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CRC Construction Innovation
BUILDING OUR FUTURE

Parametric Building Development during Early Design Stage

Research Report 2002-060-B

The research described in this report was carried out by :

Project Leader	Mr John Crawford	
Team Members	Mr David Marchant Mr Fergus Hohnen Mr Peter Bowtell Mr John Legge-Wilkinson	
Researchers	Ms Fanny Boulaire Prof. Mark Burry Mr Julian Canterbury Mr John Crawford Mr Robin Drogemuller Dr Alison Fairley Ms Loretta Kivlighon Mr John Mashford Ms Cheryl McNamara Dr Gerardo Trinidad	
Project Affiliate	Mr John Haymaker	(CIFE, Stanford)

Research Program B :Sustainable Built Assets

Project 2002-060-B

Parametric Building Development during Early Design Stage

March 2005

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Please direct all enquiries to:

Chief Executive Officer
Cooperative Research Centre for Construction Innovation
9th Floor, L Block, QUT, 2 George St
Brisbane Qld 4000
AUSTRALIA

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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 “Parametric Building Development during Early Design Stage” project in the **Sustainable Built Assets** core area is to investigate potential for the rapid evaluation of alternate architectural layout and structures at early design or massing stage, by assessing the ease with which leading architectural and engineering CAD systems can support parametric modelling. Note that “constraint-driven” design is an alternative term since parameters are not necessarily geometric, and the term *parametric* in this context refers to the relationships among and between all elements of the building model which will enable the coordination that we desire.

The project is a collaborative effort between **CSIRO** Manufacturing and Infrastructure Technology at Highett and the Spatial Information Architecture Laboratory of the School of Architecture and Design at **RMIT** University, together with the project’s industry partners: **Woods Bagot** and **Arup Australasia**.

Woods Bagot, which was founded in Adelaide in 1869, is an international design practice with offices in Adelaide, Bangkok, Brisbane, Canberra, Dubai, Hong Kong, Kuala Lumpur, London, Melbourne, Perth and Sydney. The company specialises in the design of facilities for health, education, transport, retail, residential, hospitality, sport and leisure, specialist and IT, defence and commercial clients in the private and public sectors.

Arup came to Australia in 1963 and today Arup Australasia is a multi-disciplinary practice offering services across Australia, New Zealand, South East Asia and the Pacific. Their core role as engineers to the buildings and infrastructure sectors is enhanced and complemented by a broad spectrum of consulting services. Arup undertakes projects of all types and sizes from feasibility reports and specialist studies to detailed design and large scale, high profile capital works programs with leading developers, architects and contractors and with clients in the public and private sectors.

EXECUTIVE SUMMARY

Objectives

The objectives of this project were two-fold:

- Assess the ease with which current architectural CAD systems supported the use of parametric descriptions in defining building shape, engineering system performance and cost at the early stages of building design;
- Assess the feasibility of implementing a software decision support system that allowed designers to trade-off the characteristics and configuration of various engineering systems to move towards a “global optimum” rather than considering each system in isolation and expecting humans to weigh up all of the costs and benefits.

The first stage of the project consisted of using four different CAD systems to define building shells (envelopes) with different usages. These models were then exported into a shared database using the IFC information exchange specifications.

The second stage involved the implementation of small computer programs that were able to estimate relevant system parameters based on performance requirements and the constraints imposed by the other systems. These are presented in a unified user interface that extracts the appropriate building shape parameters from the shared database

Note that the term *parametric* in this context refers to the relationships among and between all elements of the building model - not just geometric associations - which will enable the desired coordination.

Findings

This report shows that each of the four major design software systems considered has it’s own strengths and weaknesses as a vehicle for parametric development at the early design stage. Issues such as the cost of acquiring and maintaining the software; the availability or shortage of skilled design staff trained in the software; and the availability of libraries of suitable (non-proprietary) objects - that are able to embody and retain spatial intelligence and parametric associations - will all play a significant role in any decision to employ the particular design software solution. Additionally, the “naturalness” of manipulating parametric (constraint-driven) objects within the CAD environment affects the willingness of designers to use the system.

The research also highlights the viability of using commercial off-the-shelf (COTS) software (e.g. ArchiCAD, Architectural Desktop, Microstation and CATIA) together with custom developed software components, and that IFC data is a valuable source of information in the exchange of information between design systems – even at early design stage.

Parameters such as the occupancy type (residential, office/retail, carparking); floor-to-floor heights; for each occupancy type - the amount of floor space (and importantly *standard* of accommodation); the expected number of people per unit of floor space; the column and beam spacings; air conditioning and water supply requirements; number of lifts; etc. were all identified as key parameters, however it appears an overarching parameter that applies to all building services systems is the “quality” of occupancy or level of service that the building will provide.

Small computer programs were written that encapsulated particular areas of expertise:

- Architectural spatial layout.
- Structural system

- Hydraulics – water supply and fire protection
- Vertical transportation
- Air conditioning system
- Electrical supply
- Environmental impact
- Cost.

Future Directions

The results obtained in this report are potentially useful in the development of practical and effective tools for early design modelling. Such tools would retain the key design information which could then be exploited within 3D CAD models being used for detailed design and documentation later in a building project.

The work on ‘perspectors’ formed an important factor in the modelling work, and aspects of this more prescribed approach were instituted to formalise the description of the necessary inputs and outputs for the various building sub-systems being investigated. Should the opportunity arise to extend the work or if a development toolkit for this theme became available in future, then this would greatly assist in progressing the knowledge management research.

1. INTRODUCTION

1.1 Background

Building projects generally 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 (Computer Aided Design) systems. One of the aims of the project described in this Report was to investigate three major architecturally-oriented CAD systems, plus a CAD system aimed primarily at automotive and aeronautic mechanical design, for their support for the parametric description of building designs across multiple disciplines. A further objective was to develop methods of supporting multi-criteria decision-making for the various building design professions, and thus perhaps demonstrate the benefits of interoperability in providing shared information services.

1.2 Clarification

The term _parametric_ in this context refers to the relationships among and between all elements of the building model - not just geometric associations - that will enable the coordination that we desire. “Constraint-driven design” is an alternative term sometimes used in discussions and research - since the underlying parameters are not necessarily geometric, but relate to solutions that are constrained by relationships between and within the building sub-systems.

1.3 Business / Industry Imperative

Crucial to improvements in the *early design phase* are a range of architectural, structural and other building sub-system parameters that can characterise the building category and project type. Industry partners and the wider AEC business community need tools which will enable them to deliver better solutions within less time. Successful completion of this project will allow designers to assess a wider range of alternatives in architectural and structural design in a shorter time frame. This will assist in providing buildings that are better, cheaper, and more ‘environmentally-friendly’ through being able to retain the early design information, constraints and client requirements, and re-use it in the detailed design stage.

1.4 Time Slice

As with any study of software systems, new products and upgrades to existing products are being constantly released, and so an examination of ‘current systems’ such as CATIA, Microstation, ADT and ArchiCAD can only be judged from the attributes and abilities of those (mature) systems in the marketplace. Since the project was committed to examining those aforementioned systems, newer systems such as Autodesk’s Revit building modeller and Bentley’s recently announced release of Generative Components within their forthcoming Architecture and Structural products have not been examined herein.

1.5 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 in the examination of alternative design solutions. It is anticipated that future CRC-CI projects will then examine the information requirements during the intermediate stages of building design.

2. EARLY DESIGN AND MODELLING

2.1 What is Early Design ?

Early design may be considered as that stage of the design and construct process whereby the designers are working with a proposal for a selected site, but perhaps with only limited information apart from some key factors. Key factors were determined to be issues such as the proposed occupancy types (residential, office, commercial, or retail and car-parking) and the anticipated amounts of area or space required for each occupancy type; as well the extent, shape and orientation of the site.

The designer is looking to recommend the selection of key building system and to fill in an initial configuration to obtain better or more accurate information about the proposed building project without being obliged to undertake the work entailed in producing a detailed design and accompanying documentation at an very early stage.

The consensus of the industry representatives was that current modes of operation at early sketch design stage resulted in each of the architect; structural engineer; mechanical engineer; etc. tending to optimise within their own specialisation. However an overall optimisation or balance was believed critical. That is, not for a decision support system to specify the absolute "best" design, but a system that allows the architects and engineers to work in concert to achieve a balanced outcome. This in effect occurs now, but the project outcome aims at allowing faster and easier assessment of alternatives and the retention of design information which takes account of a number of factors – each of which may be given different weighting in different projects – resulting in different design outcomes.

The early design is usually undertaken by working with what are commonly known as "massing models" where blocks or prisms with little details other than size and shape are used to represent parts or the envelope of the proposed building.

2.2 Massing Models

As described in the automotive manufacturing field, "*a massing model is a highly simplified version of the model where you use rough forms as stand-ins for the finished ones. This simplified model should be very quick and easy to build, and enables you to experiment freely, scaling the major components up and down and shifting their relationships to each other.*"

In the construction arena, an explanation of a massing model is that of a dimensionally accurate summary of the fundamental exterior forms of a building. It is generally not hollow, but made of solid blocks. Conceptual mass models use basic solid shapes to verify the use of available space, whilst taking into consideration the client's requirements. Window openings in walls are generally not shown, and building detail is either left out entirely or summarised succinctly with a few relatively simple blocks.

2.3 Two and Three Dimensions

Buildings are objects perceived in three-dimensional space (3D) and time (4th D), and consequently most people (for example, clients) have some difficulty reading and understanding two-dimensional plans. Utilizing 3D computer modelling early in the design process allows for real communication between the client, contractor and the design team. The design evolves from the "fuzzy" to the more specific and the process is an iterative one, hence multiple design variations are created in the early phases of a project.

Many designers (for example, architects) use both physical and computer models as an integral part of the design process. Each model type has its advantages, but a computer model is a faster way of exploring multiple design scenarios. Computer models are also helpful because they are more abstract than physical models. For example, a digital model has no “real” scale and can be experienced from multiple vantage points without engaging the body in a physical way.

The computer modelling process should ideally begin at the earliest possible opportunity. Existing site conditions can be modelled while the program brief is being developed. This allows the design team to absorb the planning requirements and the existing conditions simultaneously. Any new design starts with the concept of the basic exterior shape of the building. At this stage a number of multiple massing scenarios are then developed as part of the design process.

2.4 Key Factors, Parameters and Issues

Round table discussions with industry partners were held at the preliminary research stage. In order not to focus too narrowly at the preliminary stage, many factors, parameters, and issues pertaining to low-rise residential design; through high-rise office; to specialist educational and hospital facilities were all discussed for their individual characteristics and merits, and a comprehensive list of factors was compiled for consideration. Grouped under the major headings of Site Constraints, Budget/Cost, Spatial Planning, Services Infrastructure, Structure, Construction/’buildability’, and Facade – although as became clear, with substantial interdependencies between and within the groups - the comprehensive list is documented as follows.

A – Site Constraints

- Planning envelope (or more realistically, a series of envelopes)
    - daylight / shading envelope
- Access to site – vehicle &/or pedestrian; traffic paths
- Plot ratio / land take – proportion of open space
- Geo-technical capacity to support structure
- Existing services – service connection points (where are they now, and where do they need to be ?)
    - ➢ power demands (perhaps extra substation required ?)
    - ➢ water ; sewer; gas demands
    - ➢ communications / data requirements
    - ➢ easements / tunnels / transport / space needs to be reserved for services

B – Budget / Cost

- Cost of land
- Net yield
- parking provision
- retail space provision
- local planning criteria (street frontage for retail ?)

C – Spatial Planning

- Departmental relationships – broad functional groups
- Spatial relationships / bubble diagrams …
- Adjacencies and not adjacencies
- Travel times within building
    - include loading for functional types (eg add 33% for nursing staff ?)
- Optimisation of function to space usage: trade-off of (little) usage of room vs. occupying key location space
- Floor-to-floor height
    - ➢ head-height vs. space for services between ceiling and floor above for ducts, structural, plumbing
    - ➢ future flexibility - head-height may be changed in future to facilitate rezoning (2.7m ± something)

D – Services Infrastructure

- Space planning requirements
    - ➢ power substations
    - ➢ duct and riser sizes
    - ➢ vertical transportation
    - ➢ waste disposal
    - ➢ reticulation; WC’s; amenities

- Residential usage mix
    - studio vs. 2BR apartments vs. larger family accommodation
- System selection
    - air-conditioned spaces vs. naturally ventilated ?
    - two plant rooms vs. single room ?
- Material selection
    - trade-offs
- Performance criteria
    - occupant comfort (eg 26 ºC vs. 21 º acceptable ?)
    - security (data centres; as well as physical occupant security; pedestrian stream separation – students vs. residents)
- Environmental rating tools (LCADesign; Green Star design; …)
    - facade
    - energy efficiency
        - power consumption
        - HVAC
        - lifts / transportation

E – Structure

- Foundation systems
    - based on site geo-technical information
    - simple pads; or bored piers; or steel / pre-cast concrete piles; …
- Structural system selection
    - framing solutions – ‘sway frame’ vs. ‘core & stick’ frame vs. … for hi-rise
    - material selection, based on …
    - cellular
- Elemental sizing
    - fire protection
    - span/depth ratio
    - strength
    - deflection

F – Construction / ‘buildability’

- Ease of access
- Occupational Health & Safety
- Availability – of labour/skills, and also materials (has cost implications)
- Project timing /schedules (eg timely materials delivery)
- Degree of modularisation / prefabrication (last three clearly linked, and have cost implications)

G – Façade

- Thermal performance
- Appearance
- System selection
- Cost
- Load capacity
- Day-lighting / glare
- Adjacencies / boundary conditions (fire ratings; neighbouring buildings; …)
- Maintenance requirements
- Building life-cycle alternatives / durability (15-25-40 year time horizon)
- Planning requirements
- Security

2.5 Sample Building Type

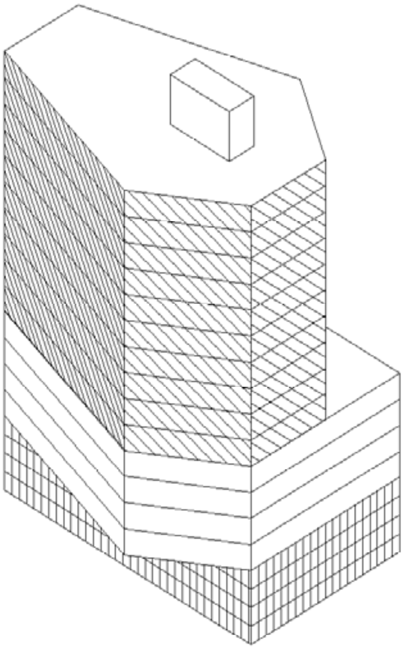
As mentioned above, in order not to think too narrowly at the preliminary stage, there was initial discussion between researchers and industry partners of a range of parameters and issues ranging from low-rise residential design; through high-rise office; to specialist facilities such as educational and hospital buildings where industry people could bring substantial experience to bear. It was concluded that maximum benefit would be achieved if the research project focused upon what may be considered a typical medium-rise, mixed-use (residential/office) building.

So, as a starting point we considered as an example a project of wide interest in Australia - a typical (new) multi-storey building of mixed-use - commonly built around the central business districts of major cities. At early design stage this project may be represented by considering a massing model of the whole building complex (as an envelope or series of prisms, see Figure 1) - given the expected usage / occupancy types and the area to be devoted to each usage (commercial, residential, car-parking) and the building core required for services. In other words, containing

- a **service core,** plus a mixture of
- several floors of **carparking**, plus
- several floors of **retail** or **office** space; plus
- a number of floors of **residential** space

Consider as an example, a building consisting of a number of storeys of offices with additional multiple storeys of residential space above the office space (depicted in Figure 1). The offices, residential space and the building core can be thought of as prisms and the building core prism can be automatically generated from the definition of the office and residential prisms.

Figure 1 : Envelope of Example Multi-storey Mixed-use Building



2.6 Given Simple Data – Design System ?

So the question remains, at the early design stage and given the anticipated building shape and expected usages, can the designer provide advice on the most appropriate options for the various building sub-systems ? For example in the structural field : for a multi-storey residential development can an early design analysis determine that for given criteria, a system of, say shear walls for the top section, should be recommended ?

2.7 Parametric Approach

This research aimed to investigate potential for the rapid evaluation of alternate architectural layout and structures at early design or massing stage, by assessing the ease with which leading architectural and engineering CAD systems can support parametric modelling. The term parametric in this context refers to the *relationships* among and between all elements of the model that will enable the coordination that we desire. These relationships are created either automatically by the software or deliberately by the user as the user works.

Some common examples of such *relationships* might be :

- The edge of a floor or roof is related to the exterior wall such that when the exterior wall is moved, the floor or roof remains connected. In this case the parameter is one of association or connection.
- The outside of a doorframe is a fixed distance, say 100 mm, on the hinge side from a partition at right-angles. If the partition is moved, the door retains this relationship to the partition. In this case the parameter is 100 mm.
- Windows are spaced equally across a given elevation. If the length of the elevation is changed, the relationship of equal spacing is maintained. In this case the parameter is a proportional characteristic, and not just a number.
- The scale of a plan view is changed from 10 mm = 1 m to 20 mm = 1 m. All annotations (text, dimensions, room labels, etc.) immediately “grow” in relation to the building to stay a fixed paper size. In this case, the text has a parameter fixing it to the scale of the drawing.
- Four walls in plan view are sketched to form a rectangle, and the design software automatically joins their ends. In elevation, the user selects a wall and drags it 2m. The other joined walls automatically stretch to stay connected. In this case the parameter is one of association or connection.

In mathematics and mechanical CAD the numbers or characteristics that define these kinds of relationships are called parameters, and hence the operation of the software is “parametric.” This concept is important because it is this capability that provides the fundamental coordination and productivity benefits of parametric software.

2.8 Summing Up

Beginning with a relatively simple rectangular-type building (see Figure 1), and with architecture and engineering knowledge of various “rules of thumb” already in use, the research team worked with parametric descriptions of building projects during the early sketch design stage to determine how a range of user requirements can be assessed from this simple outline. It has examined approaches for defining parametric models within the three major architecture, engineering and construction CAD systems (AutoCAD Architectural Desktop - ADT, ArchiCAD and Microstation Triforma) plus CATIA (a leading parametric modeller), and a popular category of mixed use commercial/residential multi-storey developments has been chosen for analysis and implementation.

Current projects within the CRC-CI (such as 2001-007-C Information Flows, and 2001-14-B Automated Code Checking) are using the Industry Foundation Classes (IFC) to define building elements during the “detailed documentation” stage of the building project and to check that the design meets requirements. It is an obvious extension of this work to start applying the IFC models to the early design process, as the IFC repository provides a catalogue of the building elements within the construction project.

3. PRODUCT MODELLING

Product and process modelling are fundamental to most Information Technology (IT) developments in the Architecture, Engineering and Construction (A/E/C) domains. Developments in this area underpin the creation and deployment of design tools for the industry, and for the interested reader some important concepts in product and process modelling are discussed in Stumpf et al. (1996), and Froese (1996).

Engineers and builders continually build models, which enable them to assess a situation or scenario, and to communicate their vision of a future state and the reasons for its desirability to others. Over the last few decades, significant progress has been made to model aspects of a building or structure with computer tools. Computer-interpretable models representing the product (building) and supporting a range of critical analyses and visualisations are now available.

3.1 STEP in the Construction Industry

The Standard for the Exchange of Product Model Data (STEP) is an international product data standard (ISO 10303) which provides a complete, unambiguous, computer-interpretable definition of the physical and functional characteristics of a product throughout its life cycle. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

Earlier and older data exchange standards such as IGES and DXF employed within the CAD industry are different from STEP since they focused on simple lines and geometric data only. The immediate advantage of STEP is its effective support for the exchange of solid modelling data, while the long-standing advantage is that STEP provides support for complete product life-cycle data exchange including design, manufacturing, application, maintenance and disposal. It is a much broader standard than (simply graphical) data interchange standards such as IGES since it is intended to support product data throughout the lifecycle of a product and to include engineering, manufacturing and support data. This aspect of STEP makes the standard suitable, not just for graphical IGES-style data exchanges, but also for implementing an integrated product information database that is accessible and usable to all the organizations and individuals involved in supporting a product over its lifetime.

Product data definition in STEP standards is written in the EXPRESS data definitions language. Thus STEP standards are computer interpretable. EXPRESS itself is a lexical object flavoured information modelling language and is defined in ISO 10303-11:1994.

3.2 EXPRESS Family of Modelling Language

EXPRESS was originally developed to provide a formal method of defining the data necessary to describe a product (i.e. a microchip or a high-rise building) throughout its lifecycle, from time of conception through its manufacture to its time of disposal. There are basically two aspects to EXPRESS:

- It provides for the modelling of data and data relationships with a very general and powerful inheritance mechanism, which is much more than is provided in Object-Oriented programming languages, and
- It includes a full procedural programming language that is used to specify constraints on data instances.

Express is actually a family of modelling languages. The EXPRESS Language Reference Manual also defines a graphical subset of the lexical language called EXPRESS-G. Note that EXPRESS-G is a subset of EXPRESS, as it does not include the constraint portions of the lexical language. The third member of the family is called EXPRESS-I and is a lexical language for the display of data instances and also for the formal definition of test cases. A fourth member of the family, called EXPRESS-X, is a mapping language for data translation between two EXPRESS models that are similar in semantic meaning but which differ in their data forms.

3.3 Establishment of IFC’s (Industry Foundation Classes)

With the increasing interest in building information modelling in the AEC (Architecture, Construction and Engineering) community, the issue of interoperability as a process to integrate the various model-based applications into a smooth and efficient workflow has emerged. An important standard for interoperability is the establishment of the "Industry Foundation Classes" or IFC’s - developed by the "International Alliance for Interoperability" (IAI, 2004).

The International Alliance for Interoperability (IAI) is a global consortium of commercial companies and research organizations founded in 1995 aimed at defining the requirements for software interoperability in the AEC/FM industry. The deliverables of the IAI are the specifications of Industry Foundation Classes (IFC TM) - an object oriented software library for application development. Many leading software suppliers are committed to releasing compliant systems, however the degree of compliance is quite variable between the design systems under investigation in this project.

The IFC system is a data representation standard and file format for defining architectural and constructional CAD graphic data as real-world objects. The IAI’s IFC system comprises a set of definitions of all the objects to be encountered in the building industry, and a text based structure for storing those definitions in a data file. A plain text file is used because that is the only truly universal computer data format. Then each producer of a CAD product can store their own data in whatever compact binary file format they wish to best suit their system. In addition they provide "Save As IFC" and "Read IFC" options, which map the IFC object definitions to the CAD system’s representations of those objects.

Whilst technical information about the IFC building model is documented in detail and is readily available for software developers who need to work with it [IAI (2003)], unfortunately there is practically very little information for the average AEC practitioner who wants to have a better understanding of the IFC model [Khemlani (2004)].

3.3.1 Historic view

While geometry-model based applications are still widely entrenched in the AEC industry, object-based data model exist within the current AEC software products. Graphisoft's ArchiCAD was developed more than 20 years ago based on an object-based building data model; so is the more recent Autodesk Revit.

There are also hybrid applications such as Bentley Architecture and Autodesk Architectural Desktop, which have a building data model built on top of the geometric data model of the original CAD applications - Microstation and AutoCAD respectively. All these are applications by commercial vendors and their internal data models are proprietary, which is why they cannot communicate their rich building information directly with each other unless specific translators for this purpose are developed.

The IFC is a similar object-based building data model that is, however, non-proprietary. The IFC model is intended to support interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle. It was specifically developed as a means to exchange model-based data between model-based applications in the Architecture, Engineering and Construction (AEC) and Facilities Management (FM) industries, and is now supported by most of the major CAD vendors as well as by many downstream analysis applications.

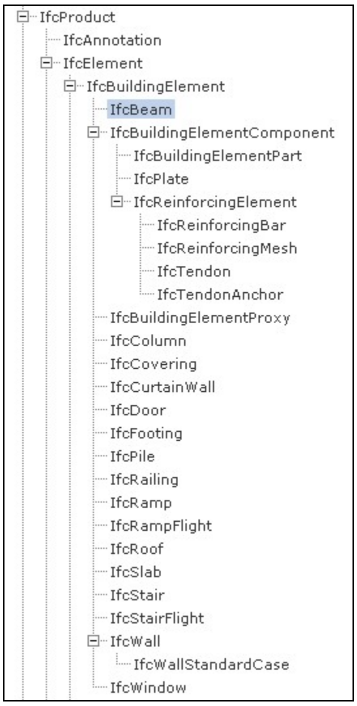
The IFC effort closely parallels another collaborative representation effort mentioned earlier - STEP (STandard for the Exchange of Product model data) - with many people involved in both the STEP and the IFC initiatives. The IFC model continues to be closely related to the STEP standard. It uses several resource definitions based on STEP and also uses the same modelling language, EXPRESS, for developing and defining the model.

3.3.2 Product modelling in IFC

A data model in any given domain describes the attributes of the entities in that domain as well as how these entities are related to each other. Since all computer programs deal with some kind of data, they must have some kind of underlying data model. Traditional 2D CAD and generic 3D modelling programs internally represent data using geometric entities such as points, lines, and rectangles (or boxes and plane is 3D). While these applications can accurately describe geometry in any domain, they cannot capture domain-specific information about entities. To overcome the limitations of general-purpose geometric representations, every design-related industry has been developing and using object-based data models that are specific to their domain. In the case of the building industry, this translates to a data model that is built around building entities and their relationships to one another. Geometry is only one of the properties, among others, of these building entities; thus, its primacy is greatly reduced, even though the interface to creating the model is still mainly graphical. Such a data model is rich in information about the building which can be extracted and used for various purposes, whether it be for documentation, visualization, or for analysis.

A simple example of the difference between a geometric data model and a building data model can be illustrated in the representation of a beam. Geometrically, a beam can be represented as a rectangular prism (a solid figure in which all six faces are rectangles). Unfortunately, most slabs, columns, footings and walls are also represented as rectangular prisms. This situation is one weakness of a geometric data model. The model is unable to represent domain specific concepts. On the other hand, a beam in the IFC data model is a much richer concept. A beam (IfcBeam) is a horizontal structural member. It represents a horizontal, or nearly horizontal, structural member designed to carry loads. A beam has a geometric representation (i.e. a rectangular prism) but it has also other properties such its material and its relation to other building elements or group of elements.

Figure 2 : Hierarchical relationships between a beam and other elements



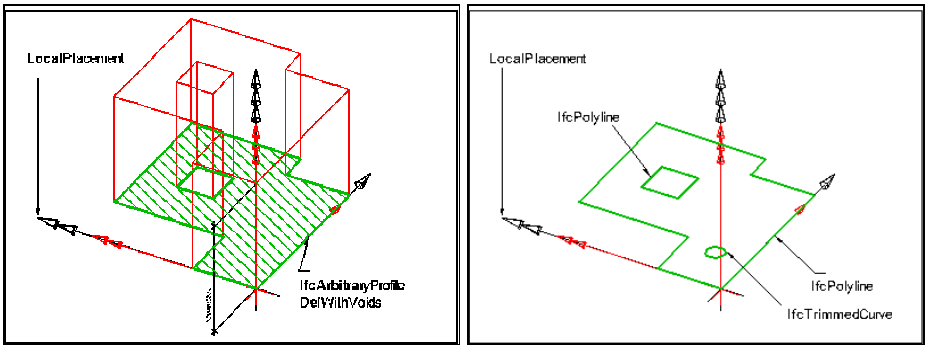
- IfcProduct
  - IfcAnnotation
  - IfcElement
    - IfcBuildingElement
      - IfcBeam
      - IfcBuildingElementComponent
        - IfcBuildingElementPart
        - IfcPlate
        - IfcReinforcingElement
          - IfcReinforcingBar
          - IfcReinforcingMesh
          - IfcTendon
          - IfcTendonAnchor
      - IfcBuildingElementProxy
      - IfcColumn
      - IfcCovering
      - IfcCurtainWall
      - IfcDoor
      - IfcFooting
      - IfcPile
      - IfcRailing
      - IfcRamp
      - IfcRampFlight
      - IfcRoof
      - IfcSlab
      - IfcStair
      - IfcStairFlight
      - IfcWall
        - IfcWallStandardCase
      - IfcWindow

A beam (IfcBeam) is a type of building element (IfcBuildingElement), which consists of all elements that are primarily part of the construction of a building (i.e. walls, beams, doors, or other physically existent and tangible things). A building element is a type of general element (IfcElement), which is defined as all components that make up an AEC product. Elements are physically existent objects, although they might be void elements, such as holes. Elements either remain permanently in the AEC product, or only temporarily, as formwork does. Elements can be either assembled on site or pre-manufactured and built on site. An element also includes a group of semantically and topologically related elements that form a higher-level part of the AEC product. An example of element assembly is stairs, composed of flights and landings. Figure 2 illustrates the hierarchical relationships between a beam and other elements.

3.3.3 Building occupancy as IfcSpace

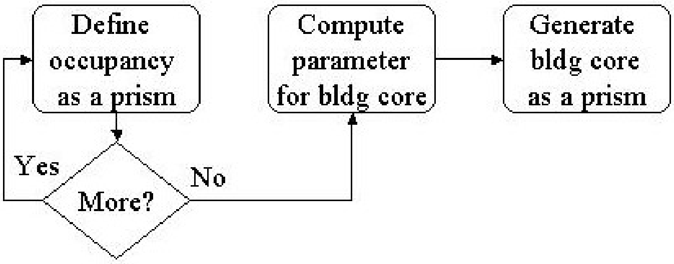
Here we briefly explain the notion of using an IFC object - IfcSpace - to define building occupancy. If a building occupancy type is modelled as an IfcSpace, then the footprint of the IfcSpace space corresponds to the floor plan (see Figure 3 below). The height of the IfcSpace corresponds to the number of storeys multiplied by the floor-to-floor height.

Figure 3: A 3D representation and footprint of IfcSpace



In some specialist computer languages such as GDL (Graphics Description Language) used by building design systems like ArchiCAD and AllPlan, an IfcSpace can be modelled as a “prism”. Consider the “prism” example building mentioned earlier, consisting of 10 storeys of offices with a further 20 storeys of residential space above the office space. The offices, residential space and the building core can be modelled as prisms in GDL, and the building core prism can be automatically generated from the definition of the office and residential prisms (see Figure 4).

Figure 4: Flowchart for generating building core from different occupancy type definitions



4. DESIGN MODELLING

4.1 Computer-Aided Design (CAD)

Fifteen or twenty years ago, when Computer-Aided Design (CAD) vendors set out to make computers useful for basic drafting tasks, geometry was the problem to solve. Simple CAD was a means to draft architectural plans more rapidly, and so concentrated on two dimensions and on the graphical aspects of plan production i.e. line thickness / weight; hatching patterns; correct symbols for electrical/mechanical features, etc. where some lines represented walls and others represented windows, doors, stairs, space boundaries, etc. Both industry and academia devoted countless hours of research and development to the problem of describing geometry digitally, in a way that it could be stored, presented and manipulated on a computer and plotter. The "geometry engines" resulting from these efforts were, and remain, the core technology in the majority of today's CAD packages.

Subsequently, the introduction of three-dimensional CAD has allowed the development of 3D models, however a 3D modeller on its own does not offer a significant advantage to the design process other than as a visual aid. Therefore neither does a CAD system that only produces 3D models.

Most recently, the most substantive progress has come from software developers in the design and construction area known by various terms such as “Virtual Building environment”; “Single Project Model”; “Building Information Modelling”; and “Virtual Product Modelling” by the vendors of alternate design systems such as ArchiCAD, Bentley, Autodesk, and CATIA, so the next generation of software provides building information modelling in place of building graphic modelling.

4.2 Integrated Digital Building Database

The key issue is not 2D representation versus 3D, but geometry-based working methods versus model-based working methods. 3D isn't the issue - the issue is the availability of an integrated digital database that fully describes the building, and whether that database can present itself in any of the conventionally appropriate ways for AEC practice. So, from CAD, to Object CAD, to parametric building modelling.

4.2.1 Building information modelling (BIM)

The massing models used in the early design stages can be considered as the foundation in the development of the building information model (BIM). BIM is a computer model database of building design information, which may also contain information about the building’s construction, management, operations and maintenance. From this central database, different views of the information can be generated automatically, views which correspond to traditional building design documents, like plans, sections, elevations, quantity take-offs, door and window schedules, 3D model views, renderings and animations. Because these resulting documents are derived from the same database, they are all coordinated and accurate. Any design changes made in the central model will be automatically reflected in the resultant drawings, ensuring a complete and consistent set of documentation. Unlike traditional 2D CAD systems in which the building design is represented in multiple drawing files made up of lines, arcs and circles, the BIM is a single database or fully integrated, fully associative building model that is constructed with intelligent “objects” which represent building elements like walls, slabs, roofs, doors and windows.

BIM provides a technology by which the building project team can improve the building design, documentation and construction process and provides a powerful digital framework for downstream facilities management, operations and maintenance. BIM enables the architect, the contractor and the building owner to simulate the performance of the building before it is built. This simulation may include energy use analysis, construction cost estimation, construction sequencing, building code compliance, and space utilization efficiency. This kind of analysis gives the architect unprecedented opportunity to improve the design based on the results received. The contractor can predict with greater reliability the cost and schedule of construction. For the building owner, the BIM provides the tools for understanding and managing the total cost of ownership of the completed facility.

4.3 Parametric Modelling

About ten years ago, a new type of core technology began to appear in the mechanical CAD (MCAD) discipline where it was realised that difficult geometry was a distinguishing feature of the industry. Software pacesetters began to invent a new core technology, the parametric change engine, to support the new requirements.

In the context of the AEC industry, a parametric change engine understands the types of relationships that exist in a building, and can preserve and manage those relationships as the user works. This parametric concept has allowed designers and not just draftspersons to benefit from increased productivity by working with systems that include some fundamental ‘intelligence’ about the size and relative location of objects in the plan as well as some (optional) information about each object (door, window, light-switch, …) plus associative and connectivity information such as linkages between objects or the adjacency of one object to another.

For example, a parametric wall understands its relationship to other building components. The wall might have a fixed height, or it might extend up to the next story, or it might be attached to the roof. This design intent is captured in the component. But a user may need to change the pitch of the roof above the wall. That change will modify the geometry of the wall – ideally without any explicit action required by the user. Similarly, parametric relationships mean that if a designer removes a wall from a design plan, then all windows and doors contained within that wall should also be removed from the plans (and any accompanying schedules); that a detail or section key cannot refer to the wrong drawing or sheet number; and that the width of a corridor is preserved as the depth of an adjoining office is altered.

4.3.1 Prism Building

As was mentioned earlier, for the purpose of early design an IfcSpace can be modelled as a “prism”. Consider as an example, a building consisting of 10 storeys of offices with a further 20 storeys of residential space above the office space. The offices, residential space and the building core can be thought of as prisms and the building core prism can be automatically generated from the definition of the office and residential prisms (see Figure 3 earlier). The height of the IfcSpace corresponds to the number of storeys multiplied by the floor-to-floor height.

Figure 5 : Simple prism massing model

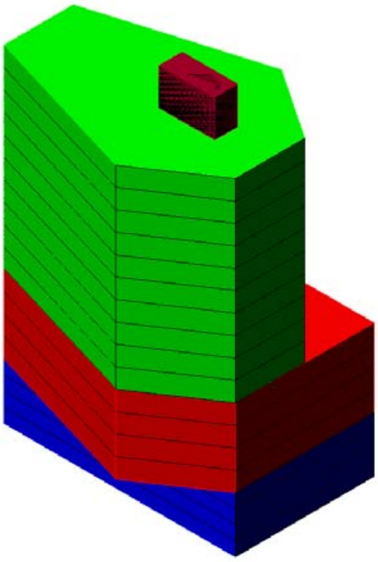
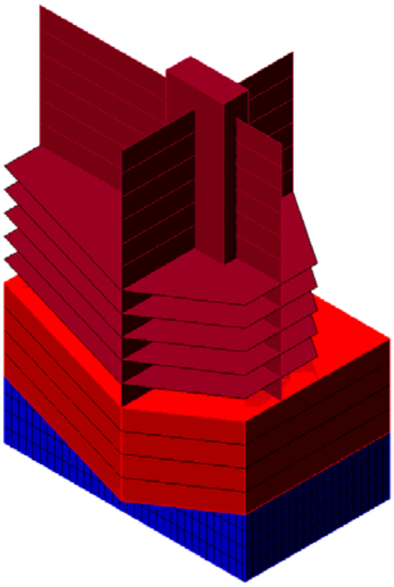


Figure 6 : Refined prism model



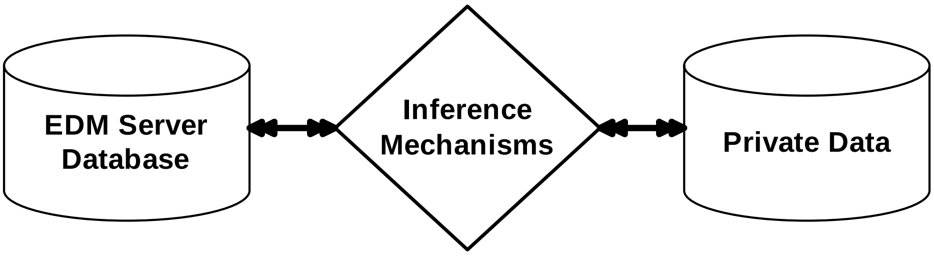
4.3.2 Process modelling in IFC

The IFC model represents not just physical building components such as walls, doors, beams, ceilings, furniture, etc., but also more abstract concepts such as adjacency, activities, spaces, organization, and costs. The IFC model contains entity definitions for concepts specific to individual domains. For instance, IFC2x2 - the latest release of the IFC (IAI, 2003) consists of nine domains, namely; Architecture, Building Controls, Construction Management, Electrical, Facility Management, HVAC (Heating, Ventilation and Air Conditioning), Plumbing and Fire Protection, Structural and Structural Analysis.

4.4 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.

Figure 7: Individual component software architecture



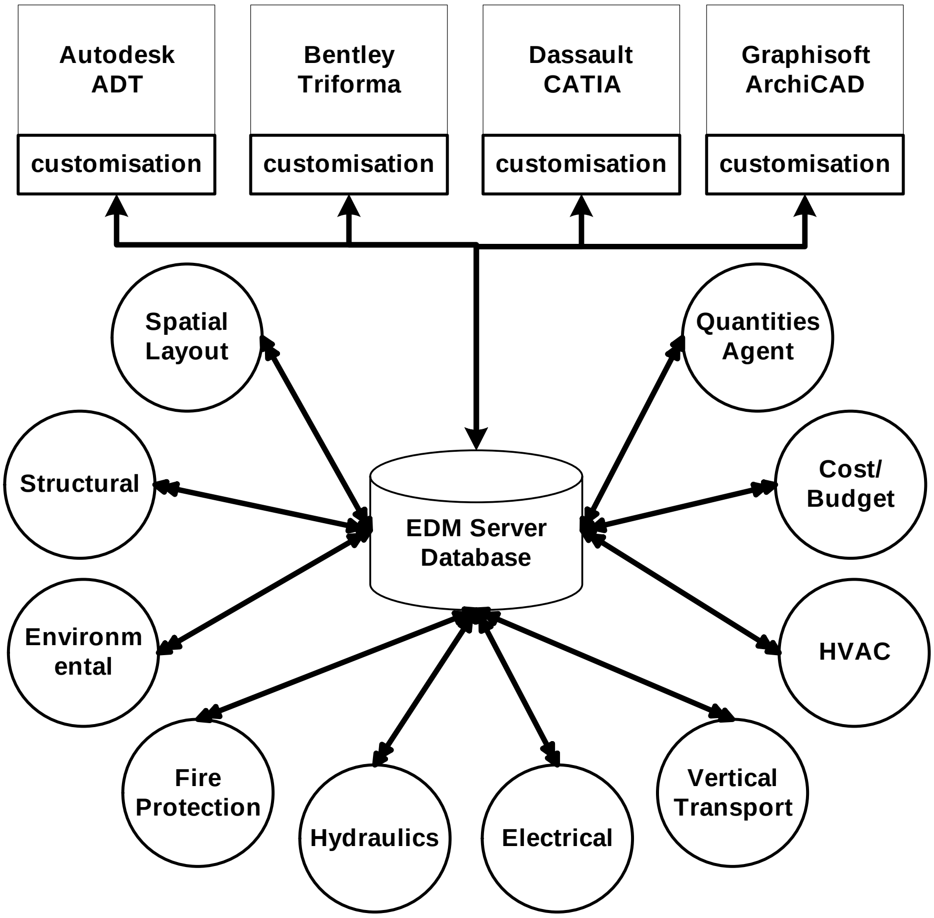
The EDM Server can store multiple projects by storing them in separate repositories. Within each repository there can also be multiple models. This provides a useful mechanism if there is a need to store different versions of the one project model for comparative analysis. Separate models are necessary 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.

4.5 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 that map the internal information on to the schema used in the shared database.

Figure 8: Overall system software architecture



4.6 Software Architecture

The overall system architecture (Figure 8) consists of three levels:

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

4.7 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, is 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.

4.8 Architectural Desktop (ADT)

ADT is architectural design software produced by Autodesk of the USA, and built on the established AutoCAD® software, Autodesk promotes Autodesk® Architectural Desktop as offering *"the productivity of automated documentation, the efficiency of intelligent architectural objects, and the flexibility of file-based collaboration. Autodesk Architectural Desktop is built on object CAD technology, adding intelligent architectural and engineering objects to the familiar AutoCAD platform. Since it is built on AutoCAD, it can also be used for design and documentation in a traditional drafting or CAD-based workflow unrelated to building information modelling.*

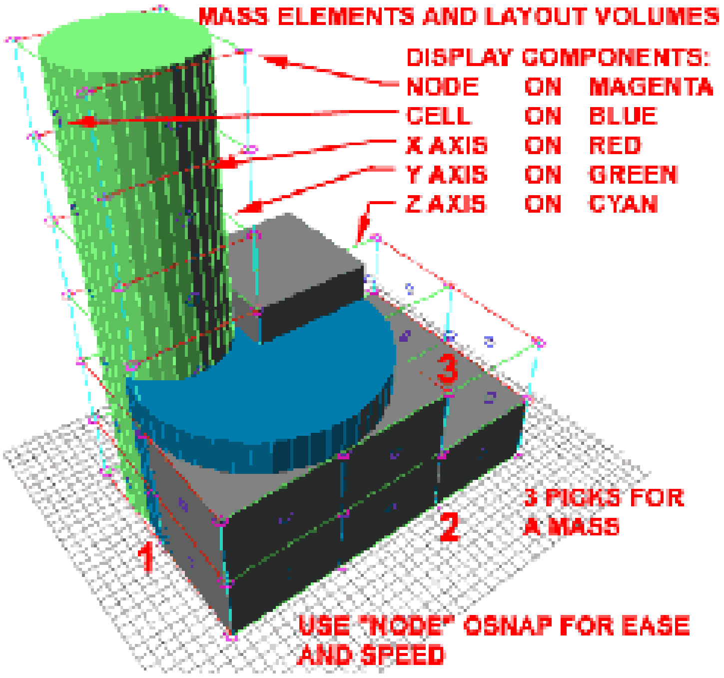
What are intelligent architectural objects? According to Autodesk, the (proprietary) ObjectARX® technology in Autodesk Architectural Desktop enables a user to create intelligent architectural objects that know their form, fit, and function and behave according to their real-world properties. *"This technology improves performance, ease of use, and flexibility. Intelligent architectural objects respond directly to standard AutoCAD editing commands in the same way that common AutoCAD drawing objects—such as lines, arcs, and circles—do, and yet they also have the ability to display according to context and to interact with other architectural objects."*

4.8.1 Massing models in Architectural Desktop

Massing modelling has been a unique feature of Architectural Desktop (ADT) since its inception. ADT uses 3D primitive shapes (called mass elements) to get the desired shapes. These elements can then be grouped (called mass group) to form larger elements, to conform to a specified volume for instance.

The primitives can be added, subtracted or you can just leave the intersecting part of the geometry. The software uses a tree-type structure (see Figure 9) so massing elements can be given hierarchy within groups. There are a number of primitives on offer to construct these studies - cones, boxes, arcs, columns, domes, gables, pyramids and triangles. It is also possible to create custom mass elements by defining a profile and either extruding it or revolving it.

Figure 9 : Example of a massing model in ADT



4.8.2 Massing models in Revit

As well as the more traditional system ADT, Autodesk now have an innovative new product called Revit® - a building modeller known for its ability to create a detailed building information model for the later phases of building design, development, and documentation. However, it can be used for the conceptual phase of building design to carry out 3D massing studies.

The massing module in Revit allows modelling a 3D building form. It automatically creates the building shell that corresponds with the mass, resulting to the external wall boundary of each level of the building. Once a massing model is developed, basic analysis can be performed and necessary modifications can be done to ensure that requirements are met. In this way the concepts developed during massing studies can actually help jump-start the detailed design process.

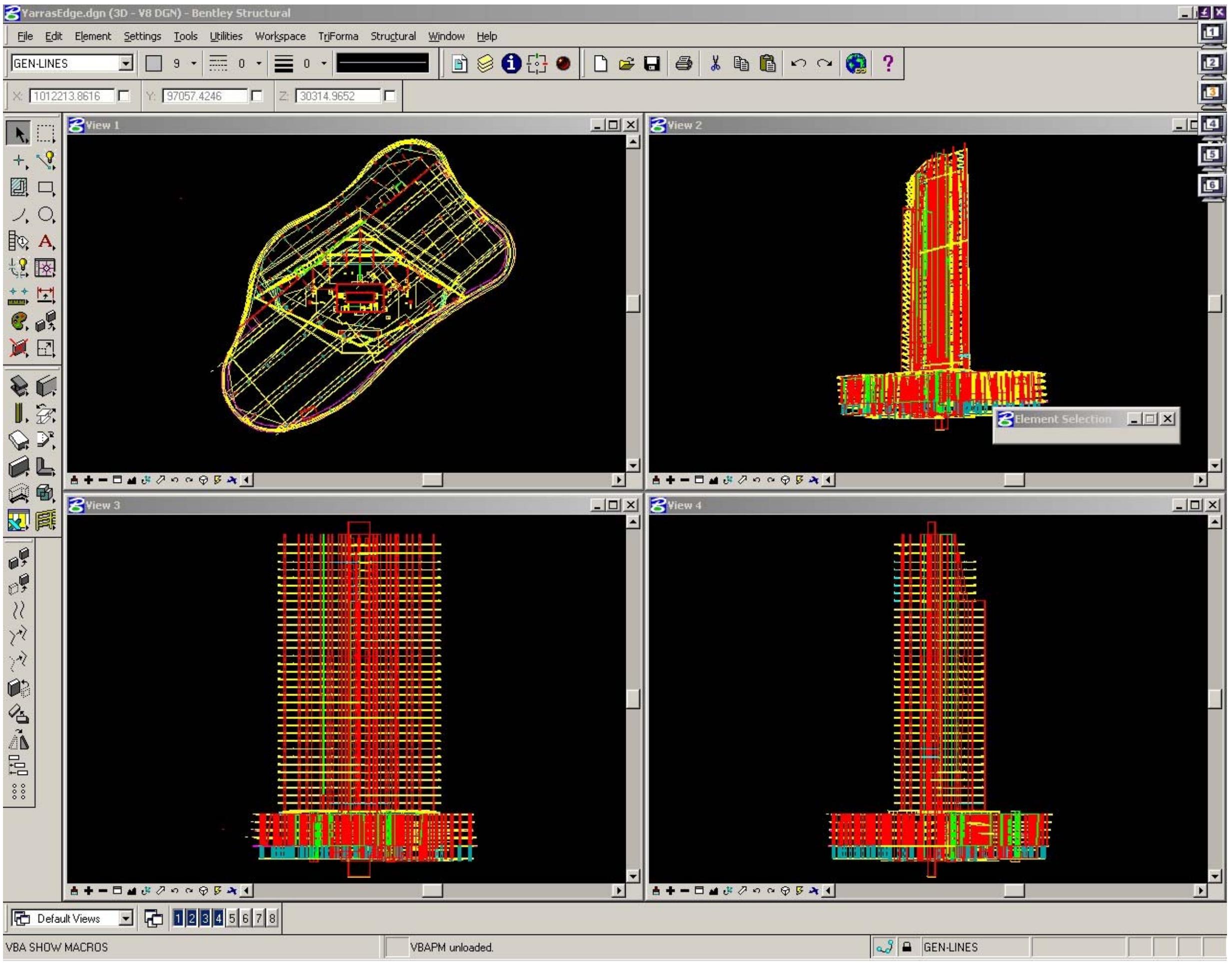
Unfortunately, since the project was committed to examining certain existing systems, newer systems such as Autodesk's Revit building modeller have not been examined in detail.

4.9 Microstation Triforma

Microstation Triforma is a specialist software suite specifically intended for architectural design, and produced and supported by Bentley Systems of the US through a dealer network around the world. The base Microstation software is widely used throughout the world, and the Triforma extension provides a further range of specialist tools tailored for architects to work with (see Figure 10).

According to Bentley Systems, *“Triforma’s design and documentation tools are based on the Single Project Model concept. Users design completely in 3D, and extract plans, sections, details or material take-offs without leaving Microstation TriForma. TriForma includes large libraries of “parametric” building parts, such as doors, windows, and structural components.”* Here, the “parametric” refers to geometrical parameters.

Figure 10 : Typical Microstation views of high-rise development



X: 1012213.8616 Y: 97057.4246 Z: 30314.9652

VBA SHOW MACROS

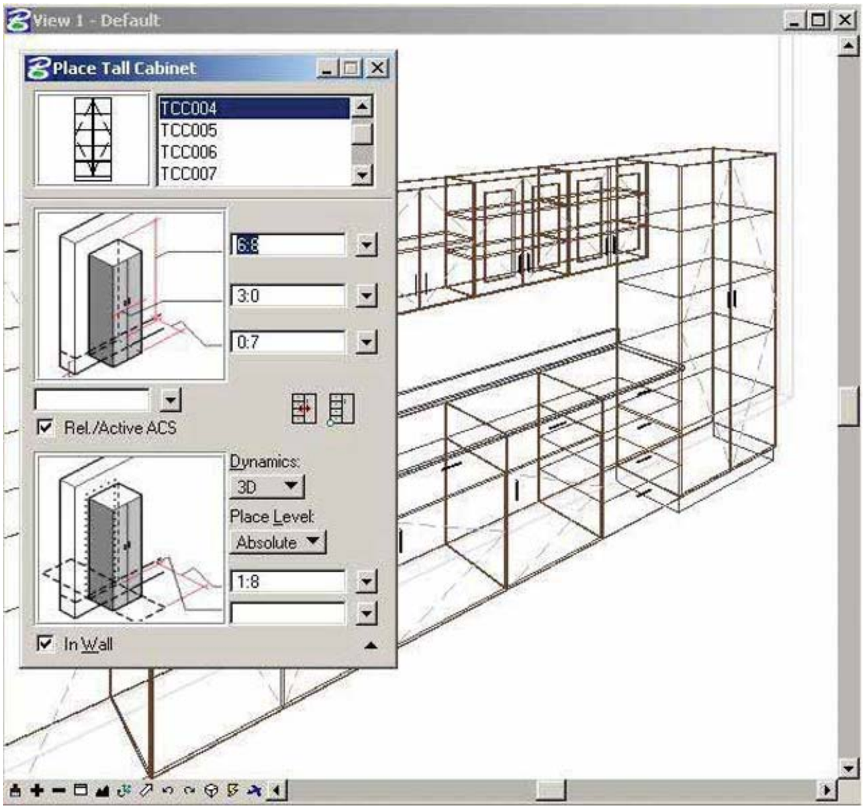
VBAPM unloaded.

4.9.1 Custom objects

In 2002, Dr Robert Aish (Bentley System’s Director of Research) gave a public demonstration of his work which he called 'Custom Objects' - for those interested in new ways to design, capture and document complex structures. By working with the companies that are pushing the geometric boundaries, Aish was developing new adaptive technology for Bentley, using a programmable parametric engine, which was to use Microstation V8 as its display engine.

To work through the concepts and demonstrate the technologies potential, Aish invited a group of leading architects, engineers, academics, researchers and software developers, from the studios of Foster, Gehry, Arup, Grimshaw, KPF and CERL, who had been working with Bentley to develop this new parametric and associative design tool and to explore practical uses. Aish stated that: "These ideas will be the foundation of future CAD systems."

Figure 11 : Example of custom object within Microstation Triforma



TCC004
TCC005
TCC006
TCC007

6:8
3:0
0:7

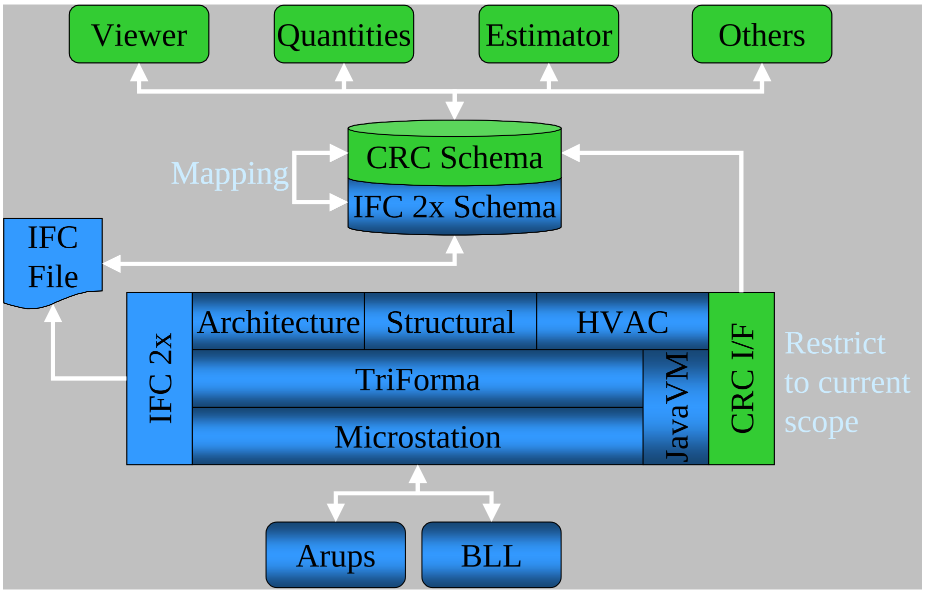
☑ Rel./Active ACS

Dynamics: 3D
Place Level: Absolute
1:8

☑ In Wall

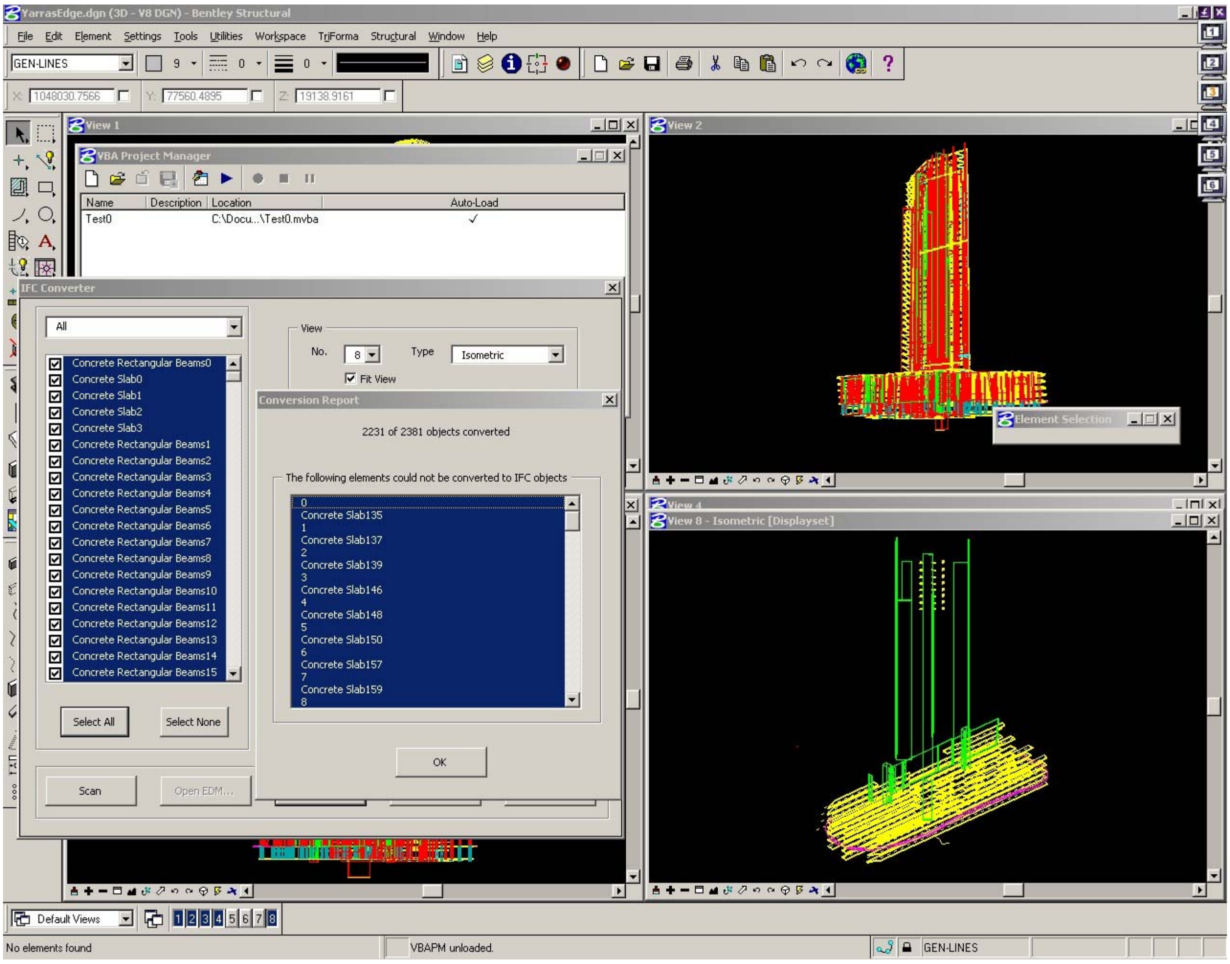
Since then, CMIT at CSIRO has undertaken a substantial amount of research and programming to allow the transfer of objects represented in Microstation's proprietary object customization language - known as MDL (Microstation Development Language) into the IFC structure for visualisation, interrogation and analysis within other design or analysis systems. This interface allows users to process a quite sophisticated model of a building developed within Microstation and held as a Microstation V8 design file (or .dgn), and to 'translate' many of the various Microstation custom objects into an equivalent representation within the IFC schema framework for use with various analysis systems (see Figure 12).

Figure 12 : Interface between Microstation and IFC Schema



In extensive tests performed on a variety of structural-related projects developed within Microstation, it was found that most of the Microstation custom objects representing beams, columns, slabs, etc. could be interpreted and ‘recognised’ by the software interface, and subsequently categorized and converted into an equivalent IFC object such as IfcBeam, IfcColumn, or IfcSlab (see Figure 13).

Figure 13 : Categorisation of Microstation objects with IFC objects


YarrasEdge.dgn (3D - V8 DGN) - Bentley Structural

X: 1048030.7566 Y: 77560.4895 Z: 19138.9161

VBA Project Manager

Name	Description	Location	Auto-Load
Test0		C:\Docu...\Test0.mvba	✓

IFC Converter

All

- ☑ Concrete Rectangular Beams0
- ☑ Concrete Slab0
- ☑ Concrete Slab1
- ☑ Concrete Slab2
- ☑ Concrete Slab3
- ☑ Concrete Rectangular Beams1
- ☑ Concrete Rectangular Beams2
- ☑ Concrete Rectangular Beams3
- ☑ Concrete Rectangular Beams4
- ☑ Concrete Rectangular Beams5
- ☑ Concrete Rectangular Beams6
- ☑ Concrete Rectangular Beams7
- ☑ Concrete Rectangular Beams8
- ☑ Concrete Rectangular Beams9
- ☑ Concrete Rectangular Beams10
- ☑ Concrete Rectangular Beams11
- ☑ Concrete Rectangular Beams12
- ☑ Concrete Rectangular Beams13
- ☑ Concrete Rectangular Beams14
- ☑ Concrete Rectangular Beams15

View: No. 8 Type Isometric ☑ Fit View

Conversion Report

2231 of 2381 objects converted

The following elements could not be converted to IFC objects

0
Concrete Slab135
1
Concrete Slab137
2
Concrete Slab139
3
Concrete Slab146
4
Concrete Slab148
5
Concrete Slab150
6
Concrete Slab157
7
Concrete Slab159
8

No elements found

VBAPM unloaded.

In the realm of Elements, slabs; beams; columns; walls; openings; grids; strip footings; raft slabs; pad footings; piles; piers; and pile caps were targeted as the elemental objects of most interest, while in the realm of Materials, the scope of research work was restricted to “In-situ concrete”, and “Steel”.

However, for the substantive structural projects analysed for this research, the successful categorisation rate between “native” Microstation .dgn objects and IFC objects varied from ~80% to ~97% (2,230 of ~2,300 objects), so for the structural modelling at least, this interface has provided a valuable tool for analysing proprietary Microstation .dgn building files within the neutral or non-proprietary IFC context.

As an aside, the Microstation proprietary objects that were not successfully classified and ‘translated’ by this first software interface typically were objects such as ‘tapering beams’, ramps, etc. which are recognised as difficult to categorise using just a knowledge of their location and their geometry.

4.9.2 Generative Components

In an innovative White Paper released in November 2004 by Bentley Systems, Aish (2004) describes the further development of intelligent objects within the Microstation environment - termed “Generative Components” - and how they may be used in a parametric and associative design system for architecture, building engineering and digital fabrication.

As noted elsewhere, the market for CAD/CAM/design/PLM software is extremely competitive and a rapidly evolving area where one product’s perceived edge can be matched and overcome by the release of new tools or improvements to existing competitors product(s). Unfortunately, the Generative Components implementation was not available to the project at the time of study, since it is not due for release until the forthcoming versions of ‘Architecture’, ‘Structural’, and ‘HVAC’ software during 2005 under the Bentley Microstation banner.

4.10 ArchiCAD

ArchiCAD is another specialist architectural software suite - originally produced by Graphisoft of Hungary, and now a leading worldwide architectural modelling design tool.

As promoted by Graphisoft, “*ArchiCAD® offers a different approach to your workflow process, which gives you more control over your design, while maintaining accuracy and efficiency in documentation. While you raise walls, lay floors, add doors and windows, build stairs and construct roofs this Building Information Authoring Tool creates a central database of 3D model data. From this you can extract all the information needed to completely describe your design - complete plans, sections and elevations, architectural and construction details, bills of material, window/door/finish schedules, renderings, animations and virtual reality scenes. That means while you're designing, ArchiCAD is creating all the project documentation so there's little repetitive and tedious drafting work. And unlike designing in 2D software, the Virtual Building™ approach also means that you can make changes at any time maintaining the integrity of your documents, without risking costly errors or costing you productivity.”*

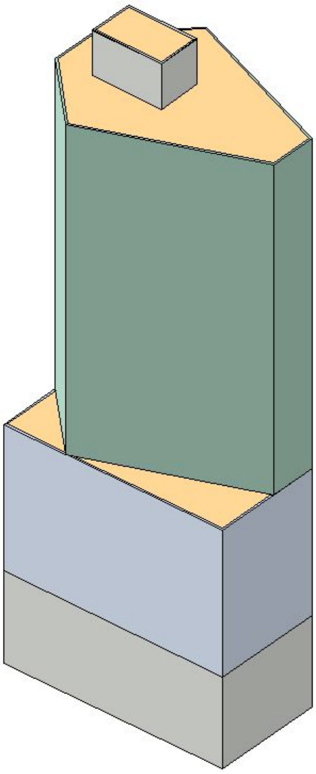
4.10.1 Massing models in ArchiCAD

Although quite comprehensive in its Virtual Building modelling support, ArchiCAD's suite does have some omissions, which are critical in early design. There are no dedicated tools for space planning, conceptual sketching, or quick 3D massing, which can allow building information developed at the early stage to be intelligently re-used in the subsequent design development phase.

A plug-in exists that can translate 3D conceptual design geometry developed in SketchUp – an intuitive, low-cost 3D design tool (SketchUp, 2004) - to the appropriate building objects in ArchiCAD.

Alternatively, slab and wall objects (see Figure 14) can be used to sketch the form of the building and the zone definition used to define various occupancy types (e.g. office space, residential, parking). Zone definition in ArchiCAD translates into IfcSpace definition in an IFC schema.

Figure 14 : Massing model, using 'wall', 'slab' and 'zone' objects in ArchiCAD



4.10.1.1 Programming language

Graphical Description Language (GDL) is a scriptable programming language - similar in many ways to the BASIC language. It can describe three-dimensional solid objects like doors, windows, furniture, structural elements, stairs, and also the 2D symbols which represent them on the floor plan. It is an open system that allows virtual objects to be defined and is used in a number of different Computer Aided Design (CAD) environments.

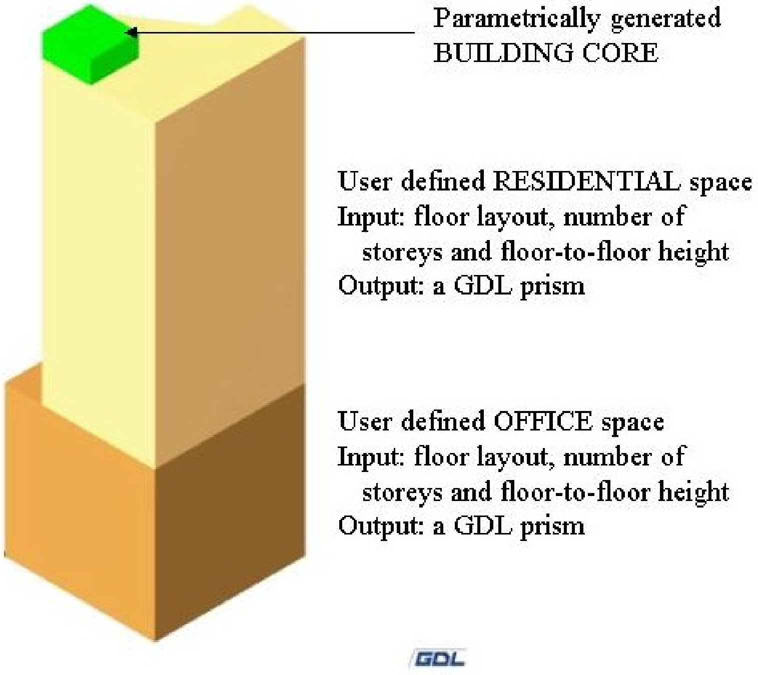
The parametric nature of GDL objects enables them to behave as if they are "smart", i.e. they can adapt to changing conditions, and the user can "easily customize" them through an interface to meet their needs. GDL uses "shapes", which are basic geometric units that can add up to form complex objects, so shapes are the construction blocks of GDL.

4.10.1.2 Massing models in GDL

As background, the reader is referred to the earlier description regarding the use of the IfcSpace concept to define building occupancy, However, in summary if a building occupancy type is modelled as an IfcSpace, then the footprint of the IfcSpace space corresponds to the floor plan. The height of the IfcSpace corresponds to the number of storeys multiplied by the floor-to-floor height.

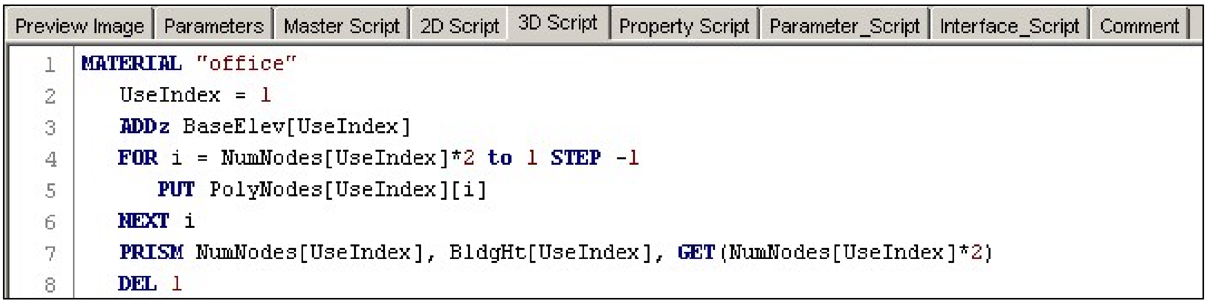
An IfcSpace can easily be modelled as a "prism" in GDL. Consider the earlier example building consisting of 10 storeys of offices with a further 20 storeys of residential space above the office space. The offices, residential space and the building core can be modelled as prisms in GDL, and the building core prism can be automatically generated from the definition of the office and residential prisms (see Figure 15).

Figure 15 : A parametrically generated building core in GDL



Although GDL documentation indicates that the user can “easily customize” GDL objects through an interface to meet their needs, the implementation of powerful parametrics within a GDL object if desired may however be quite daunting to non-programmers. A typical piece of GDL script for the prism model is reproduced below in Figure 16, and can also be seen in the right-hand panel of Figure 17.

Figure 16 : A fragment of a GDL script used in massing model generation



```
MATERIAL "office"
   UseIndex = 1
   ADDz BaseElev[UseIndex]
   FOR i = NumNodes[UseIndex]*2 to 1 STEP -1
      PUT PolyNodes[UseIndex][i]
   NEXT i
   PRISM NumNodes[UseIndex], BldgHt[UseIndex], GET(NumNodes[UseIndex]*2)
   DEL 1
```

4.10.2 GDL-based massing model in ArchiCAD

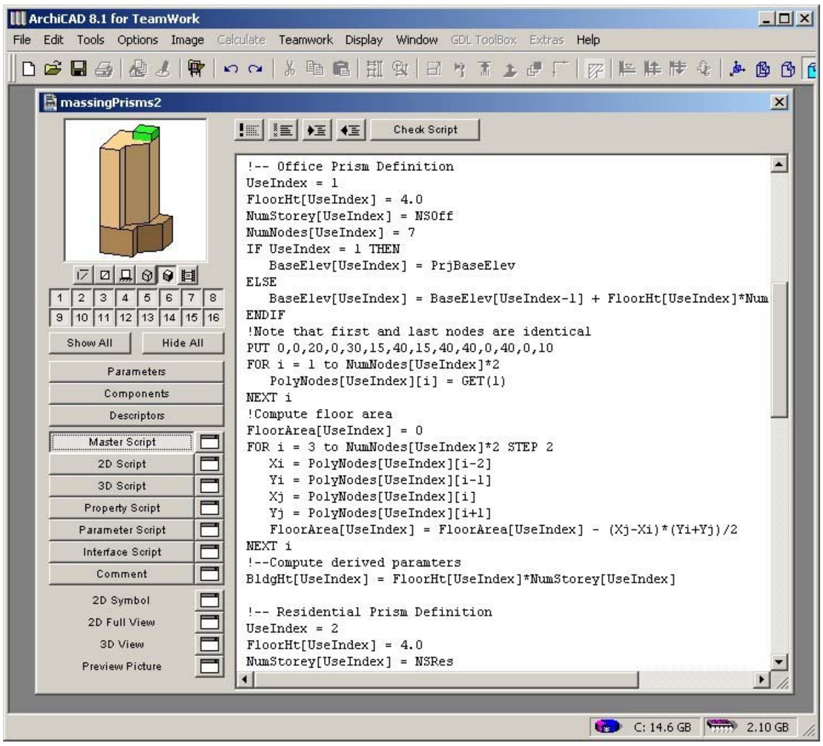
A GDL-based massing model in ArchiCAD is underpinned by the 3D-modelling facility in ArchiCAD. It is based on floating point arithmetic - meaning that there is (theoretically) no limit imposed on the geometric size of the model. Whatever size the model is, it retains the same accuracy down to the smallest details.

The 3D model is composed of geometric primitives constituting the following:

- Vertices of the building envelope
- Edges linking the vertices
- Surface polygons within the edges

The massing model is defined using a GDL script (see Figure 16 above), which defines parametric relationships between usage spaces such as residential and office space and building core. Parametric variables can then be modified to generate various permutations or variations in the massing model as shown in Figure 17. A 2D view of the massing model can also be generated (also shown in Figure 18).

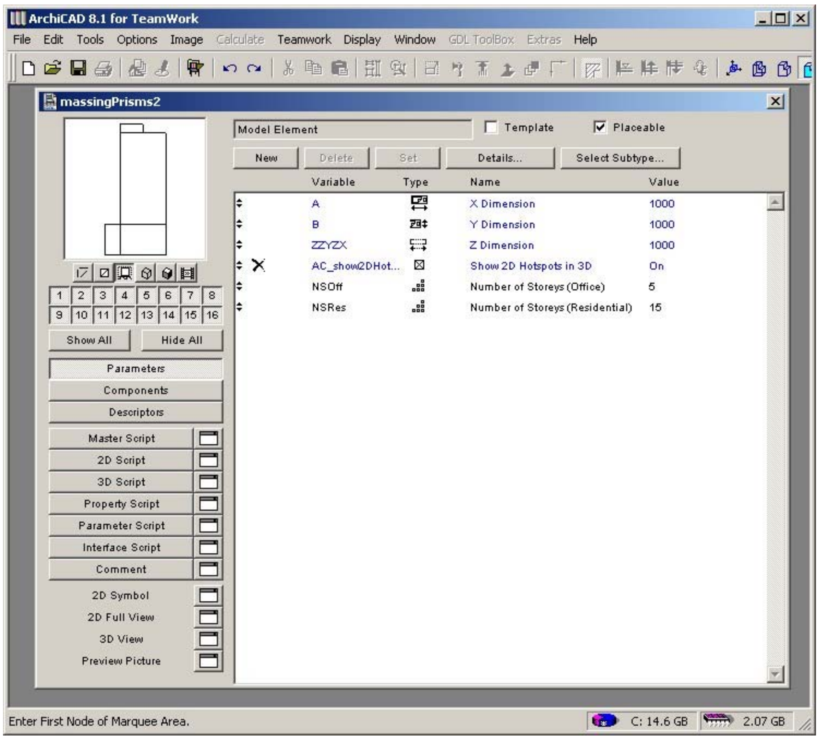
Figure 17 : Viewing and manipulating a GDL-based massing model in ArchiCAD



```
!-- Office Prism Definition
UseIndex = 1
FloorHt[UseIndex] = 4.0
NumStorey[UseIndex] = NSOff
NumNodes[UseIndex] = 7
IF UseIndex = 1 THEN
   BaseElev[UseIndex] = PrjBaseElev
ELSE
   BaseElev[UseIndex] = BaseElev[UseIndex-1] + FloorHt[UseIndex]*Num
ENDIF
!Note that first and last nodes are identical
PUT 0,0,20,0,30,15,40,15,40,40,0,40,0,10
FOR i = 1 to NumNodes[UseIndex]*2
   PolyNodes[UseIndex][i] = GET(1)
NEXT i
!Compute floor area
FloorArea[UseIndex] = 0
FOR i = 3 to NumNodes[UseIndex]*2 STEP 2
   Xi = PolyNodes[UseIndex][i-2]
   Yi = PolyNodes[UseIndex][i-1]
   Xj = PolyNodes[UseIndex][i]
   Yj = PolyNodes[UseIndex][i+1]
   FloorArea[UseIndex] = FloorArea[UseIndex] - (Xj-Xi)*(Yi+Yj)/2
NEXT i
!--Compute derived paramters
BldgHt[UseIndex] = FloorHt[UseIndex]*NumStorey[UseIndex]

!-- Residential Prism Definition
UseIndex = 2
FloorHt[UseIndex] = 4.0
NumStorey[UseIndex] = NSRes
```

Figure 18 : Setting parameters and a 2D view of a massing model



Model Element ☐ Template ☑ Placeable

Variable	Type	Name	Value
A		X Dimension	1000
B		Y Dimension	1000
ZZYZX		Z Dimension	1000
AC_show2DHot...	☒	Show 2D Hotspots in 3D	On
NSOff		Number of Storeys (Office)	5
NSRes		Number of Storeys (Residential)	15

Enter First Node of Marquee Area.

4.11 CATIA

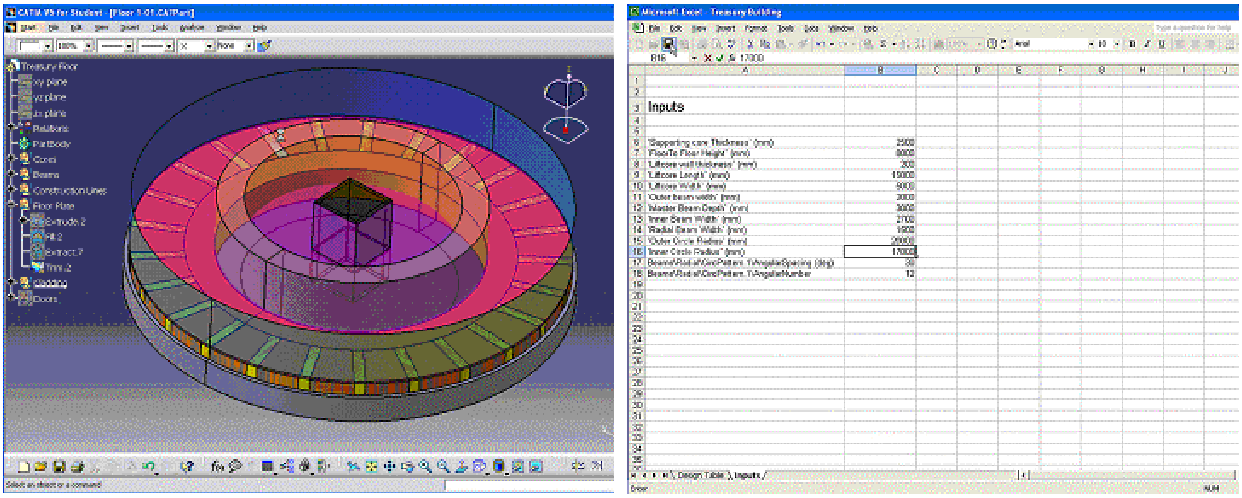
CATIA® is an acronym for Computer Aided Three-dimensional Interactive Application, and is a software suite widely used in the automotive, aeronautic and ship-building industries as a “Product Lifecycle Management (PLM) solution for digital product definition and simulation”. It is produced by Dassault Systèmes' of France who describe it thus : *“CATIA enables users to tailor product development according to their industry-specific requirements. With CATIA, users simulate the entire range of industrial design processes from marketing and initial concept to product design, analysis, assembly and maintenance. An industry standard today, CATIA has been Dassault Systèmes' flagship solution since the company's creation in 1981. In that year, Dassault Systèmes entered into a strategic partnership with IBM to distribute CATIA worldwide. In 1999, CATIA became the most popular product development system in the world through the market's wide adoption of the digital mockup process.”*

For this CRC-CI “Parametric Building Development during Early Design Stage” project, the investigations of CATIA’s potential as **an early design tool** focused upon the structural systems and individual structural elements of various mixed-use multi-storey developments. In particular, the research highlighted the use of geometric parameters to attempt to characterise such developments, and is summarised in this Report section, but for detailed background and a more comprehensive description of the Catia parametric work, interested readers are referred to a further separate document supplementing this project Report.

4.11.1 Circular tower model

To begin the investigative part of this project, a simple task of creating a parametric high rise building structure was undertaken. The left half of Figure 19 shows one floor of a circular tower modelled in Catia as a Part - Catia file types can be Model; Export; Assembly; Drawing; Part; or Product. Various geometric parameters such as beam thickness, number of radial beams, core diameter etc. can be either altered individually from within Catia directly, or in this case via an Microsoft Excel spreadsheet (see right half of Figure 19) or as it is known in Catia - a Design Table. Revisions to the model can be saved as data columns of numbers in an existing worksheet or by creating a new worksheet and the model can revert to previous settings by simply pasting these numbers back into the input sheet.

Figure 19 : Simple circular parametric structural model, and related input data spreadsheet



B16 = 17000

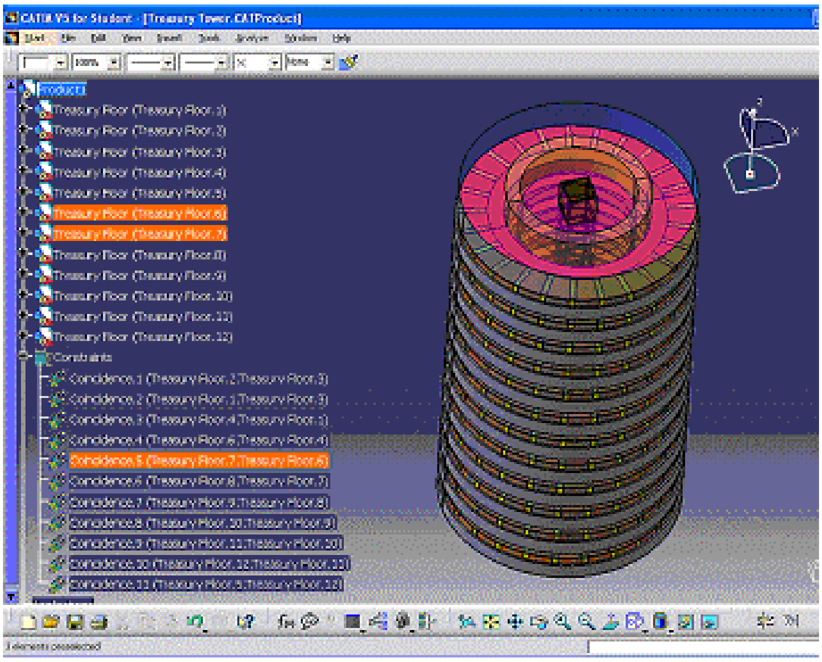
Inputs

'Supporting core Thickness' (mm)	2500
'FloorTo Floor Height' (mm)	8000
'Liftcore wall thickness' (mm)	200
'Liftcore Length' (mm)	15000
'Liftcore Width' (mm)	5000
'Outer beam width' (mm)	3000
'Master Beam Depth' (mm)	3000
'Inner Beam Width' (mm)	2700
'Radial Beam Width' (mm)	1500
'Outer Circle Radius' (mm)	20000
'Inner Circle Radius' (mm)	17000
Beams\RadialCircPattern.1\AngularSpacing (deg)	30
Beams\RadialCircPattern.1\AngularNumber	12

This can be also achieved directly from within Catia by creating configurations in the design table. Catia interacts with Excel, automatically adding a data column in the design table. Each data column can be recalled from Catia without the need to open Excel.

Figure 20 below shows a Catia product which *in this case* is an “assembly” of identical Catia parts but which would, in practice, generally be a combination of many different elements. Importantly, if a parameter of one part is changed, then each instantiation of that part within the product will automatically update. Parts can also be edited from within the product.

Figure 20 : Multi-storey model created as a Product - stack of identical Catia Parts



This model although quite powerful has obvious limitations. For instance it can only be a circular building with radial beams equally spaced. The lift core is placed centrally and cannot be moved - only re-sized. This type of model is suitable for a tower of predetermined “standard geometric form” (in this case a cylinder, see Figure 20 above) given that most of the floors will be identical with the ground floor and basement levels being the only ones which significantly differ.

The reality of the contemporary high-rise building however is often quite different. Using the example of a contemporary mixed use residential/commercial development such as may be seen at Docklands in Melbourne, it becomes apparent that the overall building shape and column layout may not follow any recognisable geometry, but rather the form may derive from a combination of a desire to optimise apartment views, and provide a good return on investment whilst accommodating the various programs. For instance, the ground floor retail structural grid may differ from the office floors above, which in turn is different to that of the upper residential floors. To represent this situation parametrically requires a far more flexible model than this one initially implemented as an assembly of identical Catia parts.

4.11.2 Rectangular to circular model

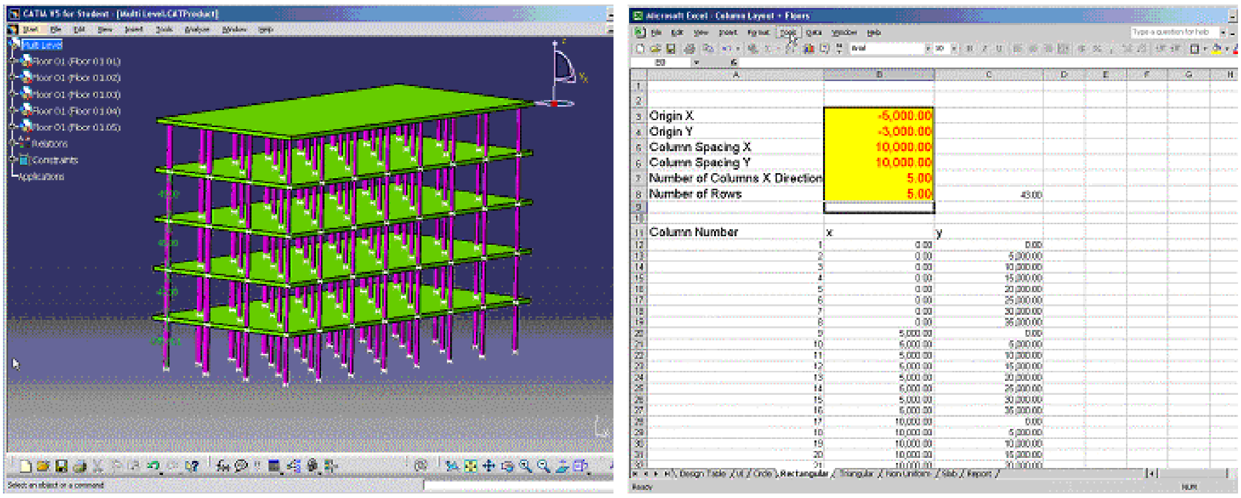
The model in Figure 21 is controlled from an Excel spreadsheet which is formula-based or programmatically-driven. The structural columns can be arranged in grids with varying numbers in either direction and the origin location can also be changed. For example, a column grid of 4 x 4 with a column-to-column spacing of 3 metres and origin of (0,0); or a grid of 4 x 8 with spacing of 4 metres and a different origin are possible.

The spreadsheet has also been coded so that columns can also be arranged in a circular formation (similar to example in Figure 20) simply by changing a value in the spreadsheet. This model - although more flexible - also has limitations and could not be used to describe the mixed retail / office / residential project referred to in previous paragraphs.

One major limitation identified with Catia as a program for early design stage modelling relates to the locating of points. For instance, the exact coordinates of a given point or its distance in relation to the end of a line must be known. In programs such as AutoCAD or Rhino, such points can be clicked and dragged, oriented or scaled in a graphical or more intuitive way. If one wishes to move a lot of points within Catia then the x, y and z coordinates of each point have to be entered individually. It is for this reason that the Excel spreadsheet or Catia Design Table becomes invaluable.

The problem of knowing the exact coordinates of these points or having a formula describing these points still however exists. With AutoCAD or Rhino or many other drawing packages, points can be more easily moved, re-oriented or arrayed without the user necessarily being aware of, or concerned by, their exact coordinates.

Figure 21 : Multi-storey model as a rectangular configuration, and related spreadsheet with data connected to all floors



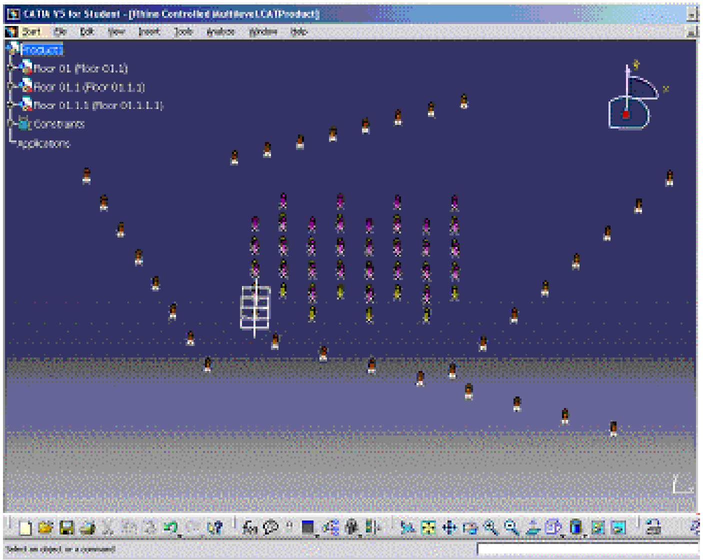
Origin X	-5,000.00
Origin Y	-3,000.00
Column Spacing X	10,000.00
Column Spacing Y	10,000.00
Number of Columns X Direction	5.00
Number of Rows	5.00

4.11.3 Modelling with Rhino and Catia (manual)

In a further improvement in usability, the desired model in Catia could again be manipulated via an Excel spreadsheet (Design Table), however this time the building coordinates are generated externally to Catia using the more intuitive software tool known as Rhino as a graphical interface. Rhino (http://www.rhino3d.com/) is an NURBS-based 3D modelling tool, and is best suited to preliminary design and design development (NURBS is an acronym for a geometric term Non-Uniform Rational B-Spline).

The 3D modelling effort in Rhino begins in conjunction with the development of the physical massing models. These building coordinates were output from the Rhino model as a CSV file (Comma Separated Variable) which is then imported into a Microsoft Excel spreadsheet - which in turn updates the Catia design software. Using this sequential method takes advantage of the strengths of all three programs.

Figure 22 : Rhino used to re-orient points/column locations, then displayed in Catia

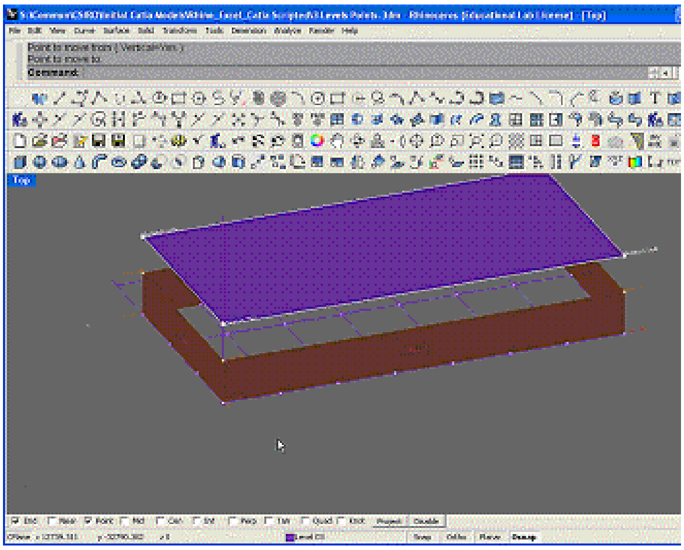


In a search for added modelling flexibility, members of the research team have used the Orient command in Rhino to more easily re-align and re-scale a series of points describing column positions for the Catia model (see Figure 22 above). This methodology indeed works successfully, however it is judged somewhat slow and tedious given the number of steps necessary to translate coordinates in Rhino to coordinates in Catia.

4.11.4 Scripted modelling with Rhino and Catia

The final sequence of research simplifies the previous (manual) process through the implementation of a Visual Basic (VB) script. This script automates the process of transferring the coordinates from Rhino to Catia via Excel, which previously was a very tedious and lengthy task. The VB script effectively means that Excel - although not eliminated - runs in the background, with the user unaware of it. Floor slabs and walls have also been introduced into this example to increase the complexity and further test the programs. It was found from the research following that this process is significantly streamlined by the introduction of the VB script. Figure 23 (below) shows the floor-to-floor height of the 3rd floor of a model building being increased (interactively) through the use of the graphically-oriented Rhino program.

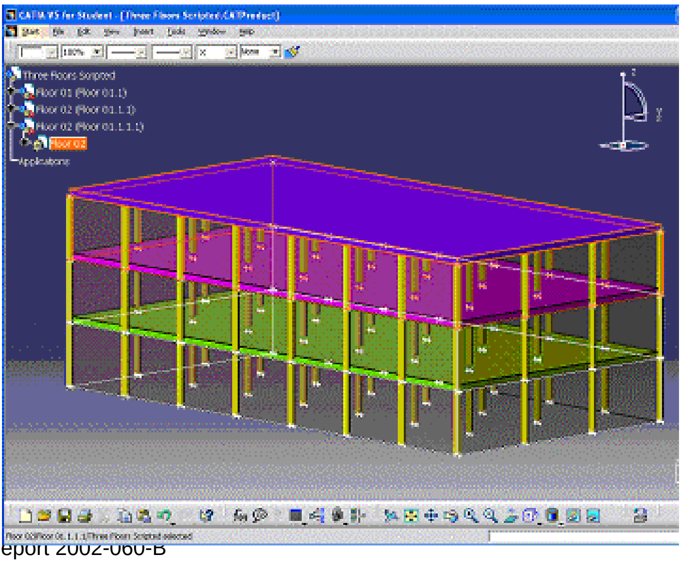
Figure 23 : Increase in floor-to-floor height, and slab and walls modelled in Rhino



```
Point to move from ( Vertical=Yes ):
Point to move to:
Command:
```

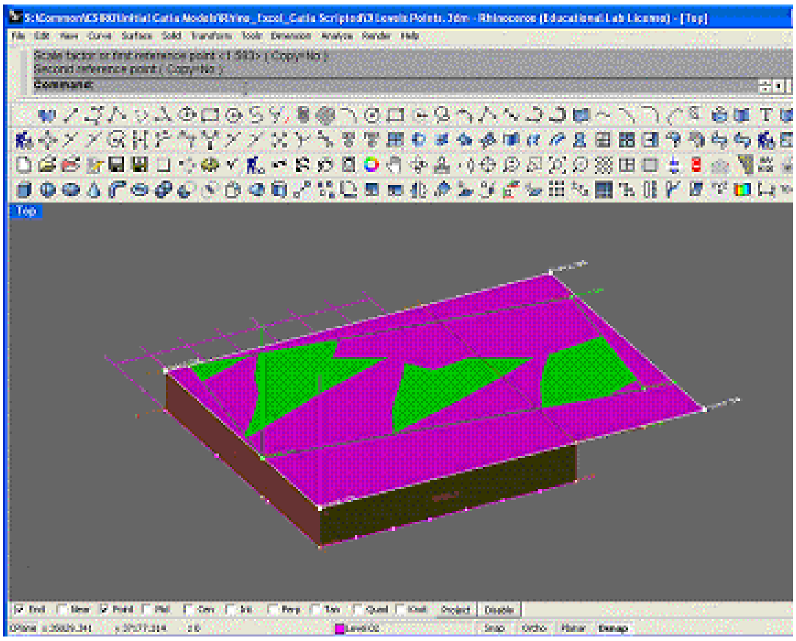
By passing the coordinates of the new positions of all slabs, columns, etc. from Rhino to Catia via a VB script, the 3rd floor of the model is updated within Catia. Note that the column heights are connected to the floor slab parametrically, so that each column on the 3rd floor will have an automatically adjusted height (see top level of Figure 27).

Figure 24 : Simple (initial) rectangular multi-storey model, displayed in Catia



In a further example focusing on the 2nd floor of the model, the walls, slab and column layout of (only) that level of the model were re-scaled in one direction. Again, these alterations were relatively easily achieved within Rhino (see Figure 25); the new positions were automatically passed via a script to Catia, and the model's modified 2nd floor was updated in Catia (see 2nd level of Figure 27).

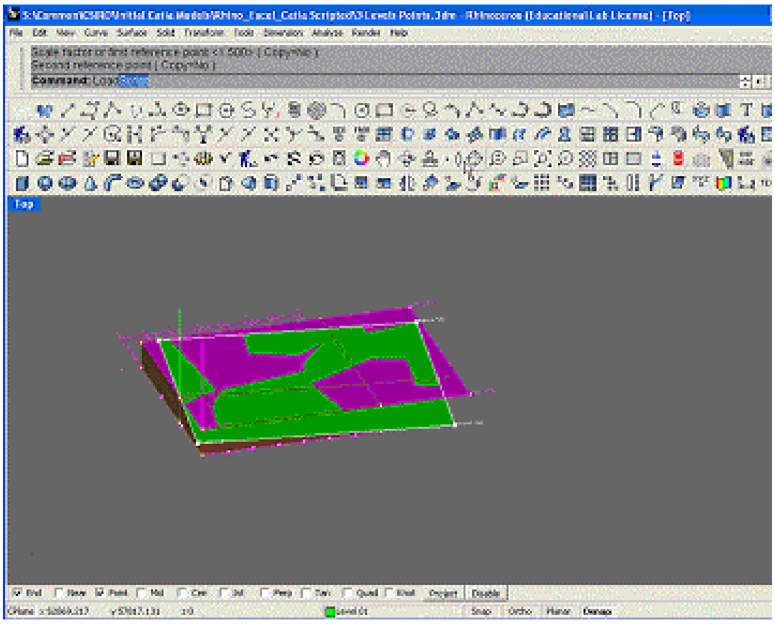
Figure 25 : Using Rhino to alter 2nd level layout of structural columns & re-orient floor layout



In the third variation researchers altered the floor-to-floor height of the Rhino model's 1st level on one side only, i.e. the level was reduced or re-scaled in one direction (see Figure 26). Thus the columns remained in the same positions, but the floor-to-floor height was reduced in places.

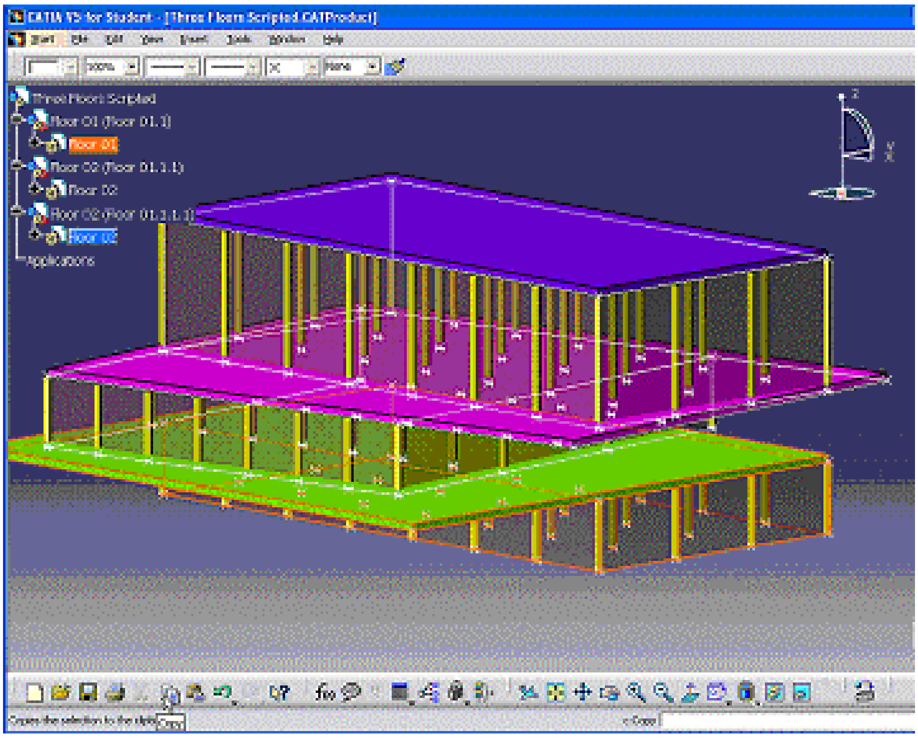
As with the previous model variations involving levels 2 and 3, the new slab edge positions were automatically passed by VB script to Catia, and the re-scaled or modified 1st floor elements were automatically updated in Catia (notice the bottom level of the Catia model in Figure 27).

Figure 26 : Using Rhino to re-scale (reduce on one side) the model's 1st level



Unlike the more rigid models of the Circular and Rectangular variety described earlier in this section on Catia (whereby the location of columns, beams, etc. were programmatically determined to a large extent), the nett effect of combining these *interactively derived* changes to levels 1, 2 and 3 of the Catia model produced a much more flexible - and hence practical - parametrically-driven structural model (see Figure 27).

Figure 27 : Catia display showing combined effects of the height increase in 3rd level; altered column layout & orientation of 2nd level; & re-scaled 1st level.



There is one additional scenario which should be considered, and that is the return path out of Catia and back into Rhino - for further (interactive) editing of the model. That work has not been completed within this project, and thus remains to be investigated.

Nevertheless, by combining the interactive manipulation ability of the Rhino software, the integration capacity of a Visual Basic script, and the display and visualisation capability of the Catia software, this most recent model representation comes much closer to what might be considered a truly flexible parametric *structural* model in Catia.

4.12 Major Impressions

The major architectural and building engineering CAD systems such as a) Autodesk’s Architectural Desktop (ADT), b) Bentley’s Microstation Triforma, c) Graphisoft’s ArchiCAD as well as d) Dassault’s CATIA were studied in some detail in the context of some simple early design stage sample buildings. The project team’s overall impression was that the first two systems - originally based on geometry engines - were somewhat less flexible in easily working with a full, integrated digital model required to support parametric modelling of a building design at the early stages.

The somewhat newer software approaches encapsulated within the specialist architectural design tool ArchiCAD and the mechanical product design tool CATIA were assessed as currently having more potential for *immediate* use in an early design stage parametric modelling exercise, but still these systems had drawbacks in terms of lack of suitable dedicated space planning tools, ease of use, and cost (particularly in the latter case).

Software	Strengths	Weaknesses
Microstation Triforma	Ability to document; reporting options; visualisation; ease of use; familiar user interface.	Proprietary objects; data interchange; proprietary scripting language.
Architectural Desktop	Market share; familiar user interface; speed; trained user-base;.	Proprietary objects; data interchange; support for scripting
ArchiCAD	Geometric flexibility; data interchange; open scripting language.	Proprietary objects; scripting tools.
CATIA	Geometric modelling abilities; management of spatial and large data-sets.	Proprietary objects; acquisition costs; customisation options; data interchange; scripting tools.

2005 is likely to see both the two major corporations Autodesk and Bentley with a even stronger commitment to “new-generation” building design embodied in products such as Autodesk Revit and Bentley Architecture/Structural (with generative components) and although these systems look quite promising, unfortunately neither they (nor Nemetschek’s AllPlan) were a part of this 2004 study. On the other hand, there is discussion of new tools and increased power for ArchiCAD, and a version of CATIA with lower entry level purchase price being released in the near future so - as is often the case with commercial software in the race to keep or increase market share - systems can leap-frog each other in providing new tools or improvements to existing systems.

3D design tools like Rhino and SketchUp seem to fill a niche that is not currently addressed within the mainstream CAD / building information systems – that of low-cost, graphically-intuitive modelling tools.

To support a true parametric modelling approach to early design, the ideal system would emerge as having the ease of use and speed of the more intuitive, 3rd-party low-cost 3D design tools, combined with the documenting, visualizing, and reporting abilities of Microstation, the trained user base, speed, and market presence of Autodesk, the power, spatial / geometric tools and data management abilities of CATIA, and the 3D modelling flexibility, support for neutral data formats, and price point of ArchiCAD.

5. STANFORD UNIVERSITY COLLABORATION

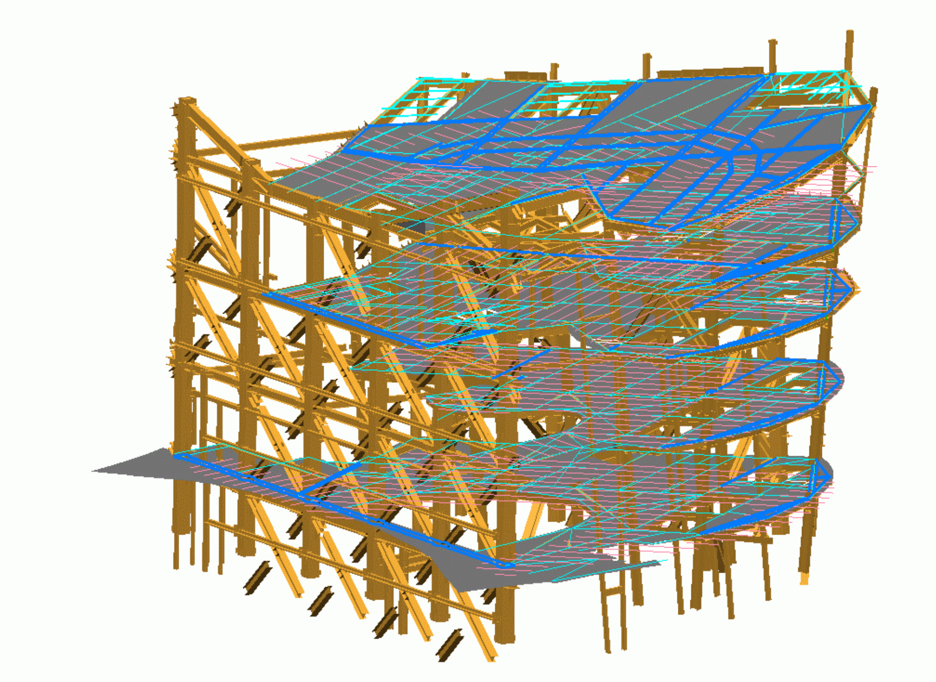
Dr. John Haymaker is a researcher and academic based at the Centre for Integrated Facilities Engineering (CIFE) (http://www.stanford.edu/group/CIFE/) at Leland Stanford Junior University (Stanford), and he visited Australia in July 2004 as part of the research collaboration between the CRC-CI and CIFE under the ICALL agreement.

Discussions between several members of the software development team for 2002-060-B “Parametric Building Development ..” and Dr Haymaker during his Melbourne visit resulted in a more thorough approach and an increased understanding of the possibilities for the representation of the building sub-systems by the software developers.

5.1 Perspectors

The key discussions centred on a set of concepts known as “perspectors”, (see http://www.stanford.edu/group/4D/perspectors/) which Dr Haymaker worked on for his Ph.D. thesis in the context of the Disney Concert Hall (see Figure 28) in Los Angeles - within US architect Frank Gehry’s design office.

Figure 28 : Disney Concert Hall steelwork & concrete



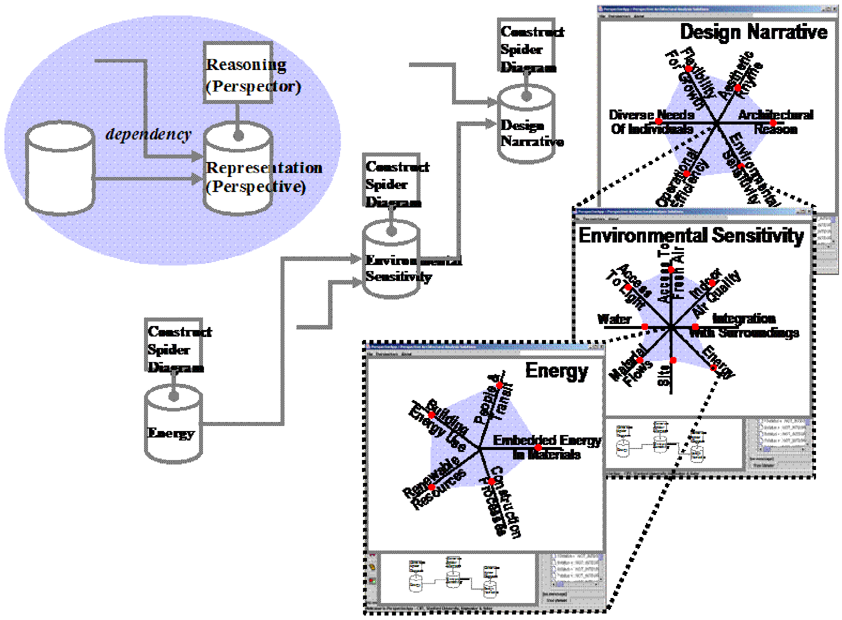
(Courtesy: Dr J Haymaker, CIFE)

Perspectors are a means of encapsulating design and construction knowledge so that automated processes can work on aspects of a shared building design model. A Perspector is defined by the operation(s) itself, the information that is necessary for it to run, the information it generates, its current state (valid or invalid) and which other Perspectors it relies upon [Haymaker *et.al.*, 2003a, b, c]. Perspectors form a network that indicates the information dependencies between Perspectors (Figure 29).

A Perspector can also contain sub-Perspectors, giving a hierarchy within the network. Dr Haymaker has also used Perspectors for environmental analyses (see Figure 29).

Prior to John’s visit, Robin Drogemuller - one of the research team members - attended a “Future Virtual Environments” workshop at Stanford University. Subsequently, both CIFE and Dr Haymaker were keen to establish collaboration with the CRC-CI due to the wide range of advanced but industry relevant research projects working off a consistent, shared ICT (information and communication technology) platform.

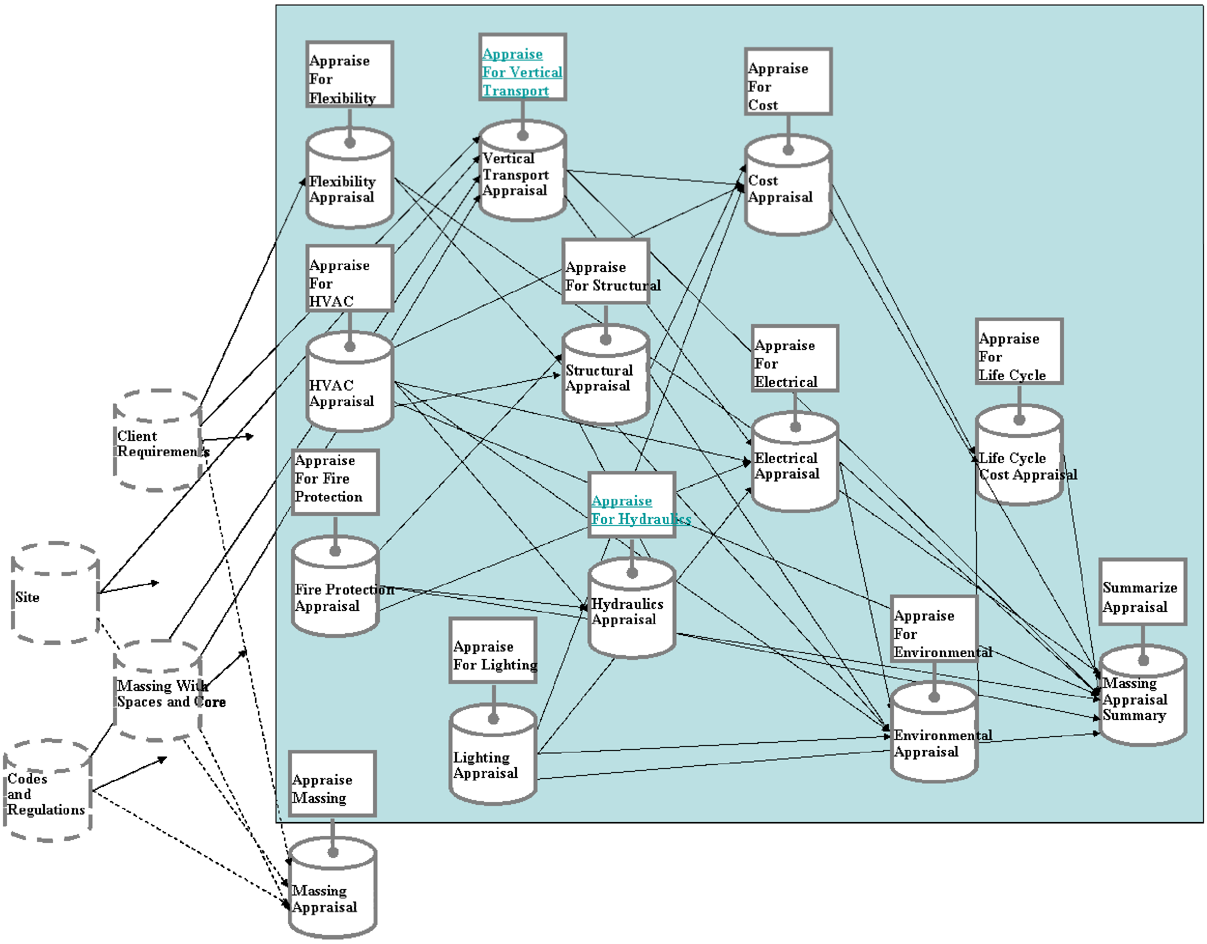
Figure 29 : Perspectors in environmental design



(Courtesy: Dr J Haymaker, CIFE)

Aspects of this more prescribed approach were instituted (see Figure 30 below) to formalise the description of the necessary inputs and outputs for the various building sub-systems (documented later, in Chapter 6) being investigated for the parametric modelling project.

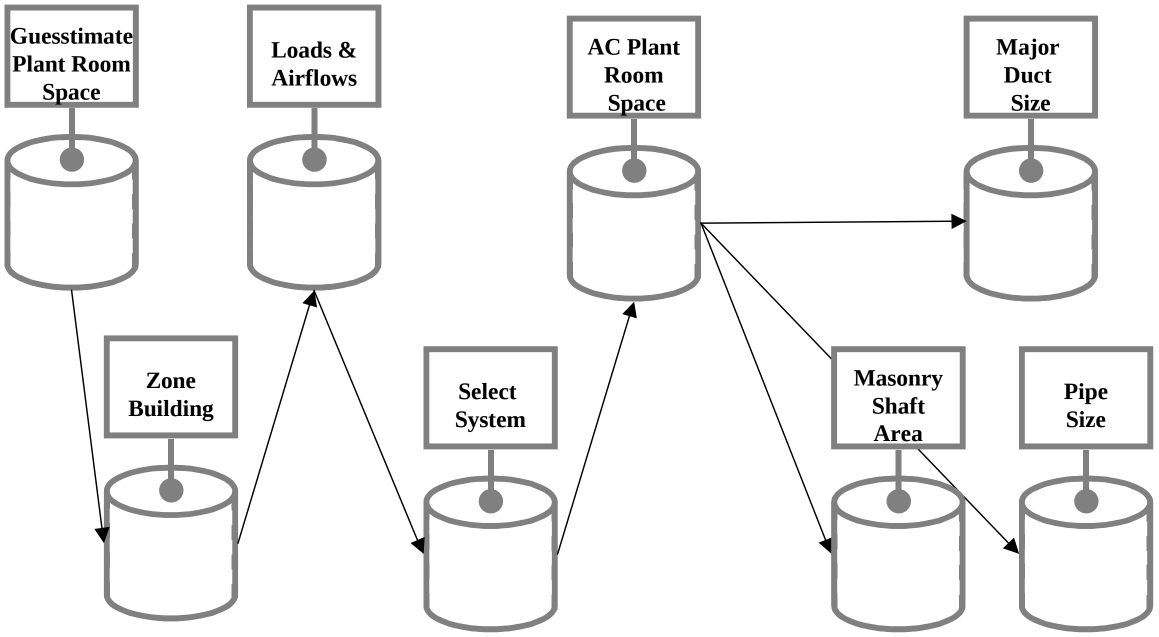
Figure 30 : (Top level) Perspectors for building sub-systems



Members of the 2002-060-B team have used the Perspectors *methodology* during software design to structure the input and output data, but have not used the Perspector software architecture itself, due to time constraints. If this current 2002-060-B Parametric Building Development project is extended then it could certainly form the basis of a collaboration that would refine the ideas on Perspectors across multiple systems and could form the basis for an advanced implementation of Perspectors in software. This is not substantially different to the methods being used in existing CRC CI projects, but it does have some refinements.

For instance, the logical flows and some of the parameters involved in an understanding of the requirements for air conditioning are shown below in Figure 31 in the Perspector representation style.

Figure 31 : Logic flows for planning Air Conditioning



There may be the opportunity to generalize the work on Perspectors into a tool that can be applied by non-programmers. This would be a most significant project, however any intellectual property issues would also need to be resolved.

6. BUILDING SUB-SYSTEMS ANALYSIS

Even at the early stages of design with which we were concerned, each of the building systems is interdependent upon the others. The project team was not able to identify any one view that could be modelled independently of the others, and 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.

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

6.1 Which Sub-Systems ?

Within the scope of the 2002-060-B 'Parametric Building Development at Early Design Stage' project, major systems for investigation included architectural, structural, electrical, mechanical, hydraulic, cost, environmental factors, and in particular :

- Architectural spatial layout
- Structural
- Fire protection
- Water supply
- Electrical (power, lighting)
- Environmental (LCA)
- Mechanical (vertical transport, HVAC)

Since a major objective of the 2002-060-B 'Parametric Building' project was to develop methods of supporting multi-criteria decision-making for the various building design professions, software interfaces for most of these key building sub-systems have been implemented. The input parameters, underlying assumptions, and user interfaces are explained and documented in the following pages, while the avid reader is also referred to Appendix1, wherein more detail of many of the building sub-systems are documented with their input parameters and requirements and further output.

6.2 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 can be 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

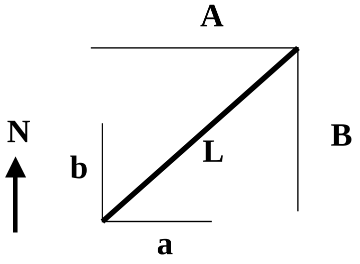
Not all of this information is currently used but it was considered important to maintain continuity of information from the briefing stage through this very early design stage.

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.

$L = a + b$ $L^2 = A^2 + B^2$ $A/B = a/b$ $a = L \times (A/(A+B))$ ← south perimeter $b = L \times (B/(A+B))$ ← east perimeter

Zones	North	East	South	West	Central	
Actual Area	0.000			112.000	635.000	sqm
External Perimeter	40.000	25.800	37.200	30.000		m
Shading Factor	1.000	0.000	0.000	0.000		
Corner Factor	2.000	1.000	2.000	1.000		
Effective Perimeter	0.000	23.800	33.200	28.000		m
Approximate Area	0.000	95.200	132.800	112.000	635.000	sqm

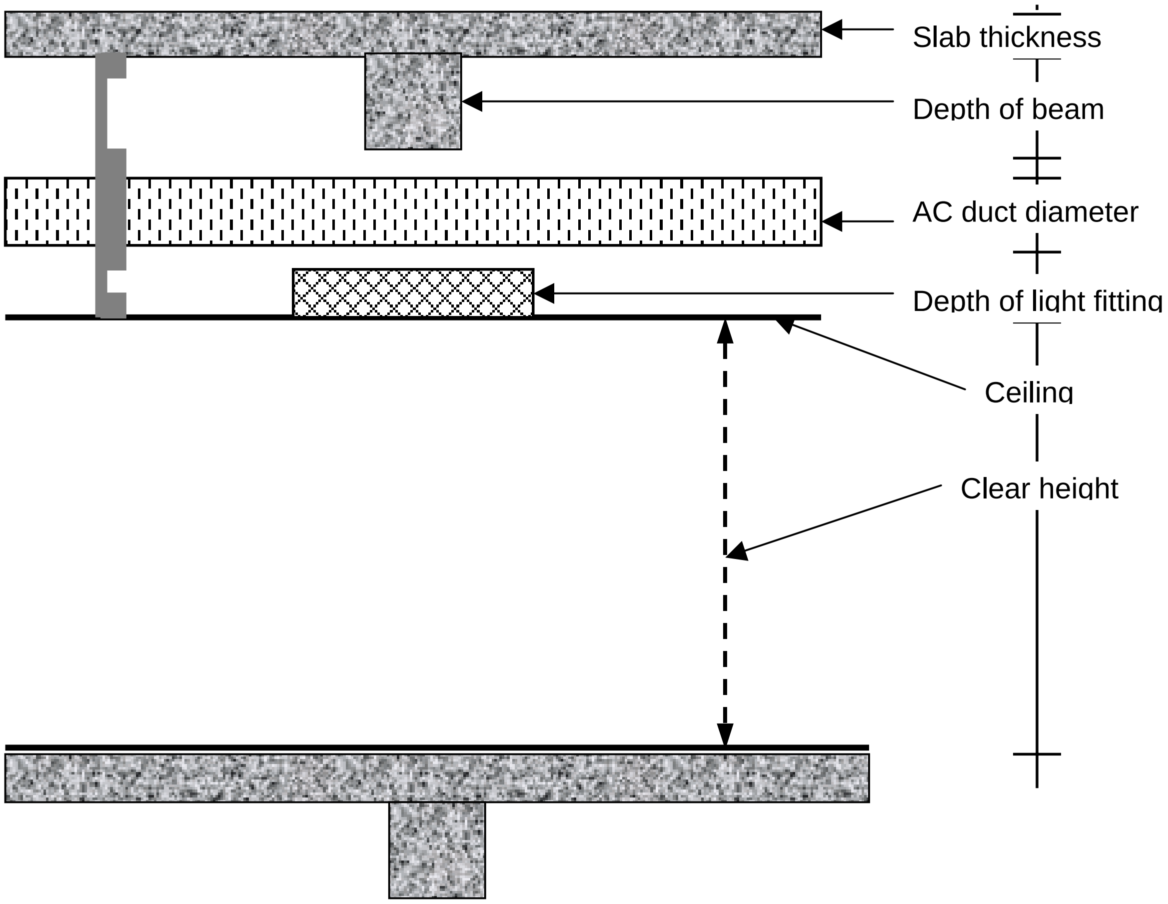
How to distribute inclined (not parallel to a major axis) perimeter wall?



Example: 18 x (10/(10+15)) = 7.2 → 7.2 + 20 + 10 = 37.2 is the southern external perimeter
18 x (15/(10+15)) = 10.8 → 10.8 + 15 = 25.8 is the eastern external perimeter

Floor-to-floor heights play a significant role in the overall scheme of the building in the total height of the development, in sunlight penetration between floors, in allowing for AC duct spaces, and in allowing for lighting fixtures. They must take into account (Figure 32) the floor (slab) thickness, the depth of any supporting beam(s), the AC duct cross-section, the depth of light fixtures; and the ceiling, as well as allowing for any reduction in 'clear height' caused by any atypical floor system.

Figure 32 : Visualisation and calculation of floor-to-floor height



6.3 Structural System

The current modelling and implementation of the structural system is quite basic. 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 may be a simple solution it gives satisfactory results for this stage of the design process. The choice of structural system can be complex. It will be influenced by many factors including site location and site constraints, building form, planning and structural grids, loading requirements and sustainability issues. Future work is planned to improve the scope of this module by refining the available structural systems and adding alternative structural systems.

6.3.1 Loading

The Australian – New Zealand standard AS\NZS 1170.1:2002 suggest imposed floor loads of between 1.5 to 7.5 kPa, with some exception for extreme loading conditions. The philosophy of the suggested live loads was based on the activity associated with a particular floor.

Activities are broadly classified into seven categories including residential, offices, commercial and industrial activities.

Standard allowances for live load for a general office area are 2.5 kN/m2 over approx 95% of each potentially usable floor area and 7.5 kN/m2 over approx 5% of each potentially usable floor area to cover high load areas.

6.3.2 Planning and column grid

The planning grid is derived primarily from work style and reflects the smallest unit of subdivision of space made available by a particular building system. A mullion grid of 3.0 m is not uncommon because cellular offices are rarely narrower; however a 1.5 m grid will inevitably provide more layout flexibility.

The column grid dimension should be a multiple of the planning grid dimension. The column grid should be as large as possible taking into account the characteristics of the proposed structural system and having regard to capital cost and floor-to-floor constraints. In general, spans of 7.5 m to 9 m are economic and greater spans will only be appropriate if work style dictates their use.

The screen capture displayed in Figure 33 shows a Java GUI that supports configuring the column spacing in early design. The user is allowed to set the column dimension and spacing. The user can then request to view and validate the choice against set criteria such as allowable deflections.

6.3.3 Deflections, tolerances and vibration

The overall depth of the structural floor zone should make adequate allowance for dead load deflection of the structure. The building elements attached to the structure should be detailed to accommodate both dead load and live load deflections of the structure. They should also be detailed to accommodate manufacturing, fabrication and construction tolerances in the structure.

The design of longer span and shallower floor systems should be checked to ensure that any vibration from footfall (and other sources) is within acceptable limits.

Some rules of thumb for minimum depth :

REINFORCED CONCRETE (RC)

Single span

One way slab = L/24
Two way slab = Perimeter/130
Joists = L/14
Beams = L/12
Girders = L/10

Multiple spans

One way slab = L/33
Two way slab = Perimeter/160
Flat slab w/ drops = L/33
Flat plate = L/30
Joists = L/18

Beams = L/15
Girders = L/12

Cantilever

One way slab = L/12
Joists = L/7
Beams = L/6
Girders = L/5

PRESTRESSED CONCRETE

Solid slab = L/48
Cellular plank = L/40
Double tee = L/32
Single tee = L/28
Flat plate = L/48
Beam = L/20
Girder = L/15

Notes:

- L = Clear span, face to face of support
- H = Clear Height
- S = Clear, unsupported width of wall
- All depths are total (i.e.: top of slab to bottom of beam, etc.)
- Joists and studs are closely spaced members
- Beams have a tributary width = 1/3 to 1/2 of span
- Girders have a tributary width = span
- The width of concrete beams, joists and girders is usually determined by the fit of the longitudinal rebar, although, for very heavy loads, the shear strength may govern. A common approximate width is ½ the depth. Although longitudinal bars may be bundled, it is prudent to select member widths that allow one bar diameter between longitudinal bars.

6.3.4 Example (Prism Building)

If we return to the so-called “prism building” example (see Figure 5), and assume that the beams are reinforced concrete (RC) beams, whilst recalling that the maximum column-to-column spacing is 15,000 mm, then

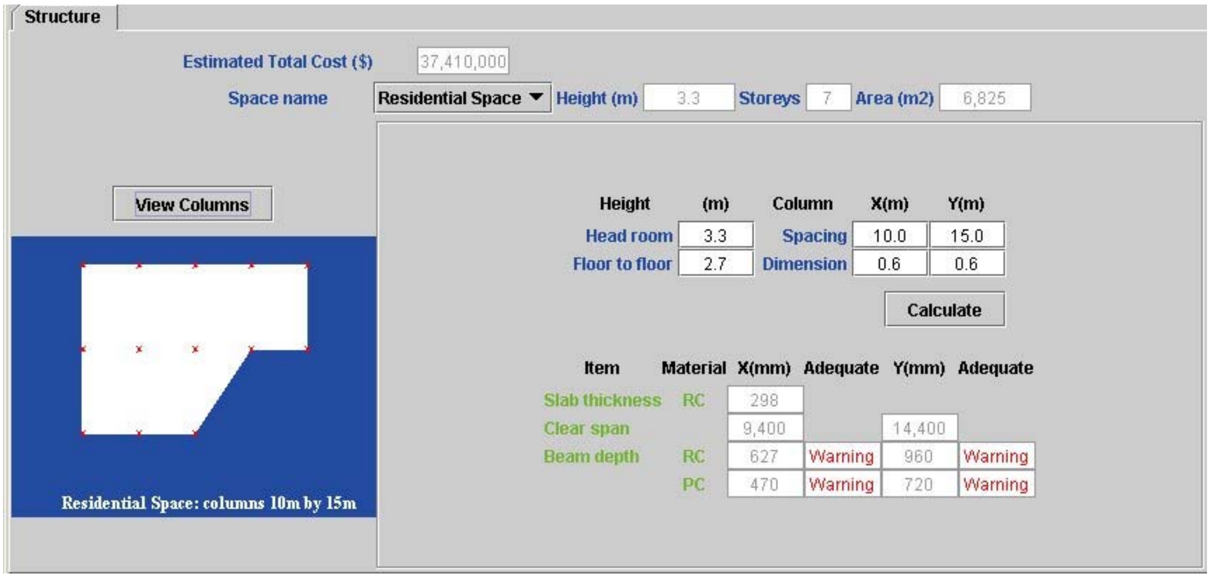
Beam Depth ≈ 15000 mm / 15 = 1000. Note that the floor-to-floor spacing is set at 3300 mm. So if the headroom (floor-to-ceiling height) is set at 2700 mm, then there is NOT sufficient space for a beam 1000 mm in depth !

Option 1: Decrease the spacing between columns, thus requiring more columns. The architect will lose some layout flexibility. Reducing the column spacing to 10,000 mm would require a beam depth of about 670 mm.

Option 2: Use pre-stressed concrete - which would result in a minimum beam depth of about 15,000 / 20 or 750 mm. Either the headroom can be reduced to 2400 mm, the floor-to-floor height can be increased, or the column spacing can be reduced. A column spacing of 10,000 mm would result in a beam depth of 500 mm.

Option 3: Use steel beams (i.e. Universal Beam), which may result in a likely choice of UB610x229 section, however the resulting beam is still too deep (3300 – 2700 = 600 mm).

Figure 33 : Setting column spacing for each type of building occupancy.



Estimated Total Cost ($) 37,410,000

Space name Residential Space Height (m) 3.3 Storeys 7 Area (m2) 6,825

Height	(m)	Column	X(m)	Y(m)
Head room	3.3	Spacing	10.0	15.0
Floor to floor	2.7	Dimension	0.6	0.6

Item	Material	X(mm)	Adequate	Y(mm)	Adequate
Slab thickness	RC	298			
Clear span		9,400		14,400	
Beam depth	RC	627	Warning	960	Warning
	PC	470	Warning	720	Warning

Residential Space: columns 10m by 15m

6.3.5 Frame and materials

In general, a steel or reinforced concrete structure is equally acceptable. However, RC structures are the most common choice in residential building construction in Australia. A clear strategy for flexibility and future adaptability of the structure should be developed. The efficient and sustainable use of structural materials should be a vital consideration, such as capital cost, embodied energy cost, and adaptability (ease of retro-fitting).

6.4 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.

Much of the key information related to the fire protection, and cold and hot water supplies in this section can be found in the extremely useful reference book for architects on building services engineering, by Parlour (1994). The working and living population of the building provides the necessary information for the estimation of water tank sizes. The output is a requirement for a tank size in floor area and headroom.

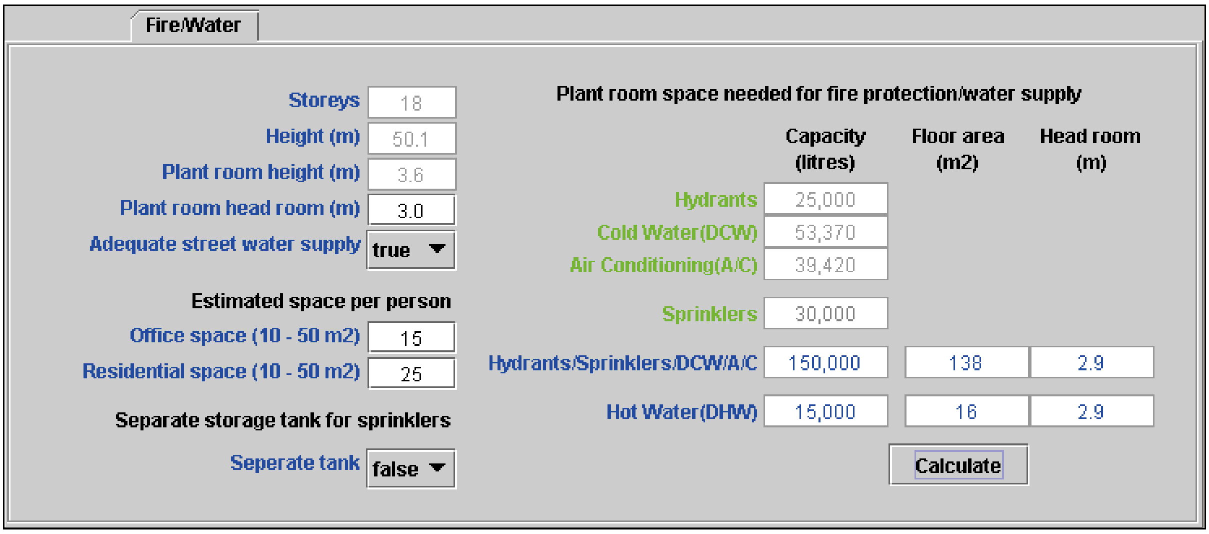
Fire protection systems are pervasive in modern multi-storey buildings. Local building regulations will often mandate the type of system that must be used for buildings of various heights, occupancies and areas.

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 then the capacity of any storage tanks; whether a fire control centre is required; and whether diesel/electric booster pumps are required. Assessment for smoke protection systems could be added in the future.

6.4.1 Fire protection / Water storage

The Fire/Water tabbed panel shown in Figure 34 calculates the size of water tanks required to store water necessary for fire protection, plus cold and hot water. The water storage volumes required for fire protection, cold water and air conditioning are summed, and are shown with green labels in the centre of the interface screen (Figure 34). Blue labels, on the other hand (left column and last two RH values), show the tank capacity, floor area and head-room necessary to store the required volumes.

Figure 34 Fire/Water tabbed panel.



Storeys 18
Height (m) 50.1
Plant room height (m) 3.6
Plant room head room (m) 3.0
Adequate street water supply true

Estimated space per person
Office space (10 - 50 m2) 15
Residential space (10 - 50 m2) 25

Separate storage tank for sprinklers
Seperate tank false

Plant room space needed for fire protection/water supply

	Capacity (litres)	Floor area (m2)	Head room (m)
Hydrants	25,000		
Cold Water(DCW)	53,370		
Air Conditioning(A/C)	39,420		
Sprinklers	30,000		
Hydrants/Sprinklers/DCW/A/C	150,000	138	2.9
Hot Water(DHW)	15,000	16	2.9

6.4.2 Fire protection

References suggest that a 25,000 litre capacity tank is necessary when a hydrant/hose reel system is required, whereas a larger 30,000 litre capacity tank is required for an automatic sprinkler system. The user may decide if these tanks should, or should not, be combined.

6.4.3 Water storage

6.4.3.1 Cold water

The volume of cold-water storage that is required is determined by multiplying *person/occupancy type* by *usage/person/day,* and summing. *Person/occupancy type* is estimated from the total space area and is user variable, while *usage/person/day* is set at 90 litres/day for residential, and to 40 litres/day for office space usage - based on our reference.

6.4.3.2 Cold water for air conditioning

Cold water needed for washing down plant rooms and the continuous demand for any cooling tower is simply calculated as:

$2.4 \times floor\ area\ m^2$

6.4.3.3 Hot water

In a similar manner to cold water, storage needed for hot water is determined by summing *person/occupancy type* by *usage/person/day*. In this case, *usage/person/day* for residential is set at 30 litres/day, and office space usage at 5 litres/day – based on Parlour (1994).

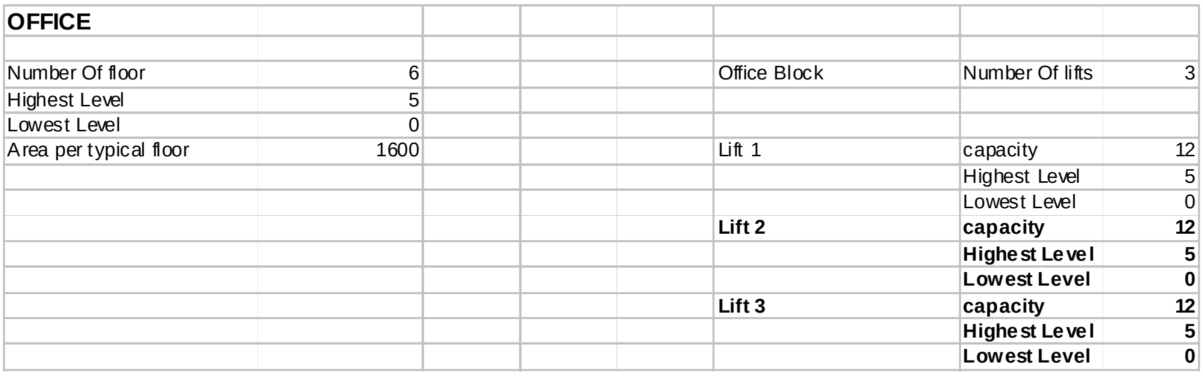
6.5 Mechanical

6.5.1 Vertical transport

The choice of vertical transportation system depends heavily on the height of a building, the usage or occupancy type, 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 (see Figure 35).

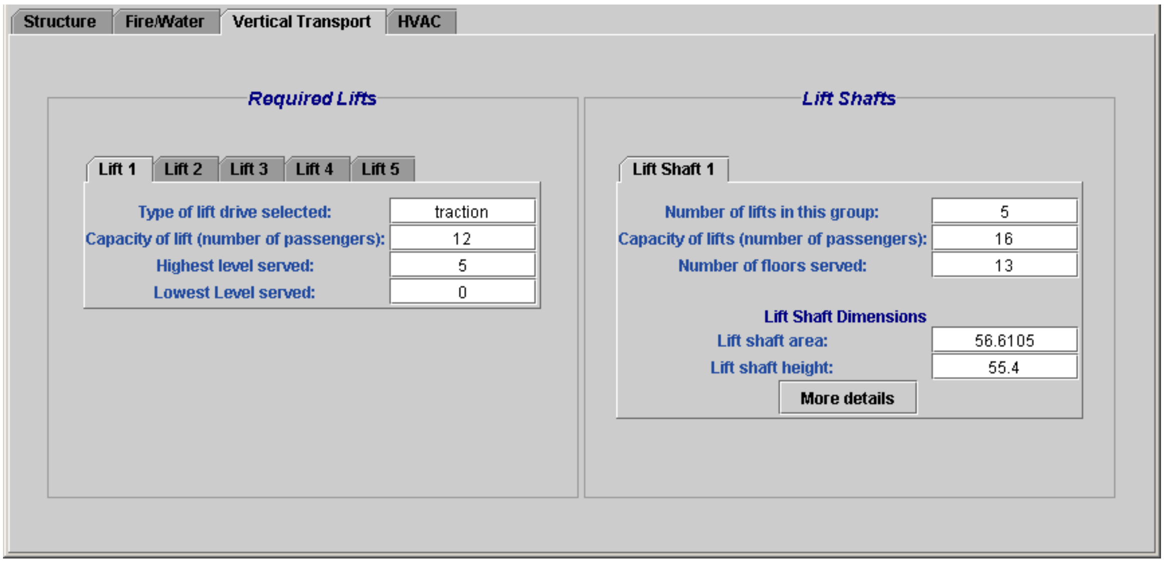
Figure 35 : Sample vertical transport values



OFFICE							
Number Of floor	6				Office Block	Number Of lifts	3
Highest Level	5						
Lowest Level	0						
Area per typical floor	1600				Lift 1	capacity	12
						Highest Level	5
						Lowest Level	0
					Lift 2	**capacity**	**12**
						Highest Level	**5**
						Lowest Level	**0**
					Lift 3	**capacity**	**12**
						Highest Level	**5**
						Lowest Level	**0**

The Vertical Transport panel, shown in Figure 36, displays the different components required for the vertical transport in a given building: the lifts and lift shafts, with their properties.

Figure 36 : Vertical transport panel



Required Lifts

Type of lift drive selected: traction
Capacity of lift (number of passengers): 12
Highest level served: 5
Lowest Level served: 0

Lift Shafts

Number of lifts in this group: 5
Capacity of lifts (number of passengers): 16
Number of floors served: 13

Lift Shaft Dimensions
Lift shaft area: 56.6105
Lift shaft height: 55.4

Again, much of the key information related to the lift drive selection; required lifts; and lift shafts in this section can be found in the reference book on building services engineering by Parlour (1994). The details of the calculation for the definition of the number of lifts and lift shafts are described below.

6.5.1.1 Analysis method

a) Lift Drive Selection

Two types of lift drives exist: hydraulic or traction. “*Both hydraulic and traction are suitable for* *low rise building, however the traction type are usually preferred for buildings higher than about six floors, because of their greater speed."* (Parlour 1994).

Hence, the lift drive is selected here depending on the number of floors of the building. If the number of storeys is greater than six, a traction lift drive is selected; otherwise the user is advised that it can be either type of lift drive. Once the lift drive is selected, all the lifts in the building will have the same type of drive.

b) Required Lifts

The number of lifts and their capacity (i.e. number of passengers per liftcar) is then calculated. This is performed for each type of occupancy: office, residential, and car-park as the calculation method is different for each occupancy type.

For the office block, we have used a reference table to give the number of lifts required and their capacity, depending on the number of storeys and the area per typical floor.

For the car-park; if it is just beneath the office space, 1/3rd of the lifts required for the office block have to serve the car-park; their capacity being the same as those of the office block.

The number of lifts required for the residential block depends on the number of single bed units per floor, and the number of floors. The number of single bed units is calculated here by dividing a typical floor area by 45, assuming that a standard single bed unit is approximately 45 m^2. Once knowing how many floors are served and the number of single bed units, again a reference table indicates how many lifts are required. The lift car should be between 12 and 20 passengers. For simplicity, here the capacity was set at 16 passengers.

The left side of the panel in Figure 36 is a tabbed panel where each tab is a required lift in the building. Each tab shows which lift drive is selected, its capacity, and the lowest and highest floors it serves.

c) Lift Shafts

From the number of lifts required for the building, groups of lifts are defined. These groups then constitute the number of lift shafts. A maximum of six lifts per lift shaft is accepted, since if the number of lifts is greater than six, then additional lift shafts will be required.

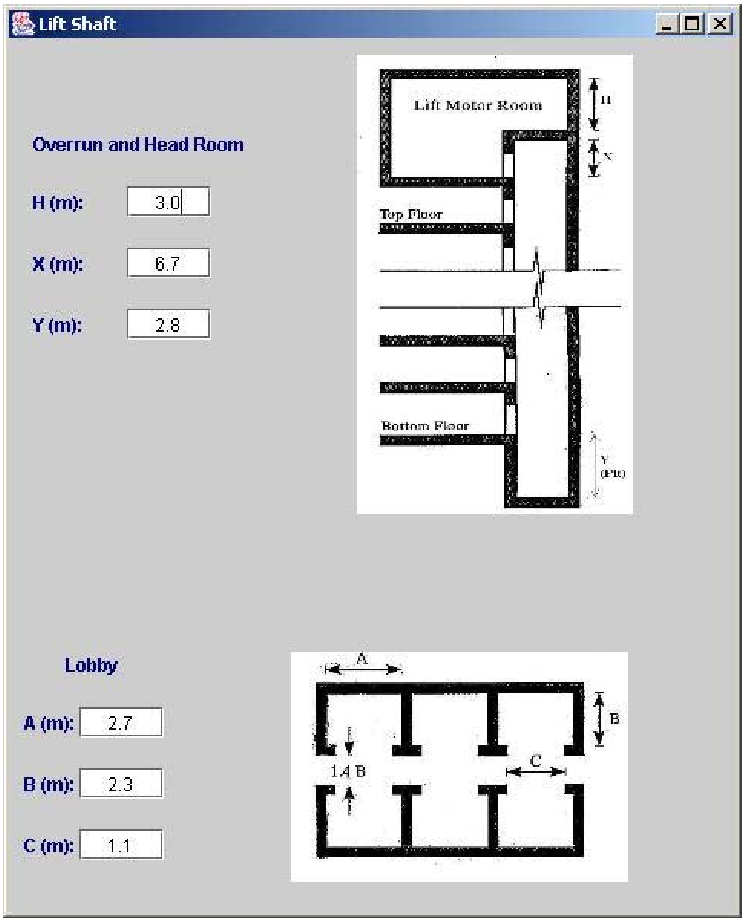
For each of the shafts, the lift motor room area, the overrun, headroom and lobby dimensions are calculated (based on reference tables from Parlour, 1994).

- The area of the motor room is given in a reference table, and it depends on the number of lifts in the group and the capacity of the lift car.
- The overrun and headroom dimensions are also given in reference tables, and they depend on the number of floors served.
- For the lobby dimensions, they depend on the capacity of the lift car, and are also set out in reference tables

The panel shown in Figure 37 opens when the user clicks on the "Details" button at the bottom of the panel shown in Figure 36. Figure 37 shows the dimensions for the overrun and headroom calculated for the example building. The overrun is given by X and Y, and the headroom by H. The lower part of the panel gives the dimensions for the lobby (A, B, C).

The lift shafts dimensions are shown on the right side of the panel on Figure 36. The lift shaft has an area and a height.

Figure 37 : Lift Shaft Details - overrun & head-room dimensions, and lobby dimensions.



Overrun and Head Room

H (m): 3.0

X (m): 6.7

Y (m): 2.8

Lobby

A (m): 2.7

B (m): 2.3

C (m): 1.1

The area of the lobby depends initially on the configuration of the lobby. Either the lifts can be in line, facing each other or, if an odd number of lifts is required, some facing each other and one not. For simplification purpose, only two cases were considered, viz. if the number of lifts is even all the lifts are facing each other, if odd then the same except for one.

The area of each lift car is given by Area = (A + margin)*(B + margin) where A is the length of the car, and B is the width (see Figure 37). The margin was set at 10% of A.

The area of the lift shaft is then calculated as follows: either

Area of Lift Shaft = Number of Lifts in group * Area + 1.4B*(A + margin)*Number of Lifts facing each other, <u>or</u>

Area of Lift Shaft = Number of Lifts in group * Area if no lift is facing another.

The height is found by adding the overrun (X + Y) to the head-room (H) to the number of storeys multiplied by their floor to ceiling height, giving :

Height = X + Y + H + Number of Floors*height Of Floor

6.5.2 Heating, ventilation & air conditioning (HVAC) background

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 centralised 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 or occupancy 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 vital role in HVAC loads so a load factor can be applied for locations where explicit data is not available (if data for 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.

Figure 38 : Heating/Ventilation/Air Conditioning (HVAC) zones

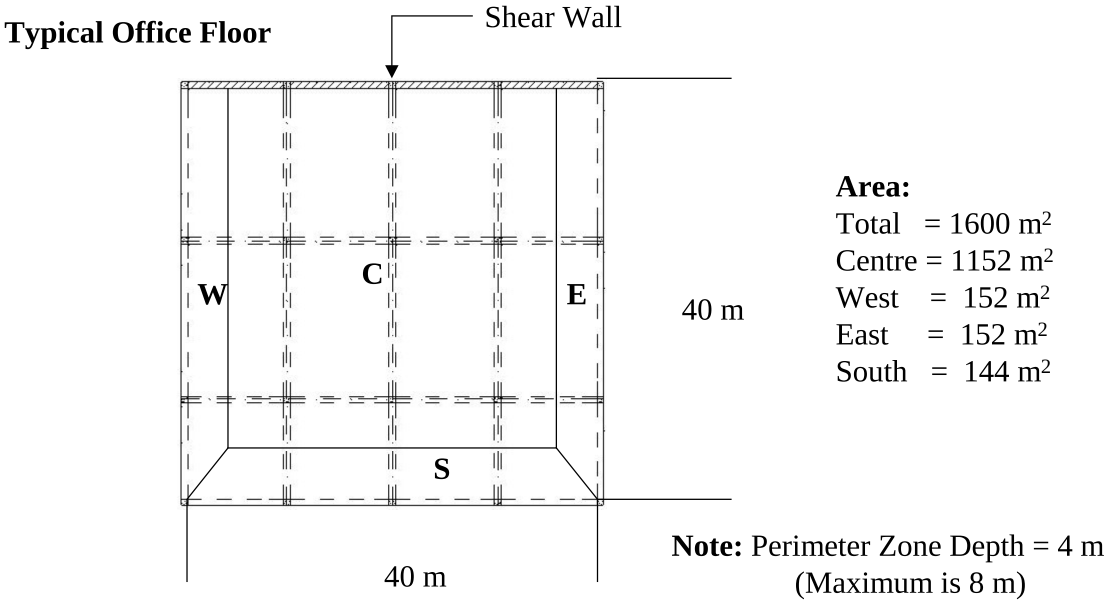
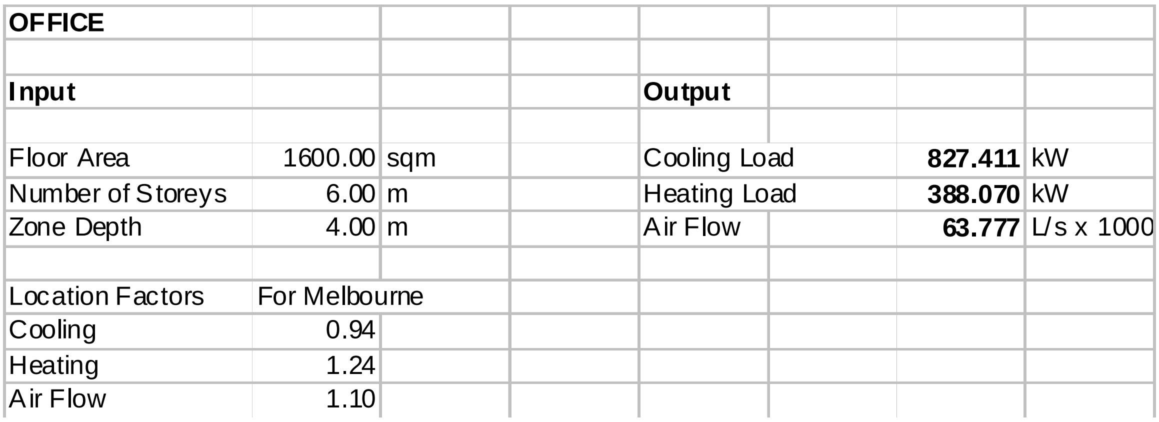


Figure 39 : HVAC loads



OFFICE							
Input				**Output**			
Floor Area	1600.00	sqm		Cooling Load		**827.411**	kW
Number of Storeys	6.00	m		Heating Load		**388.070**	kW
Zone Depth	4.00	m		Air Flow		**63.777**	L/s x 1000
Location Factors	For Melbourne						
Cooling	0.94						
Heating	1.24						
Air Flow	1.10						

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.

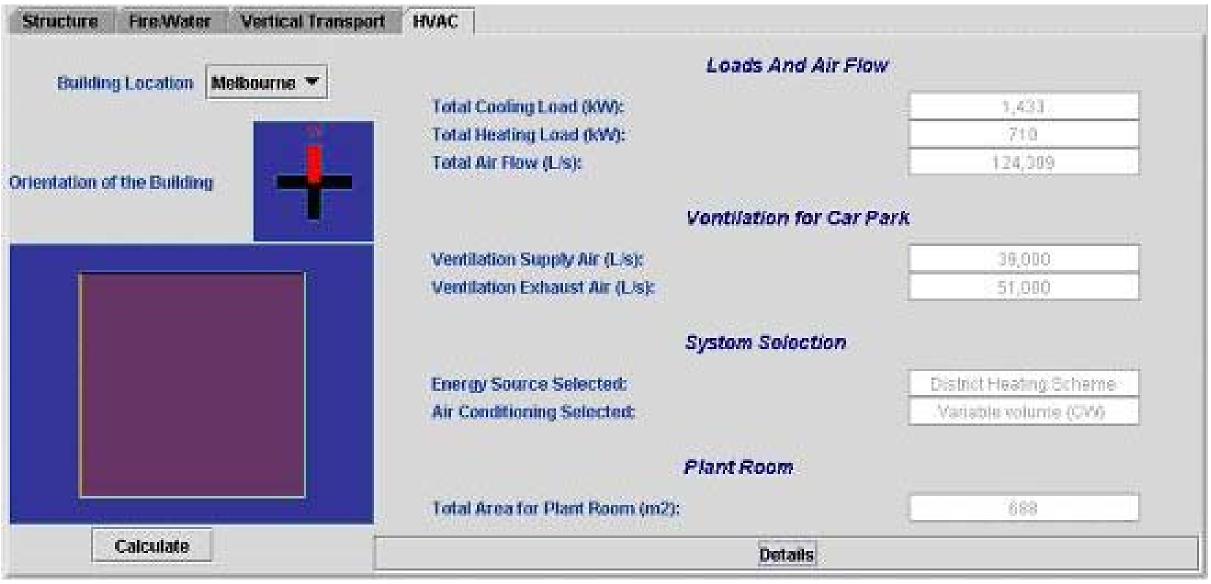
6.5.2.1 Air conditioning (AC)

The air conditioning interface panel, shown in Figure 40, computes the air conditioning system required for a given building, as well as the dimensions of the plant room and core needed. Again, much of the key information related to the HVAC requirements in this section are based on the reference book on building services engineering by Parlour (1994).

This panel is divided into two parts. On the left side, data needs to be entered by the user regarding the location of the building, its orientation and which façades are glazed. The "Calculate" button starts the analysis and the output data are then shown on the right side.

The cooling and heating loads, the air flow, and the ventilation supply and exhaust air for underground car park are displayed, as well as the type of air conditioning system required, and the area of the plant room.

Figure 40 : HVAC tabbed panel



Building Location: Melbourne

Total Cooling Load (kW): 1,433
Total Heating Load (kW): 710
Total Air Flow (L/s): 124,309

Ventilation Supply Air (L/s): 39,000
Ventilation Exhaust Air (L/s): 51,000

Energy Source Selected: District Heating Scheme
Air Conditioning Selected: Variable volume (CW)

Total Area for Plant Room (m2): 688

Clicking the "Details" button located at the bottom of the interface panel will open a further new interface panel in which intermediate results from the analysis are displayed. Some input data have been set by default, but it is possible to modify them in this panel and start the analysis again - to see what implications they have on the selection of air conditioning or size of the plant room. This interface panel's parts are shown in Figure 41, Figure 42, Figure 43, Figure 45, and Figure 46 - as individual parts.

6.5.2.2 Analysis method

In order to determine the required air conditioning system for a given building, a step by step procedure from Parlour (1994) was followed.

The different steps are :

- Definition of the different zones of typical floor for each occupancy type
- Calculation of total cooling and heating loads and air flow
- Determination of energy source and air conditioning system
- Calculation of plant room area required
- Sizing of duct and pipe work

The calculation methods of the different parts are described below and each part is illustrated by the input and output data as shown in the detailed interface panel.

a) Zoning

Applying zoning to the different floors of the building is required to calculate the cooling and heating loads, and the airflow. Since the car parking space only requires ventilation, not air conditioning, the residential and office blocks only are considered for the calculation of the loads.

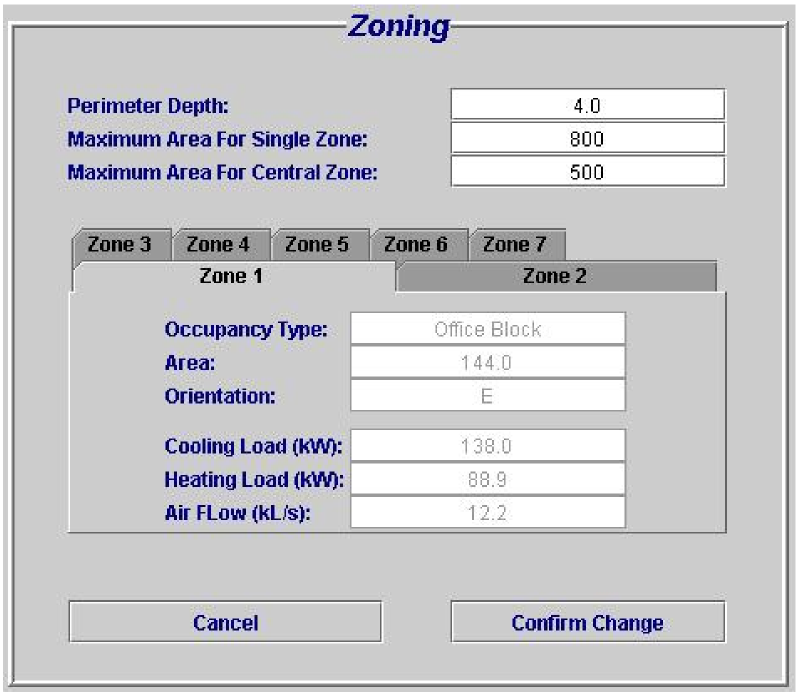
From Parlour (1994), loads and airflow for residential units are given per m^2, hence no zoning is required for it; so only the office block needs to be zoned - which is determined as follows:

> from a standard floor belonging to the office block, we determine if the floor has one or many zones by comparing its area with a maximum given value. If the area is greater than this value, then many zones are required. The default value set here is 800 m^2 as shown in Figure 41.
>
> then, if many zones are required, they are set such that each façade associated with a zone depth determines a zone. The default value for the zone depth is set at 4 meters, as shown in Figure 41.

The zones have an area and an orientation that is given by the orientation of the façade, or if the zone is not on the perimeter of the floor, the value for orientation is "central". For the central zone, if the area is greater than a given value (default is 500 m^2), then the area is divided in many smaller ones such that any of them is greater than this value.

Figure 41 shows the different zones defined with this method. We can see here that seven zones have been set, with each of them having its occupancy type, area and orientation defined. Changing any of the values for perimeter depth, maximum area for single zone or maximum area for central zone and clicking on the "Confirm change" button will redefine and recalculate the number of zones and their areas.

Figure 41 : AC Zoning interface panel



Perimeter Depth: 4.0
Maximum Area For Single Zone: 800
Maximum Area For Central Zone: 500

Occupancy Type: Office Block
Area: 144.0
Orientation: E

Cooling Load (kW): 138.0
Heating Load (kW): 88.9
Air FLow (kL/s): 12.2

b) Loads and Air flow

The cooling load is equal to the unit cooling load multiplied by the air conditioned floor area, and similarly for the heating load and airflow. Unit loads and airflow are again found in tables in Parlour (1994) and generally depend on the occupancy type (office space, residential block…). For office space, values also depend on the orientation of the zones.

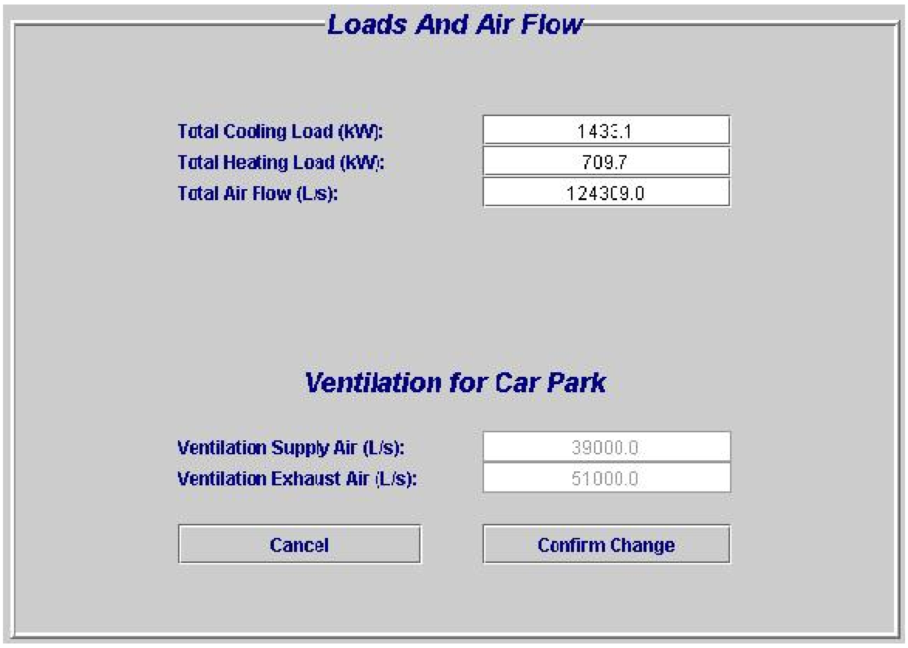
The loads and airflow are calculated for the different zones, and are shown on Figure 41. Changing any of the three input data may have an impact on the loads and airflow values since the zones might have different areas.

The total loads and airflow for the building are then calculated summing each of those of the different zones. A factor is then applied depending upon which city the building is located in.

The supply and exhaust air for the ventilation of the car-park is again determined from reference tables. Depending on the type of car-park (deep basement, or first basement car park), a different unit supply and exhaust air is given. Multiplying these data by the total area of car-park space gives the supply and exhaust air required for the ventilation.

The software interface panel in Figure 42 shows the loads and airflow for the building. In the top half of the panel, the cooling and heating loads for the building are shown, as well as the airflow. The bottom half of the panel shows the supply and exhaust air required for the ventilation of the car park.

Figure 42 : Loads and air flow panel



Loads And Air Flow

Total Cooling Load (kW): 1433.1
Total Heating Load (kW): 709.7
Total Air Flow (L/s): 124309.0

Ventilation for Car Park

Ventilation Supply Air (L/s): 39000.0
Ventilation Exhaust Air (L/s): 51000.0

c) System Selection

Two types of system have to be determined, the energy source and the air conditioning system.

The selection of the energy system depends upon the size of the building and the total heating load. If the building is small and heating load minimal, the energy system can either be an electric resistance or reverse cycle equipment. For a large heating load but still a small building, the energy system is likely to be a Central Hot Water system, using a gas or oil-fired hot water boiler. For a medium to large building it can be gas, oil-fired hot water boiler or a district-heating scheme. The default values here for a small building are one with fewer than six storeys, and a minimal heating load is less than 100 kW.

The selection of the air conditioning system is a somewhat more complex - it depends first on the cooling loads of the building. If the cooling loads are less than 350 kW, a direct expansion system (DX) is selected; otherwise a central chilled water (CWS) one is chosen.

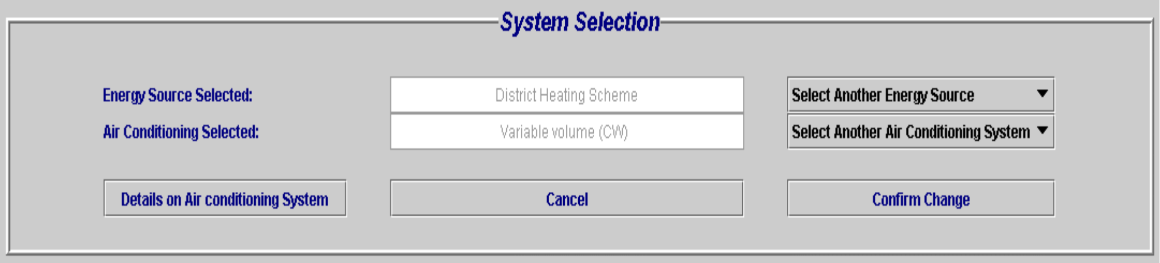
If a “direct expansion” system is required, depending on the zoning type (simple or multi-zones), the type of occupancy (similar or not) and the cooling load, one of the following systems is selected: rooftop packaged unit, split package unit (condensing unit), multiple packaged unit or variable volume unit.

If a “central chilled water” system is required, the system can either be a variable volume; local air handling units; local fan-coil units; or a packaged units (water cooled) system. The selection of these systems requires more precise information than for the direct expansion system. As such information is not available at this stage, and we only consider two occupation types (office and residential), a simplified assumption is used to determine the system. Hence, a variable volume system is chosen if the building is a prestigious high-rise, otherwise a local fan-coil units system is chosen. The criterion determining the type of the building here is its number of storeys - if the building has more than 15 storeys it is considered a prestigious high-rise building, and hence the system chosen is variable volume system, otherwise it is a local fan-coil units system.

Although this is a restriction in the selection of air conditioning system, it is still possible to choose another one (as shown in Figure 43) if the user thinks that is more appropriate. The choice of another energy source is also possible.

Clicking on the “Confirm Change” button will save parameters related to the new selected system and restart the analysis. The “Details on Air Conditioning System” button opens a new interface panel in which a schema of the selected air conditioning system is displayed. It is then possible to visualise which kinds of units are required (see Figure 44).

Figure 43 : System selection panel



System Selection

Energy Source Selected: District Heating Scheme

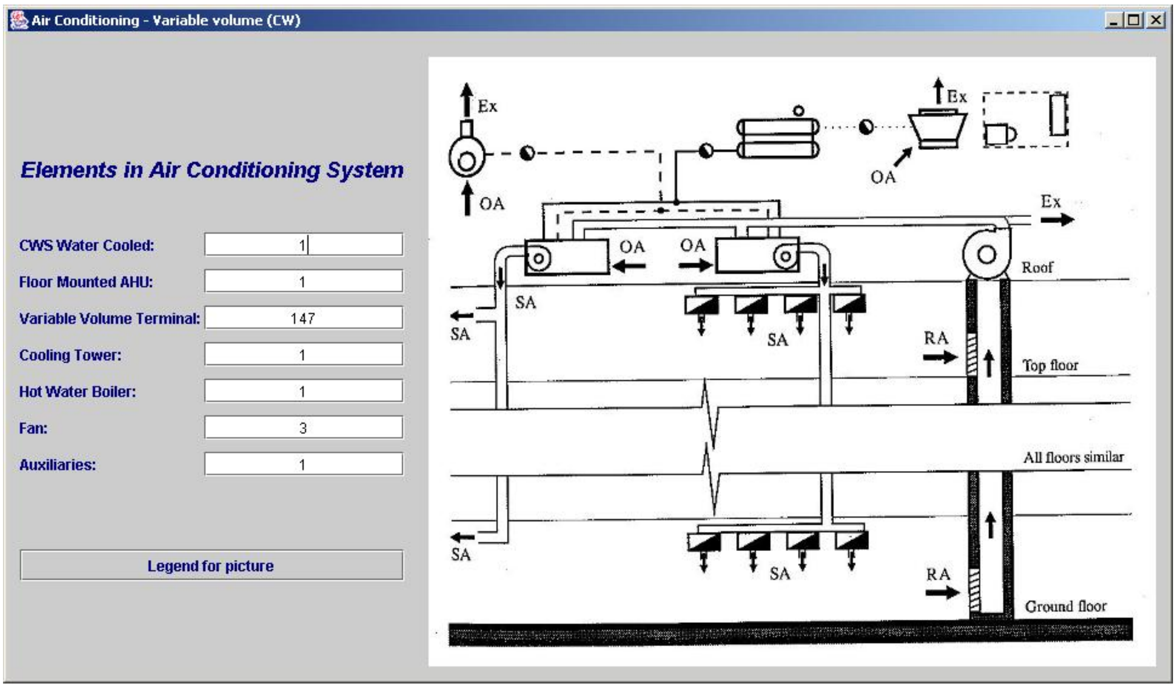
Air Conditioning Selected: Variable volume (CW)

Once the system is selected, the elements required throughout the building are also set by reference to the Parlour (1994) handbook. The different elements required for each system are as follows :

- for a Rooftop Packages unit (DX): Rooftop Packages unit
- for Split Package Unit (DX): indoor AHU, outdoor air-cooled condensing unit with refrigerant pipe work
- for Variable volume (DX): Rooftop Unit or Condensing Unit, VV Terminals, electrical resistance or hot water coils in VV terminals
- for Variable Volume (CW): central AHU, VV terminals, ducted air supply, Chilled Water set (air-cooled or water-cooled), cooling tower, Hot Water Boiler, central plant auxiliaries, fan
- for Local AHU (CW): independent AHU, central Chilled Water set (water-cooled or air-cooled), central hot water boiler, cooling Tower, central Plant Auxiliaries
- for Fan-coil units (CW): fan coil units, Chilled Water Set (water-cooled or air-cooled), central hot water boiler, cooling Tower, central Plant Auxiliaries
- for Packaged units (water-cooled): water-cooled packaged units, central hot water boiler, cooling Tower, central Plant Auxiliaries

Depending on the type of unit selected, many elements might be required (such as variable volume terminals, fans…). The number of required units for the building is determined by taking the total cooling or airflow and dividing by the maximum capacity of this kind of unit. These elements are shown on Figure 44 with their required number.

Figure 44 : Details of the air conditioning system selected.



Air Conditioning - Variable volume (CW)

Elements in Air Conditioning System

CWS Water Cooled: 1
Floor Mounted AHU: 1
Variable Volume Terminal: 147
Cooling Tower: 1
Hot Water Boiler: 1
Fan: 3
Auxiliaries: 1

d) Plant Room

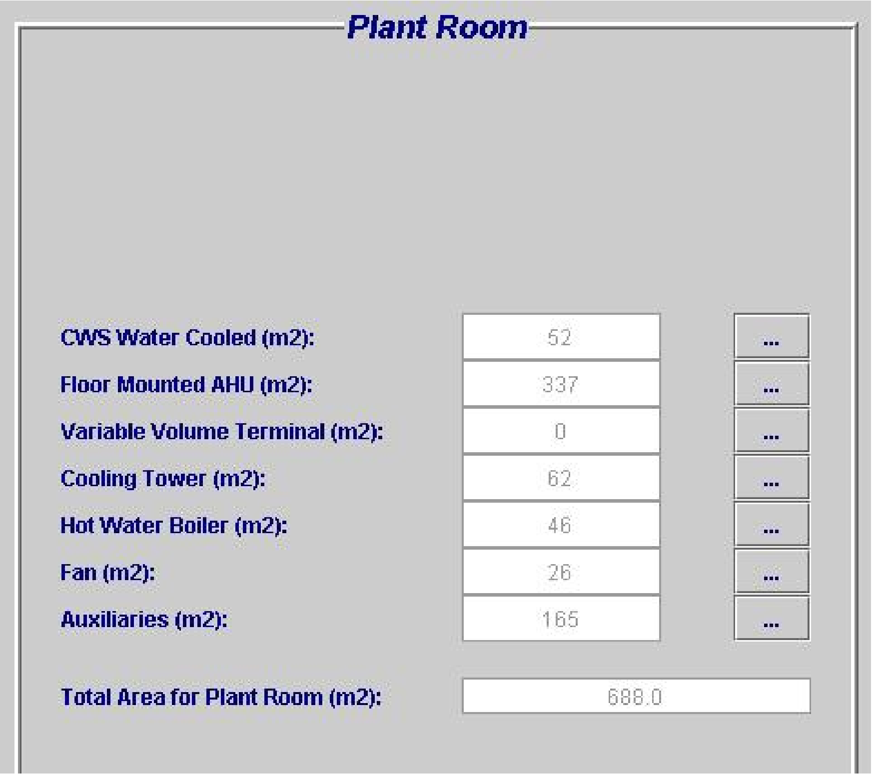
The size of the plant room is calculated by summing all the different elements that require to be in a central plant room. Depending upon the system selected, some elements are spread throughout the building, whereas others are stored in a central plant room.

Again, the dimensions and area of each element are given in tables in Parlour (1994), and summing the areas of the elements located in the plant room gives the total area needed for the plant room.

In addition, space for auxiliaries is also needed. Auxiliaries cover all those minor items necessary for the effective operation of a central plant system, and the area and height of the auxiliaries are also given in tables in Parlour (1994). Three types of auxiliaries exist - the first one is for central air conditioning system with all Air Handling Units (AHUs) centralised; the second is with all AHUs localised; and the third is for any central heating system. Once the appropriate auxiliaries are selected, the dimensions are determined depending on the cooling load for the first two types, and the heating load for the latter one.

The software interface panel reproduced in Figure 45 shows the different elements comprising the Air Conditioning system and their associated area. If the area is set to zero, this means that this unit is not located in the plant room. The total area for the plant room is shown at the bottom of the panel.

Figure 45 : Plant room panel



CWS Water Cooled (m2):	52
Floor Mounted AHU (m2):	337
Variable Volume Terminal (m2):	0
Cooling Tower (m2):	62
Hot Water Boiler (m2):	46
Fan (m2):	26
Auxiliaries (m2):	165
Total Area for Plant Room (m2):	688.0

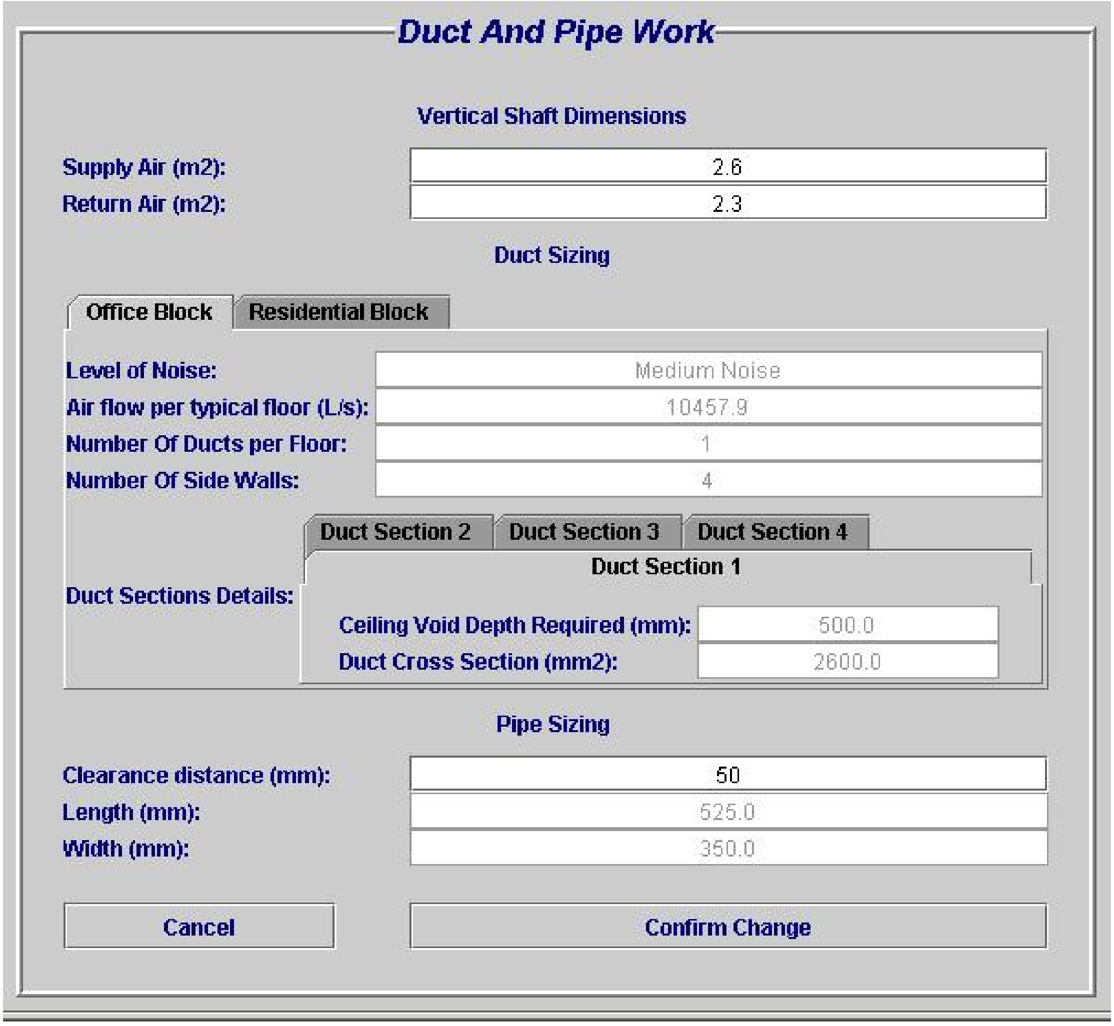
e) Duct and Pipe work

In this interface, the sizing of the vertical shaft, the ducts and pipes is performed.

The vertical shaft is normally provided to enclose any vertical supply air ducts, and also to convey the return air to and from the centralised Air Handling Unit. With a central AHU at roof level, the cross-sectional area of the shafts may decrease down the building. Once again, tables in Parlour (1994) give the cross sectional area of the shaft - depending on the area of the floor immediately adjacent to the centralised AHU.

The panel reproduced in Figure 46 shows the vertical shaft cross-section for the supply air and the exhaust air.

Figure 46 : Duct and pipe work panel


Duct And Pipe Work

Vertical Shaft Dimensions

Supply Air (m2): 2.6
Return Air (m2): 2.3

Duct Sizing

Office Block | Residential Block

Level of Noise: Medium Noise
Air flow per typical floor (L/s): 10457.9
Number Of Ducts per Floor: 1
Number Of Side Walls: 4

Duct Sections Details:

Duct Section 1

Ceiling Void Depth Required (mm): 500.0
Duct Cross Section (mm2): 2600.0

Pipe Sizing

Clearance distance (mm): 50
Length (mm): 525.0
Width (mm): 350.0

The noise generated by the air flowing through a duct is a major factor in duct sizing, since noise generation and duct sizes depend on air velocity. Depending on the building occupation, different levels of noise may be accepted or demanded. For example, minimal air noise may be permitted for an auditorium, whereas the noise level could be higher in a general office or car-park.

As the horizontal ducts are to be placed in the ceiling space on each floor, the depth of the duct is constrained by the ceiling space dimension. The number of outlets to which airflow is delivered defines how many sections the duct requires. The airflow delivered by each outlet is constant, which means that for a required airflow on a floor, the airflow delivered at each outlet is going to be the total airflow divided by the number of outlets. This also means that the duct sections decrease in size to allow the constant airflow to be delivered. Hence the first sections of ductwork need to be large enough to carry the total airflow.

If this is not the case, then many ducts will need to be installed on that floor. Again, ideas of the preferred maximum airflow is given in tables in Parlour (1994)

Then, from the shape of the duct (rectangular or circular), the depth of the duct and the airflow to be delivered, the cross-sectional area is given in tables as above.

Then depending on the noise level permitted for the occupancy type (low, medium or high), these cross sections are multiplied by a factor documented by Parlour (1994).

The duct sizing parameters and calculations are shown in Figure 46. For each type of occupancy (residential or office), the level of noise, airflow, number of ducts and sidewalls per floor is displayed. Then each section of the duct is shown with the ceiling void depth and cross section area.

The sizes of both chilled and condenser water pipes depend on the cooling load. The hot water pipe sizes depend on the heating load. Pipe diameter is given in tables (Parlour 1994) depending on the heating and cooling loads. Those values are given assuming typical water velocities, temperatures and insulation as appropriate.

The overall chilled, condenser and hot water pipe sizes are all added together - as well as the clearance between pipes - to calculate the slab penetration. Those data can be seen in the interface panel shown in Figure 46. Clearly, changing the clearance between the pipes will modify the dimensions of the slab penetration.

6.6 Electrical

The major impact of the electrical system in the early stages of design is in deciding if a power 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, more highly developed sites this can be a major decision.

6.6.1 Power

The major impact of the electrical system in the early stages of design is in deciding if a power 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, more highly developed sites this can be a major decision.

Taking the area of the building and applying a load density appropriate for the particular usage(s) can identify whether or not a substation will be needed. 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 can 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.

6.6.2 Lighting

Unfortunately although the Power and Lighting sub-systems were investigated, and the former system modelled, due to time pressures neither the Power or Lighting sub-systems were able to be implemented within the current project timeframes.

6.7 Environmental System

At the outset of the 2002-060-B Parametric project, it was anticipated that the environmental analysis system would be provided by a modified version of LCADesign (Tucker et al, 2003), with the expectation being that an automated take-off module could provide the quantities of all building components. The specific production processes, logistics and raw material inputs could be identified to calculate a complete list of quantities for all products such as concrete, steel, timber, plastic etc. This information is then combined 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, and the outputs are graphs that allow assessment and comparison of the building performance. However, slower than anticipated progress with LCADesign and its demand for detailed data at the very small scale, have made the implementation of parametric environmental factors (at the early design stage) inappropriate at this time.

6.8 Financial 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 (Ferry and Brandon, 1999). The cost module uses user-defined rules and unit rates to calculate a cost estimate based on elemental data extracted from the shared model.

The costs are calculated using the following unit rates for each occupancy type :

Office space	\$1,850 / m^2
Residential space	\$2,000 / m^2
Underground carpark	\$1,000 / m^2

and the total is shown at the top of the panel “Setting column spacing for each type of building occupancy” - shown earlier in Figure 33.

In future work, it is expected that the quantities will be 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.

7. CONCLUSIONS

This report has investigated a range of parameters - across various disciplines such as architectural, structural, electrical, mechanical, hydraulic, and cost - which was anticipated might characterise the early stage design. A number of those parameters were identified as critical since they often support individual building sub-systems which are key to the early design.

Even at the early stages of design with which we were concerned, each of the building systems is interdependent upon the others. The project team were not able to identify any ***one*** view that could be modelled independently of the others, and 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.

Parameters such as the occupancy type (residential, office/retail, carparking); floor-to-floor heights; for each occupancy type - the amount of floor space (and importantly *standard* of accommodation); the expected number of people per unit of floor space; the column and beam spacings; air conditioning and water supply requirements; number of lifts; etc. were all identified as key parameters, however it appears an overarching parameter that applies to all building services systems is the “quality” of occupancy or level of service that the building will provide, since normally the rental return on a building will be closely linked with the quality. In Australia, and most likely in other countries, there is a list of requirements for the various “grades” of office accommodation that makes the requirements very explicit.

This report also sets out that at the time of study, a number of the commercially available design software suites were more suited to the implementation of parametric modelling at the early design stage of building projects than others. Systems such as Architectural Desktop, Microstation Triforma, ArchiCAD, and CATIA were studied in some detail in the context of some simple early design stage sample buildings, and the team’s overall impression was that the first two systems - originally based on geometry engines - were somewhat less flexible in easily working with a full, integrated digital model of an early stage building design. 2005 is likely to see both Autodesk and Bentley with a even stronger commitment to “new-generation” building design products (Autodesk Revit and Bentley Architecture/Structural) and although these systems look quite promising, unfortunately neither they (nor Nemetschek’s AllPlan) were a part of this 2004 study.

The somewhat newer software approaches encapsulated within ArchiCAD and CATIA were assessed as currently having more potential for immediate use in an early design stage parametric modelling exercise, but still these systems had drawbacks in terms of lack of suitable dedicated space planning tools, ease of use, and cost (particularly in the latter case).

To support a true parametric modelling approach to early design, the idyllic system would seem to need the ease of use and speed of the more intuitive, 3rd-party low-cost 3D design tools (like Rhino and Sketch-Up), combined with the documenting, visualizing, and reporting abilities of Microstation; the trained user base, speed, and market presence of Autodesk ADT; the power, spatial / geometric tools and data management abilities of CATIA, and the 3D modelling flexibility, support for neutral data formats, and price point of ArchiCAD.

This report has also showed that IFC data is a prospective source of information in the implementation of an integrated digital building model that underpins a parametric modelling approach. The use of the neutral format IFC data ensures that data and models which are derived at the early design stage can be retained and further refined as the project proceeds from early design to more detailed design and more data becomes available. The report illustrates the feasibility of using a range of quite straightforward parameters to characterise the building model at the early design stage. In other words, the initial results of the Parametric Development initiative can provide a framework for a practical approach to the representation of various critical building sub-systems - at the early design stages.

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9. GLOSSARY

2D, 3D – two and three spatial dimensions

AC – Air Conditioning

ADT– AutoCAD Architectural Desktop

AEC – Architecture, Engineering and Construction

ArchiCAD – widely-used software package produced by Graphisoft P/L

AutoCAD / ADT – widely-used software package(s) produced by Autodesk P/L

BIM – Building Information Modelling

Building Model – (digital) representation of planned building

CAD – Computer Aided Design

CATIA – widely-used software package produced by Dassault Systèmes

Express – a formal method describing a product throughout its lifecycle, from time of conception through its manufacture to its time of disposal

Express-G – graphical representation for EXPRESS language

FM – Facilities Management

HVAC – Heating, Ventilation and Air Conditioning

IAI – International Alliance for Interoperability is a global consortium of commercial companies and research organizations founded in 1995 aimed at defining the requirements for software interoperability in the AEC/FM industry

IFC – Industry Foundation Classes are a specification for sharing data throughout a project lifecycle, globally, across disciplines and technical applications.

Lift – vertical transport system within a building (also known as passenger or goods elevator)

Microstation / TriForma – widely-used software package(s) produced by Bentley Systems

Parametric - relationships among and between all elements of the building model

RC – Reinforced Concrete

Rhino – software package from Robert McNeel & Associates

Single Project Model – similar to building model

SketchUp – software package from @Last Software Inc.

STEP – Standard for the Exchange of Product Model Data (ISO 10303 Standard)

Virtual Building Environment – similar to building model

Virtual Product Model – (digital) representation of planned product

VB – Visual Basic; one of Microsoft’s introductory programming languages

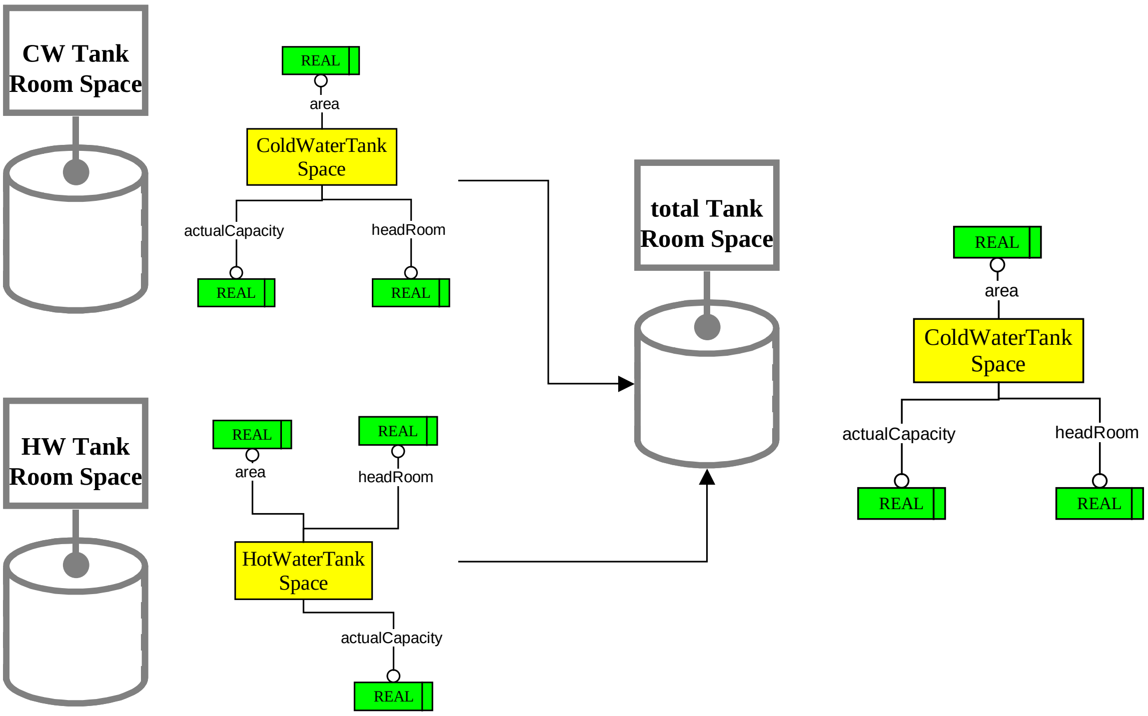
10. APPENDIX A

10.1 Data Requirements for Selected Building Sub-Systems

The Express-G representation of key parameters used as data inputs and outputs for a number of the selected building sub-systems are documented in this Appendix, and the abbreviation AC is often used to denote Air Conditioning.

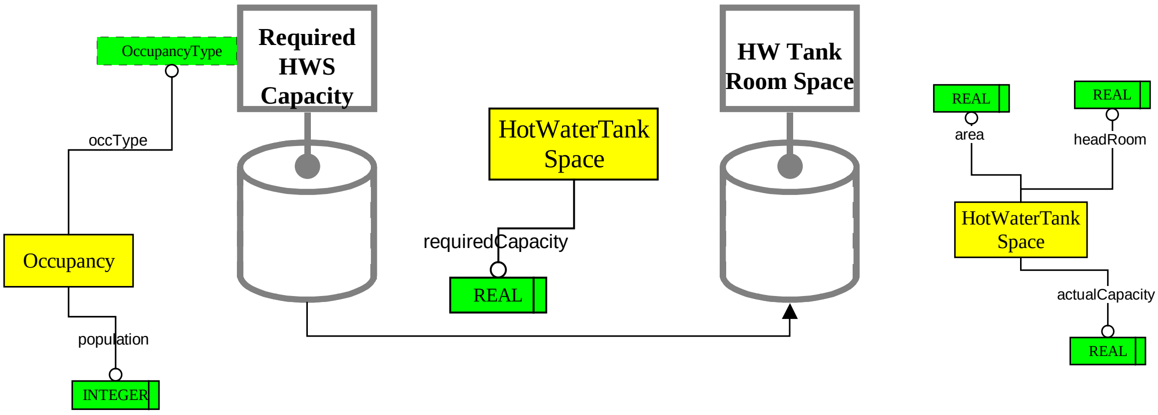
For example, the overall Water Supply system can be represented as below in Figure 47, with constituent parts as shown in Figure 48and Figure 49 below.

Figure 47: Water Supply System



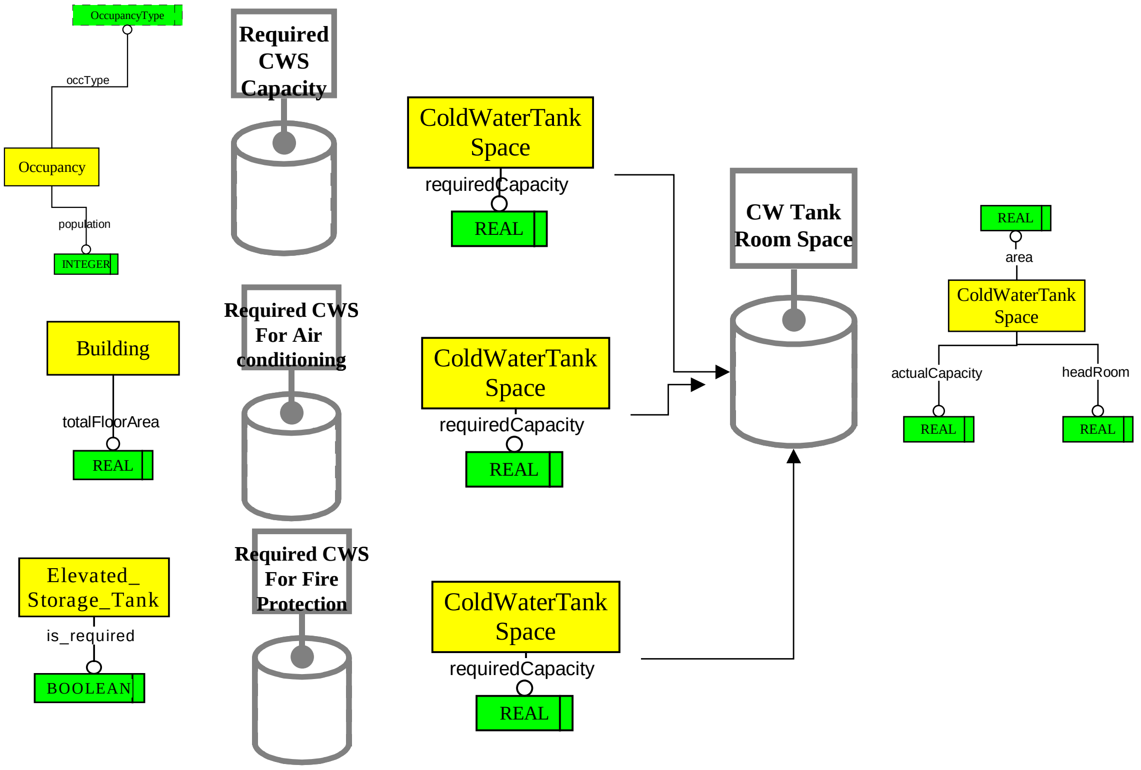
The Hot Water Supply sub-system can be represented as below in Figure 48.

Figure 48: Hot Water Supply



And the Cold Water Supply sub-system can be represented as below in Figure 49.

Figure 49: Cold Water Supply



Similarly, the Fire Protection system can be represented as below in Figure 50.

Figure 50: Fire Protection

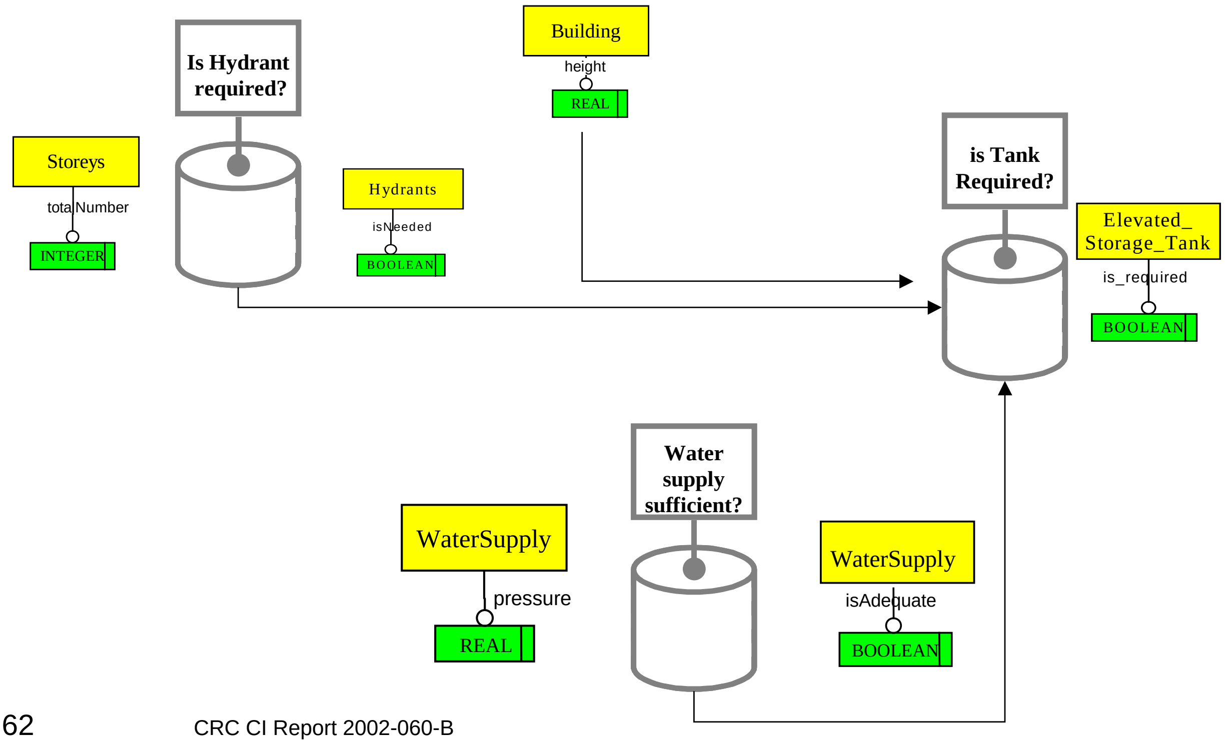


Figure 51: Vertical Transport

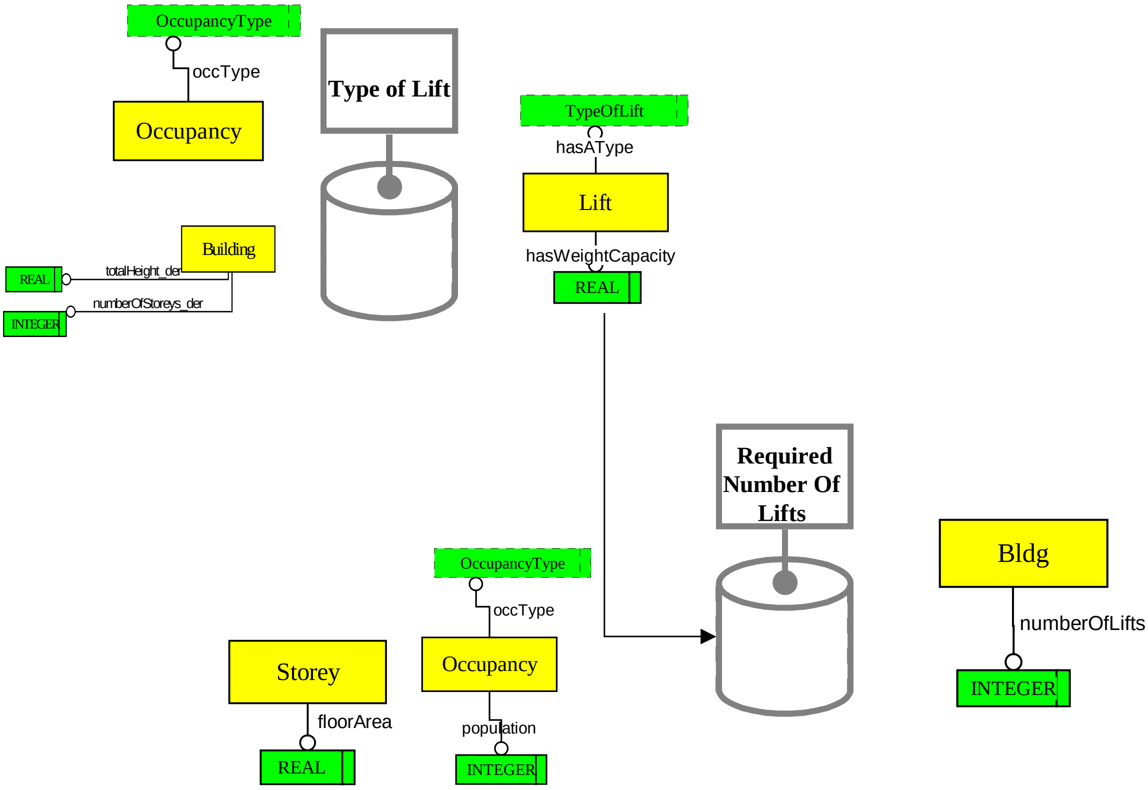
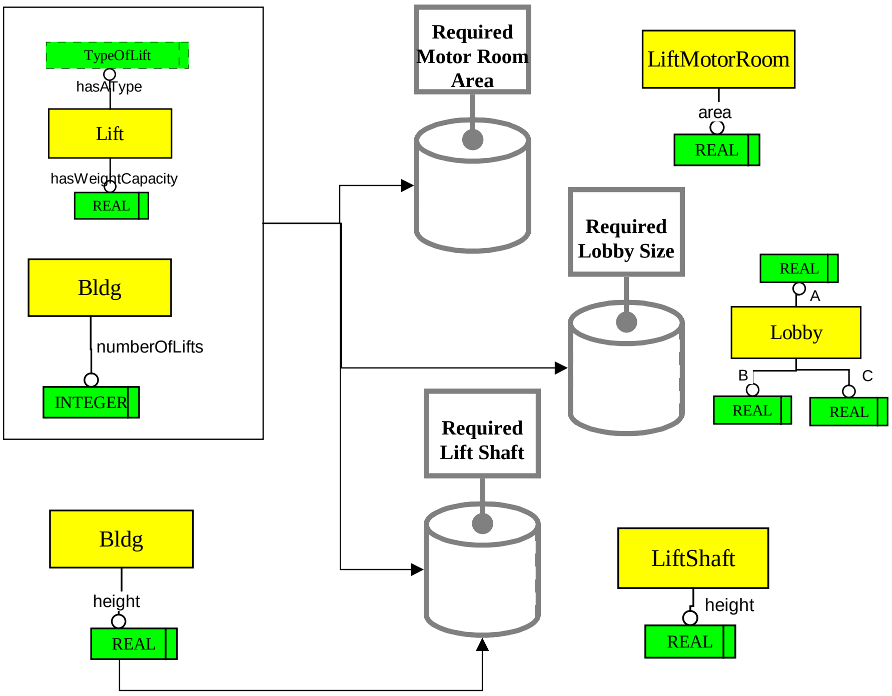


Figure 52: Vertical Transport (2)



Alternative/more
Detailed view
->next slide

Figure 53 : Vertical Transport (2A)

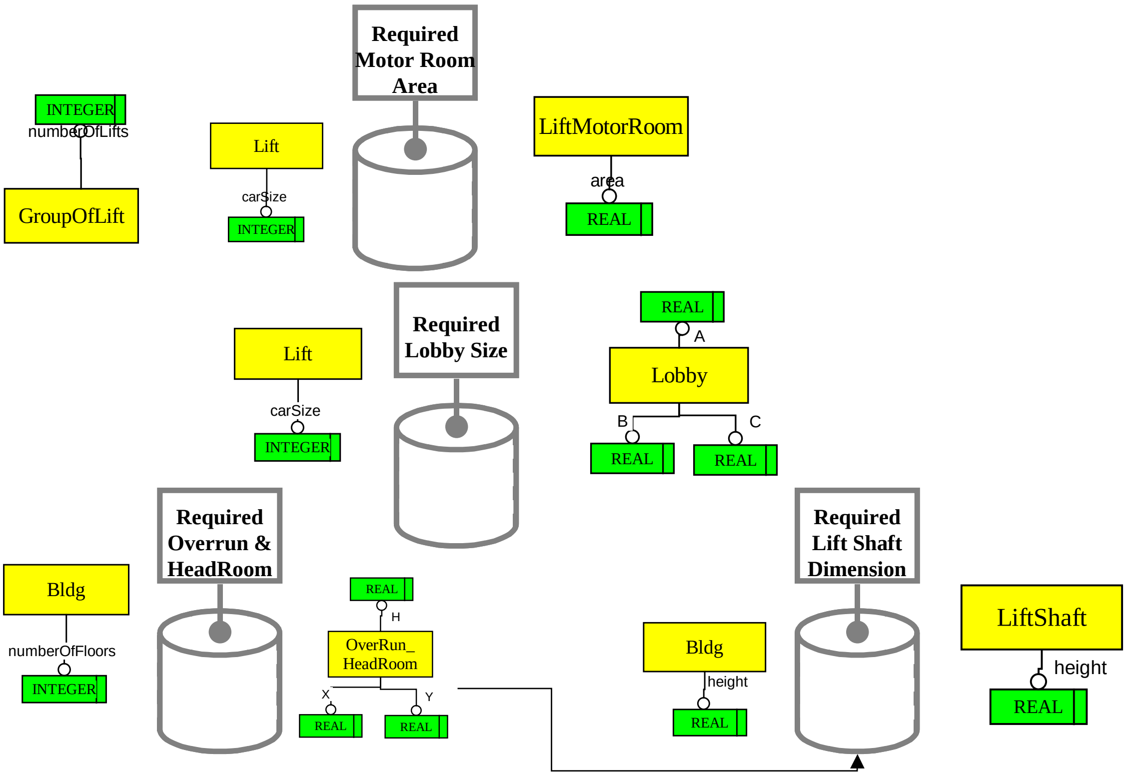
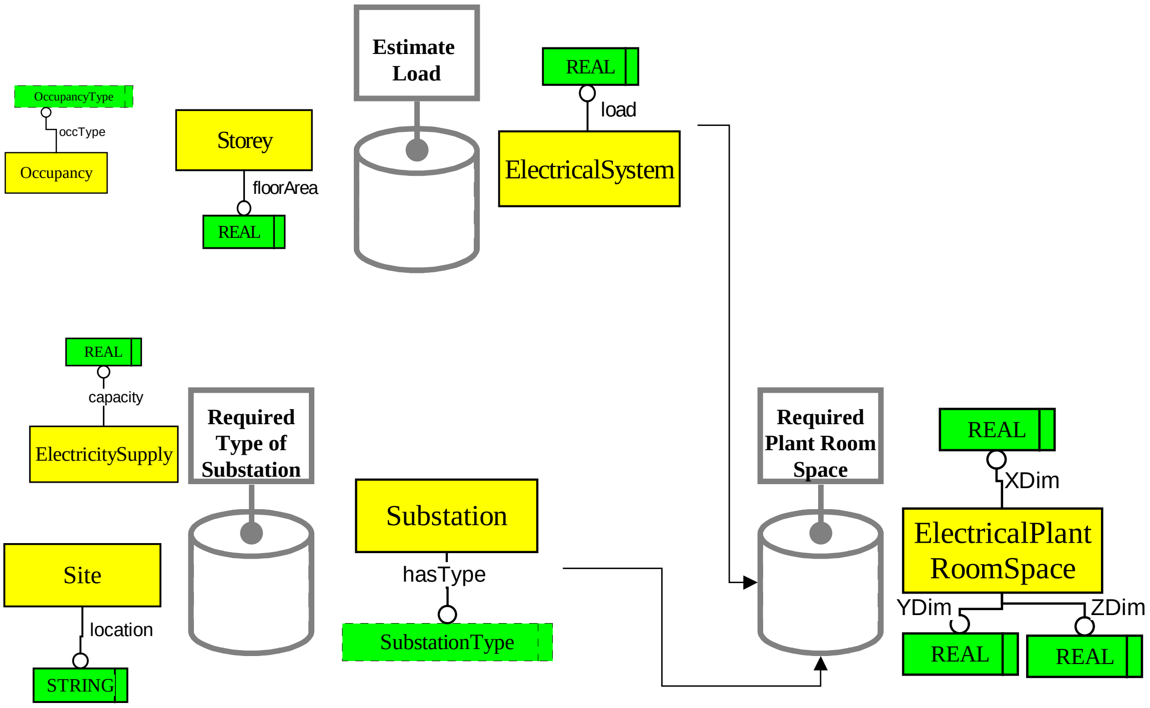


Figure 54 : Electrical Power



Due to project time constraints, although their Express-G representations have been specified, the Power sub-system and the Total Plant Room sub-system have not yet been implemented in software.

The anticipated Air Conditioning (AC) requirements for a building can be calculated at early design stage using the following logic of Figure 55, and the component sub-systems depicted in the following figures.

Figure 55 : Overall Air Conditioning (AC) Constituents

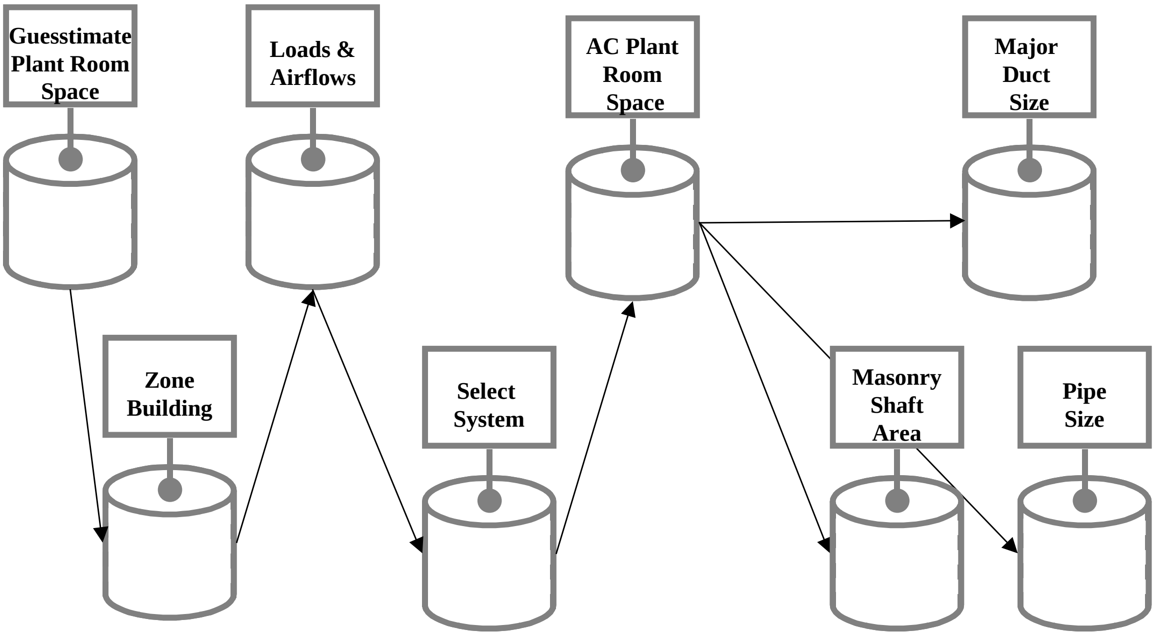


Figure 56 : 'Guesstimate' of Plant Room Space

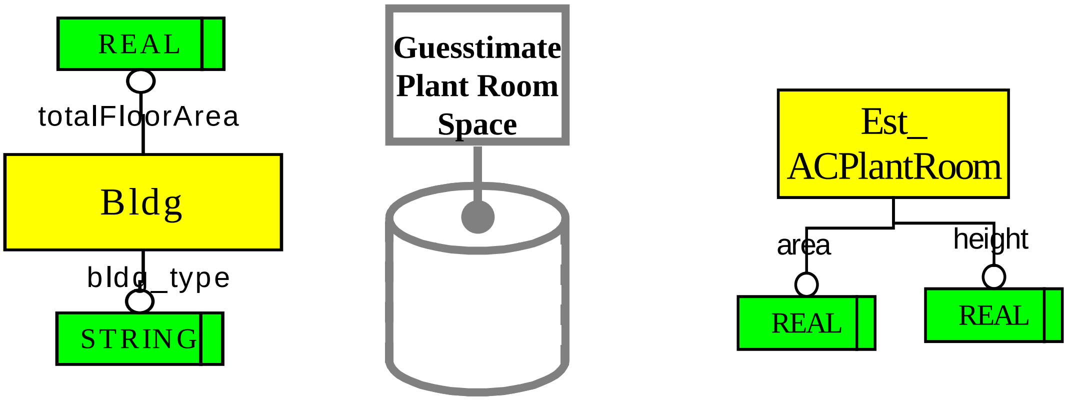


Figure 57 : AC Zones for Building

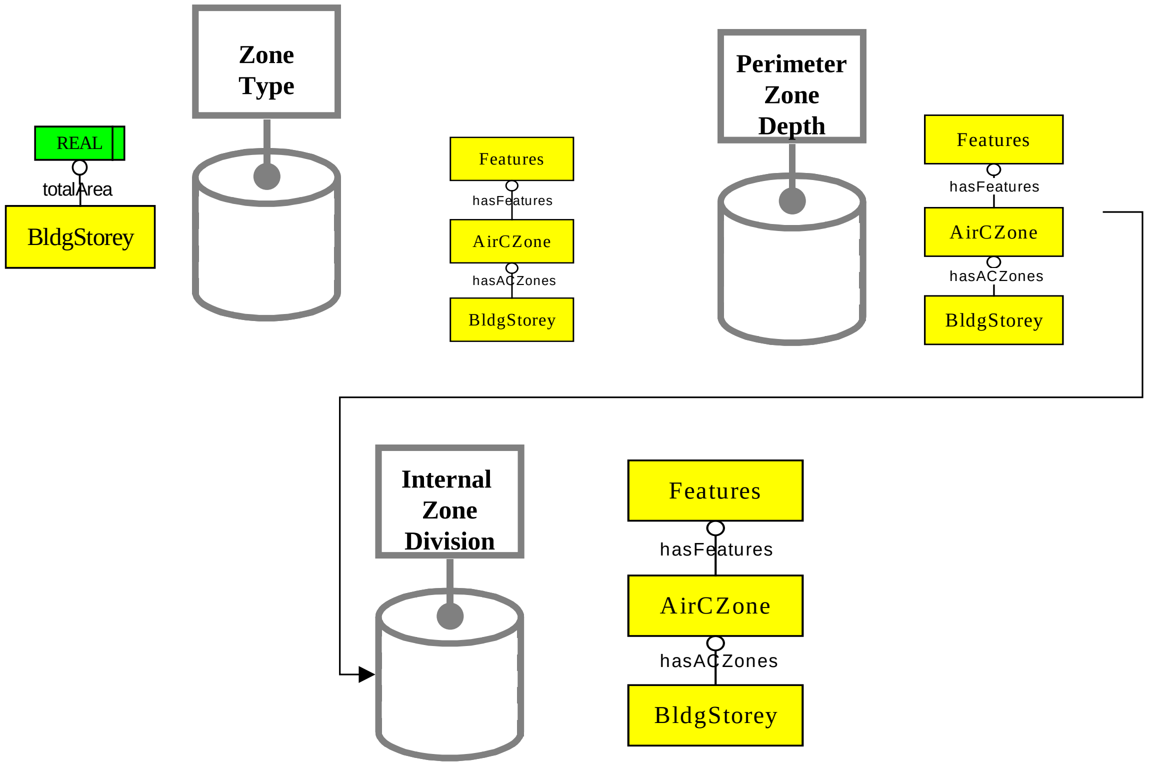


Figure 58 : AC Load and Airflow

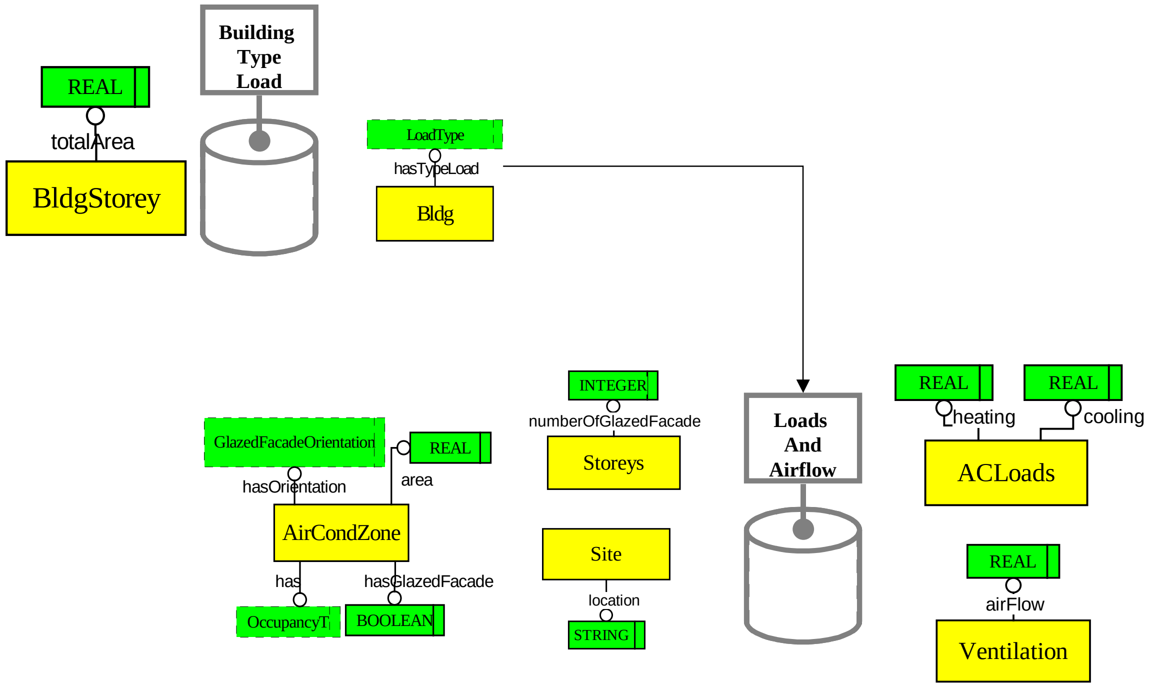


Figure 59 : AC System Selection

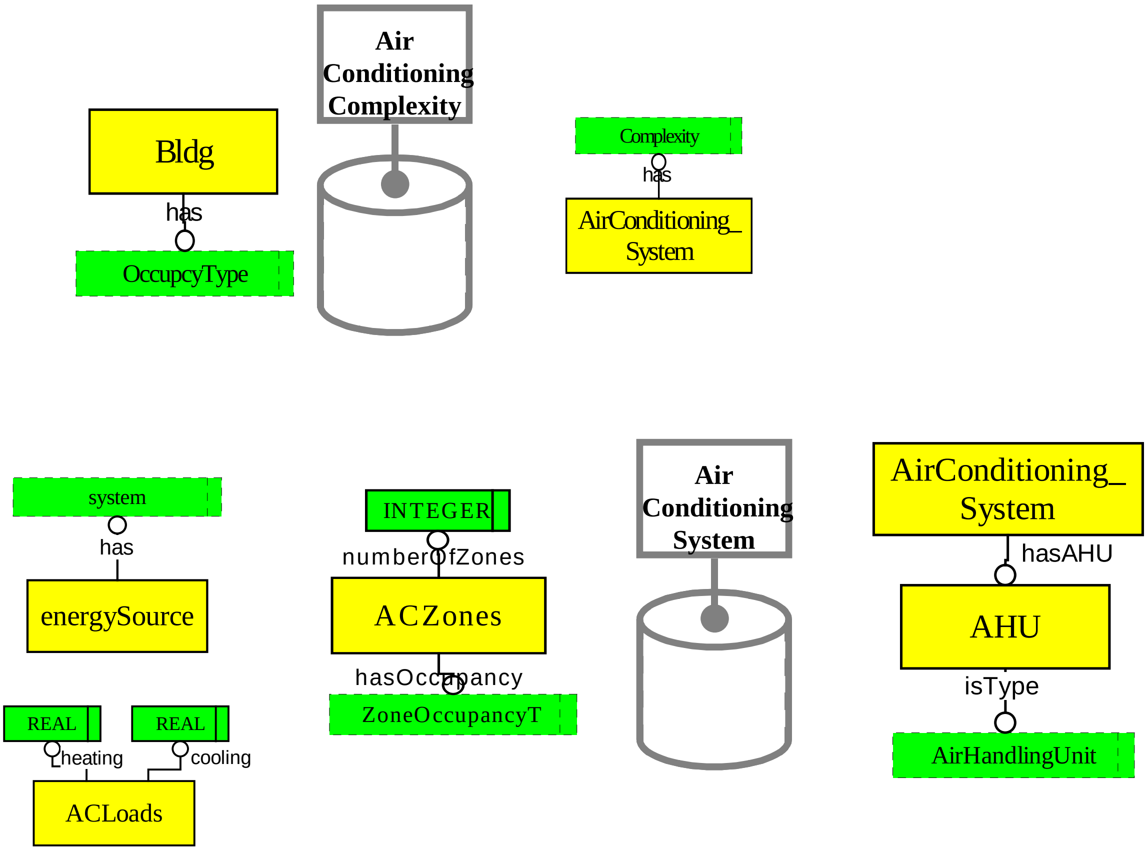


Figure 60 : AC Plant Room Space

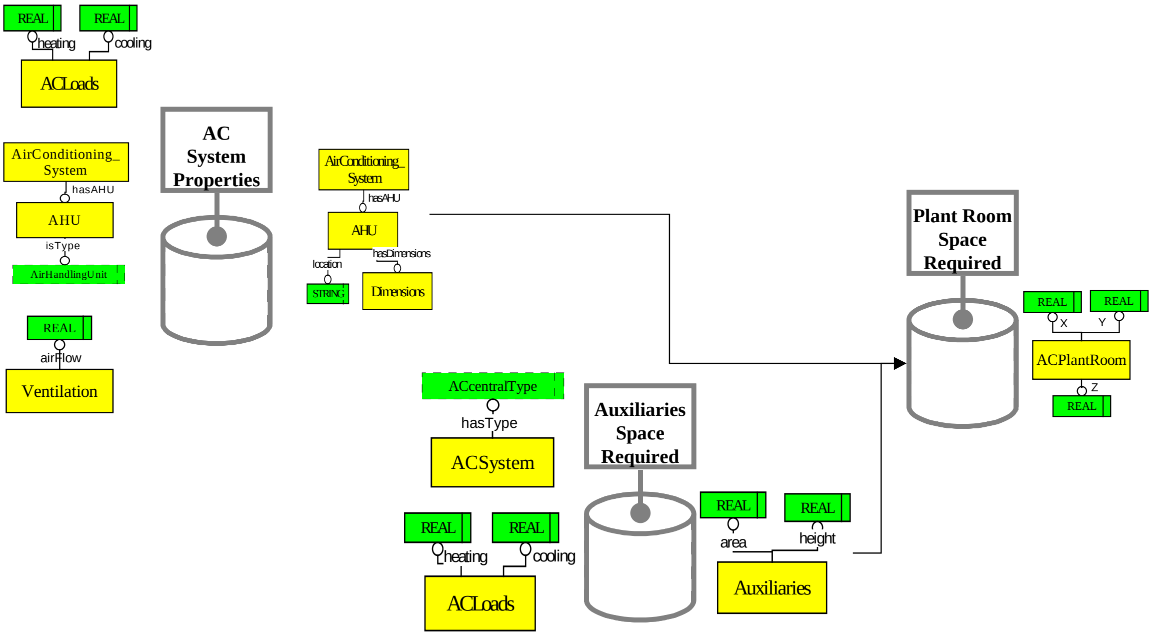


Figure 61 : Total Plant Room Space

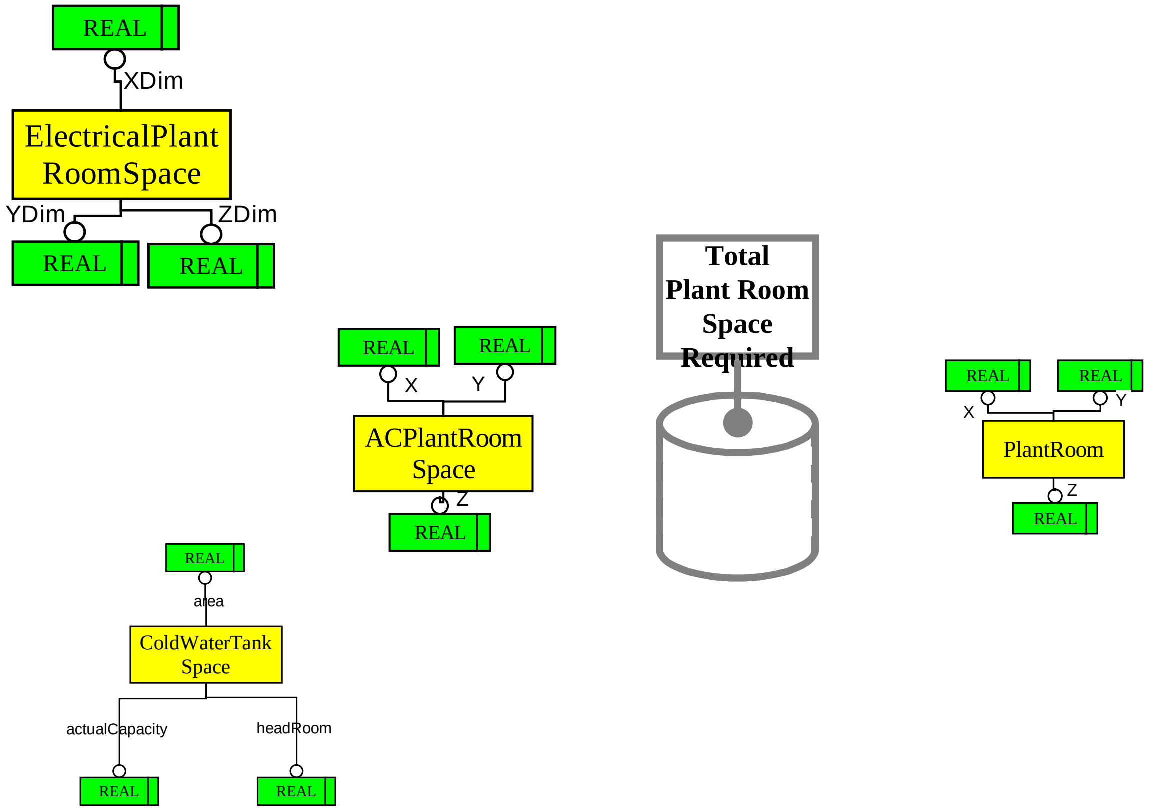


Figure 62 : Masonry Shaft

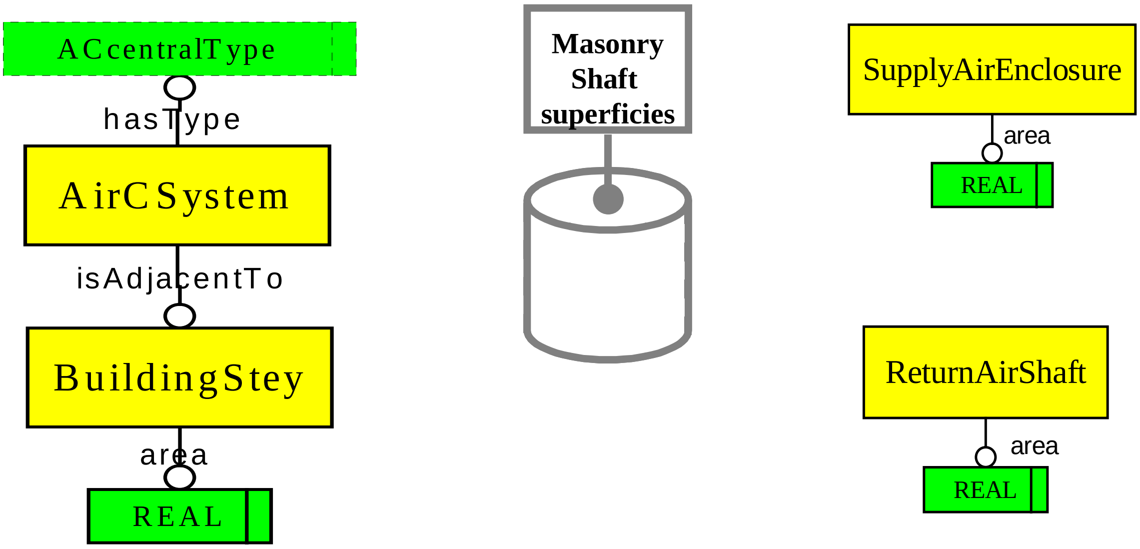


Figure 63 : Duct Sizing

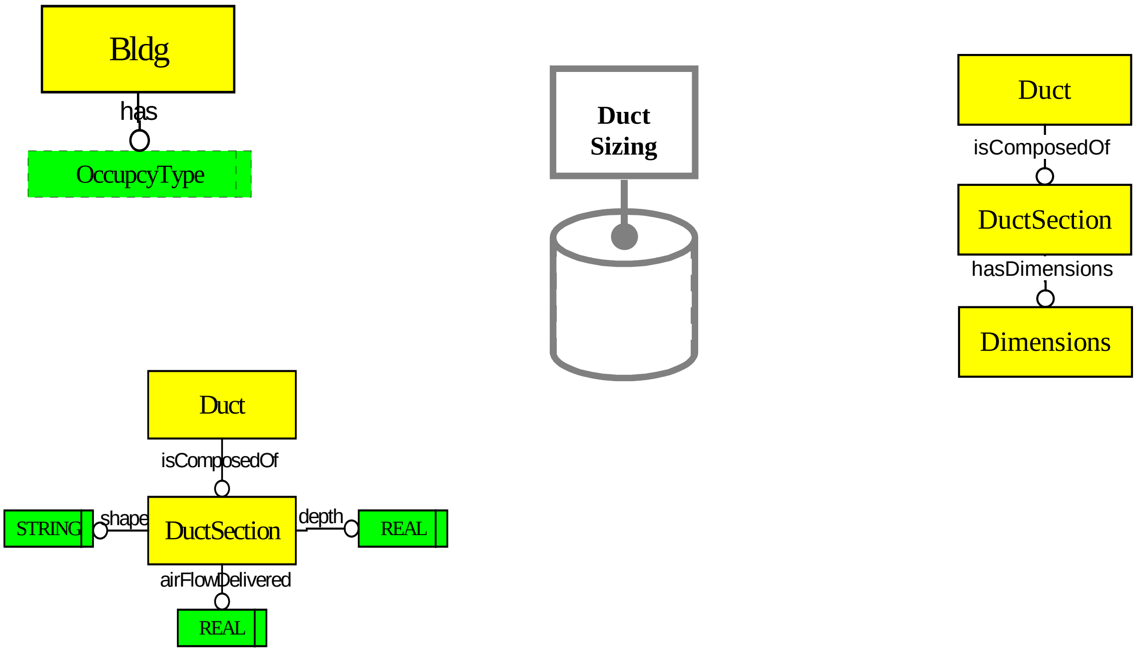
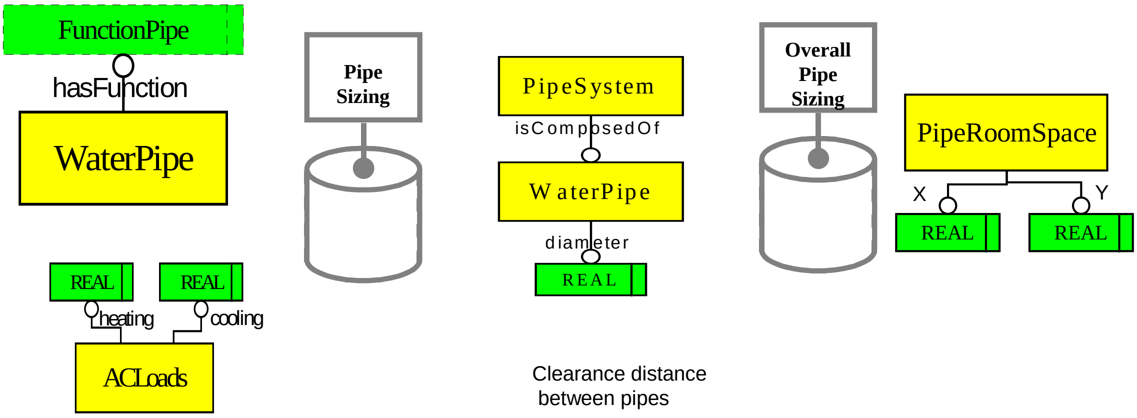


Figure 64 : Pipe Sizing



Clearance distance
between pipes