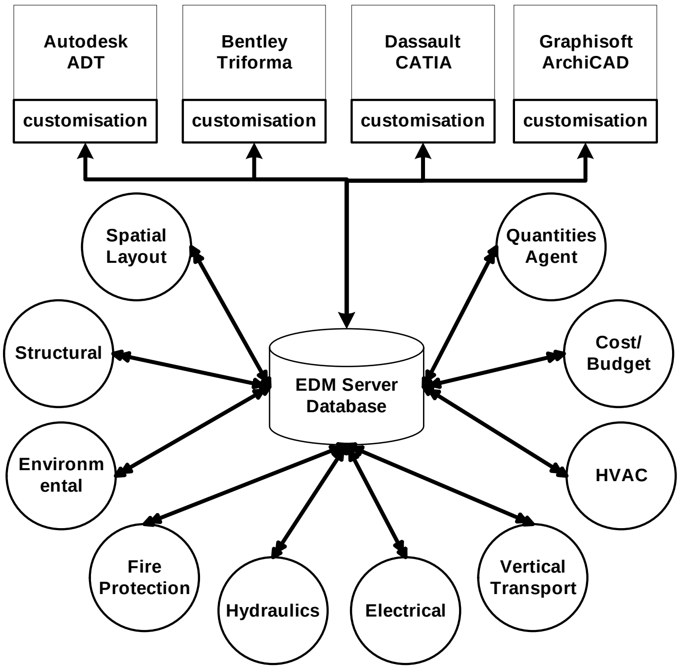

Figure 2: Overall System Software Architecture

4 SOFTWARE ARCHITECTURE

The overall system architecture (figure 2) consists of three levels:

1. The user interface is provided from within the CAD system. This is the sole interface to the various services which sit behind it.
2. The shared database which provides access to all of the shared information within a project.
3. The individual components which read and operate on the shared information within the database.

An “event” model has been defined to support the interaction between the various components. This is a synchronous model that assumes that only one human is interacting with the system at any particular time.

5 SERVICE COMPONENT ARCHITECTURE

The structure of each building service design component is very simple. The EDM server provides a shared database where all of the information that must be available to others components can be stored. Within the component itself the inference mechanisms recognize particular facts or groups of facts and draw conclusions from these facts and then add the new information into the shared database. When necessary, non-project specific information, such as unit rates in the cost estimating component, are stored in a private database. This private database can also be used as a persistent store for project specific information that is not needed by other components.

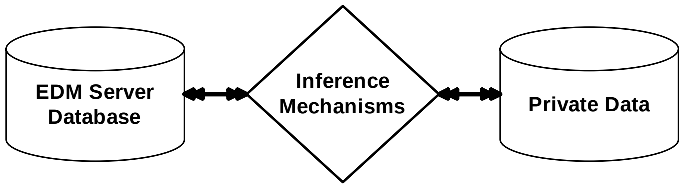

Figure 3: Individual Component Software Architecture

6 OVERALL AND LONG TERM STRATEGY

This work is one aspect of the work being undertaken by the CRC for Construction Innovation)CRC CI, 2004). The major effort in IT deliverables to date within the CRC CI has focused on the information and functions occurring at the end of the documentation phase when a comprehensive and detailed three dimensional product model is available. This has allowed the definition of the information requirements for a fully populated model.

This project has moved to the start of the building design process and is examining which information is available at the early design stage, how this information is generated and used and methods for supporting designers in their decision making and examination of alternatives.

Future projects will then examine the information requirements during the intermediate stages of building design.

7 FUTURE WORK

One of the overarching aims of the CRC CI is to change the way that the AEC-FM industry works. A suite of projects (CRC CI, 2004) are developing ICT deliverables - which will provide wide support for the design and construction process.

This project is unashamedly taking a pragmatic approach to supporting the design process. The focus is on what can be done now, to improve existing tools, to provide benefits to building designers in the very near future.

The longer term strategy is to use this first generation of deliverables as a test bed which will then be used as a basis for the next generation of design and construction support tools.

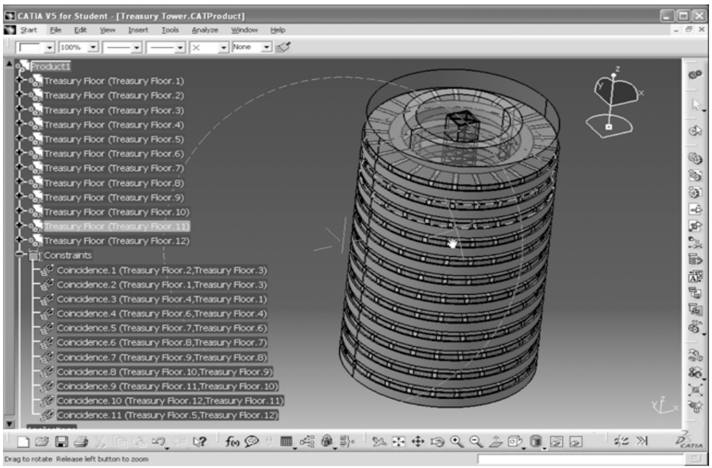

Figure 4: Structural Model in CATIA (RMIT)

As part of this strategy, more formalized methods of viewing information and providing decision support are being examined. One promising approach, which will be examined and tested over the next few months, is “perspectors” (Haymaker, 2003). It is expected that other methods will be tested subsequently.
One important capability that has not been addressed in this project is collaboration between designers within a discipline and between designers in separate disciplines. The need for collaboration gives rise to many other issues that will also be taken up in future projects.

8 ACKNOWLEDGEMENTS

This paper describes work undertaken in CRC for Construction Innovation project 2002-060-B, “Parametric Building Development during Early Design”. The authors acknowledge the contributions of Professor Mark Burry, Julian Canterbury and Alison Fairley of RMIT, Peter Bowtell of Arup Australia and David Marchant of Woods Bagot.

REFERENCES

CRC CI (Cooperative Research Centre for Construction Innovation), 2004, http://www.construction-innovation.info/ourprojects.php
Drogemuller, R. An ICT Platform for AEC, Proc. INCITE 2004, Bejaya Beach Resort, Malaysia
EPM Technology, 2004, www.jotne.com/epmtech/
Ferry, D.J. & Brandon, P.S., 2002, Cost Planning of Buildings
Gielingh, W.F., 1988, General AEC Reference Model, TNO Tech. Rep., P.O. Box 46 2600 AA, the Netherlands, BI-88-150, October
Haymaker J., Suter, B., Fischer, M., and Kunz, J., 2003, “The Perspective Approach: Enabling Engineers to Construct, and Integrate Geometric Views to Generate an Evolving, Integrated Project Model Working Paper Nr 081, CIFE, Stanford University
Parlour, R.P., 1990, Air Conditioning: Design at the Early Stage, Integral Publishing, Sydney
Parlour, R.P., 1994, Building Services: Egineering for Architects, Integral Publishing, Sydney
Schevers, H., Tolman F.P., 2001, "Modelling the first building life cycle stages", in Proceedings of the CIB W78 conference, White River, Mpulanga, South Africa
Stein, B., 1997, Building Technology: Mechanical & Electrical Systems, 2nd Edition, John Wiley & Sons
Stein, B. & Reynolds, J.S., 2000,Mechanical and Electrical Equipment for Buildings, 9th Edition, John Wiley & Sons
Tucker S.N., Ambrose M.D., Johnston D.R., Newton P.W., Seo S. and Jones D.G., 2003, LCADesign: An integrated approach to automatic eco-efficiency assessment of commercial buildings, Proc CIB W78, Auckland
van Leeuwen, J.P. and R.H.M. van Zutphen, 1994, Architectural Product Modelling - a Case Study. In: Proceedings of the CIB W78 Workshop, Helsinki, August 1994