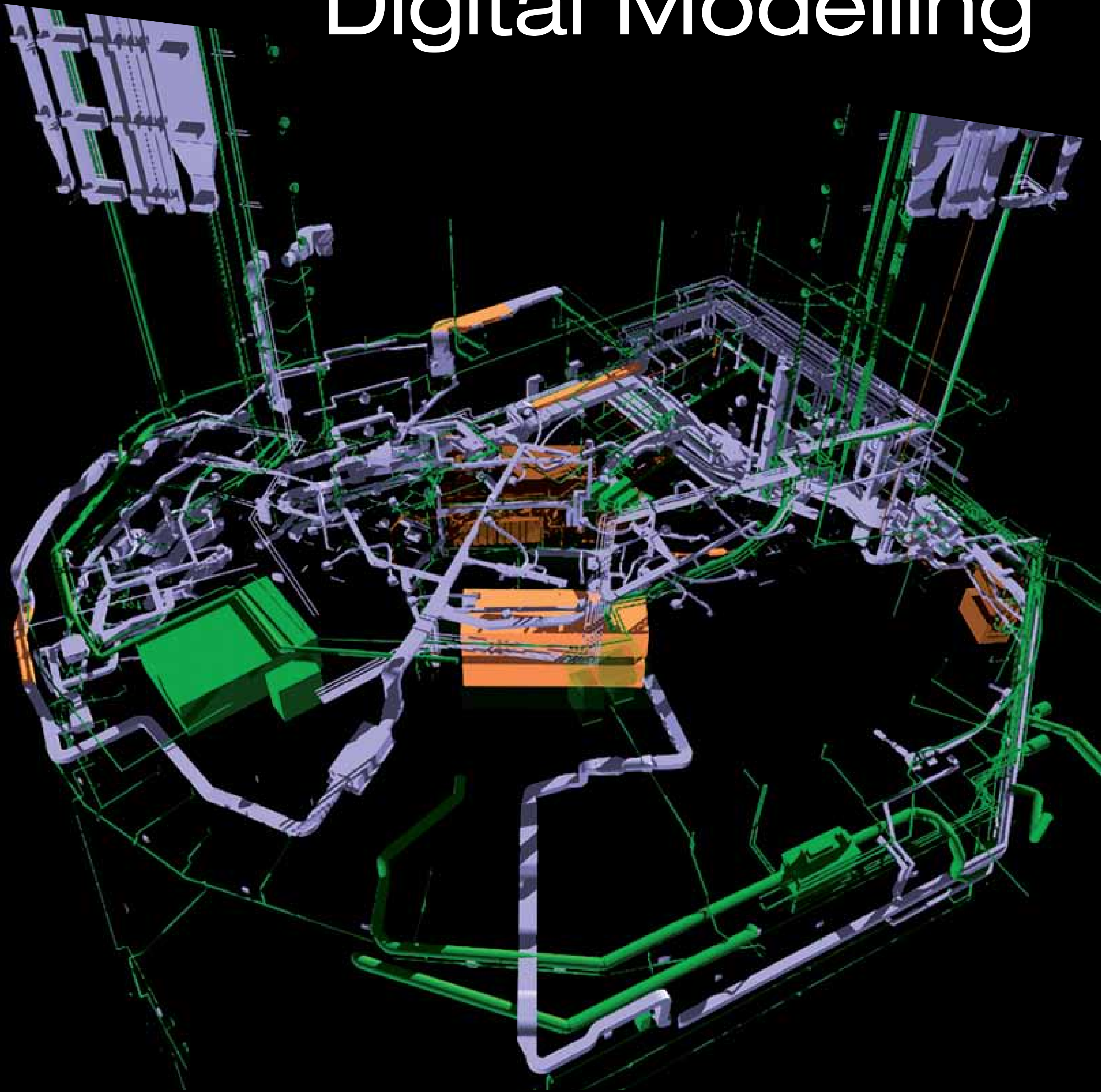
National Guidelines for Digital Modelling



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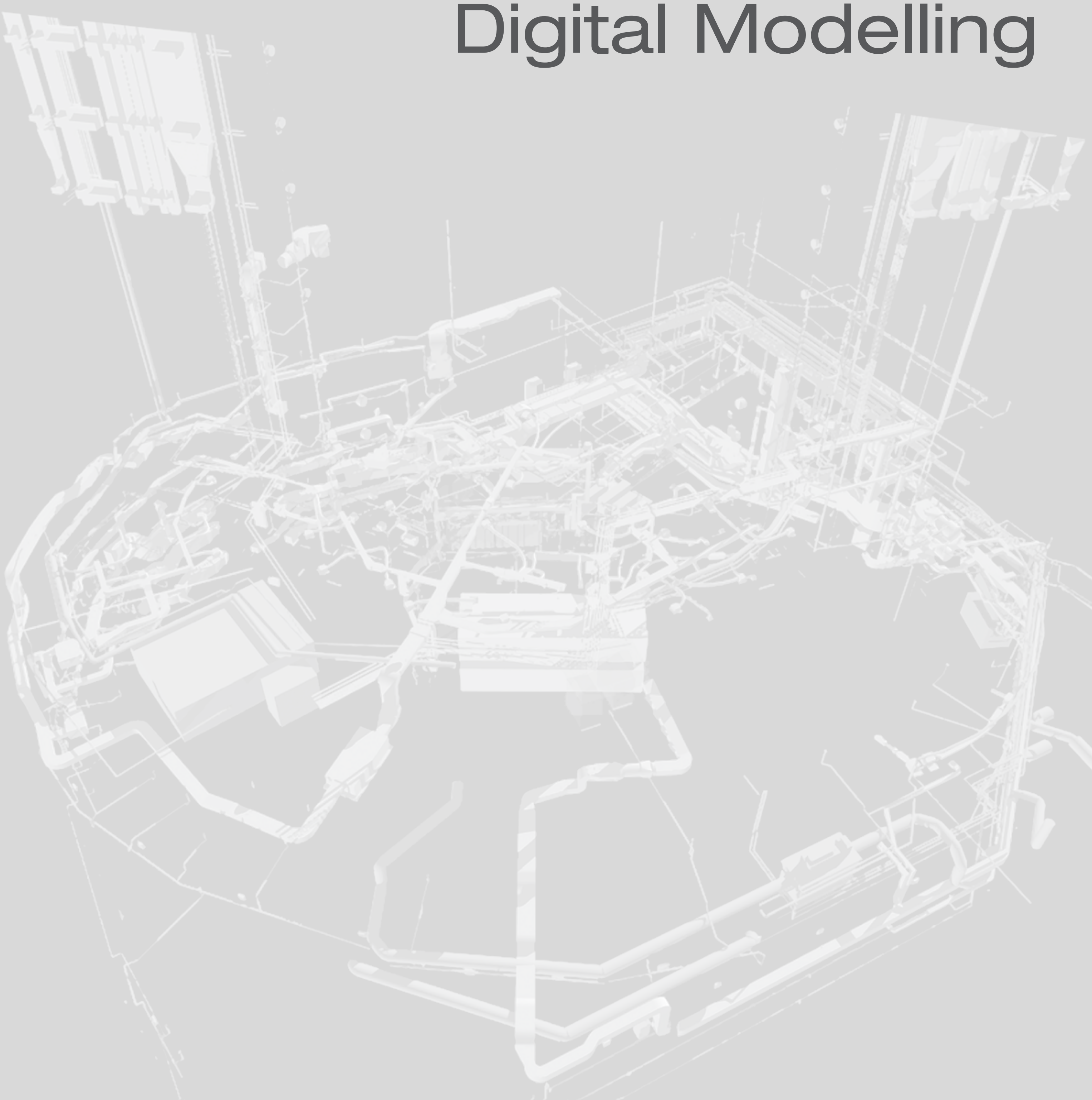

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The 1 Bligh project is a landmark for its use of BIM technology to achieve high ESD outcomes (a Six Star Green Star Rating is targeted), coordination and optimisation of the construction process. The cover image shows the multi-service coordination of blackwater treatment, mechanical services, fire and hydraulic services in the basement of the building.

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Foreword

These *National Guidelines* and *Case Studies for Digital Modelling* are the outcomes from one of a number of Building Information Modelling (BIM)-related projects undertaken by the CRC for *Construction Innovation*. Since the CRC opened its doors in 2001, the industry has seen a rapid increase in interest in BIM, and widening adoption.

These guidelines and case studies are thus very timely, as the industry moves to model-based working and starts to share models in a new context called integrated practice. Governments, both federal and state, and in New Zealand are starting to outline the role they might take, so that in contrast to the adoption of 2D CAD in the early 90s, we ensure that a national, industry-wide benefit results from this new paradigm of working.

Section 1 of the guidelines give us an overview of BIM: how it affects our current mode of working, what we need to do to move to fully collaborative model-based facility development. The role of open standards such as IFC is described as a mechanism to support new processes, and make the extensive design and construction information available to asset operators and managers. Digital collaboration modes, types of models, levels of detail, object properties and model management complete this section. It will be relevant for owners, managers and project leaders as well as direct users of BIM.

Section 2 provides recommendations and guides for key areas of model creation and development, and the move to simulation and performance measurement. These are the more practical parts of the guidelines developed for design professionals, BIM managers, technical staff and 'in the field' workers.

The guidelines are supported by six case studies including a summary of lessons learnt about implementing BIM in Australian building projects.

A key aspect of these publications is the identification of a number of important industry actions: the need for BIM-compatible product information and a national context for classifying product data; the need for an industry agreement and setting process-for-process definition; and finally, the need to ensure a national standard for sharing data between all of the participants in the facility-development process.

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Contents

Appendices 49

References 60

Preface

Since 2001, the Cooperative Research Centre for *Construction Innovation* has been committed to leading the Australian property, design, construction and facility management industry in collaboration and innovation. We have been dedicated to disseminating practical research outcomes to our industry — to improve business practice and enhance the competitiveness of our industry. Developing applied technology and management solutions, and delivering education and relevant industry information is what our CRC is all about.

We look forward to your converting the results of this applied research project into tangible outcomes and working together in leading the transformation of our industry to a new era of enhanced business practices, safety and innovation.

John V McCarthy AO
Chair
CRC for *Construction Innovation*

Dr Keith Hampson
Chief Executive Officer
CRC for *Construction Innovation*

Acknowledgments

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Australian Institute of Architects
Australian Institute of Building
Australian Institute of Quantity Surveyors
BuildingSMART Australasia
Facility Management Association of Australia

The project participants

Industry

ARUP

Bovis Lend Lease

mirvac

Sydney Opera House

Woods Bagot

Government

Building Commission

Brisbane City

Queensland Government

Research

QUT

RMIT University

Our thanks go to all those who attended and contributed to the success of this publication through their participation in the workshops held in Sydney, Melbourne, Brisbane and Perth.

Construction Innovation also wishes to thank and acknowledge Colleen Foelz (*Construction Innovation* and edenink) for managing the production of this publication, as well as Sue Ferguson (itzdesign) and Gail Cartwright (wordwright) for their design and editing respectively.

1. Introduction and structure of guidelines

1.1 Introduction

1.1.1 Building Information Modelling

The term Building Information Modelling (BIM) is widely and increasingly used within the building and construction industry. It is also a term which can cause confusion rather than providing clarification. Unfortunately it means different things to different people, and we don't propose to offer yet another definition here. We will, however, try to describe some characteristics of BIM that may be helpful.

For the authors of these guidelines, a model needs only two essential characteristics to be described as a BIM model. The first is that it must be a three-dimensional representation of a building (or other facility) based on objects, and second, it must include some information in the model or the properties about the objects beyond the graphical representation. Three-dimensional models without information, whether based on objects or line/arc/circle representations of the building, may still be useful, but they do not qualify as 'BIM'.

Within this description, there is a very wide range in the richness and complexity of the building model created. In a simple form, BIM models can be prepared for a single discipline and contain minimal information. The model can also provide for the integration of the contribution from many or all of the disciplines involved and be rich with useful information for contractors, trade contractors and facility managers in addition to the design consultants. In this second form, the model approaches or achieves the status of 'virtual building' where issues can be explored and resolved digitally before the building is created physically on site.

The degree of difficulty in migrating from the first to the second of these forms is significant, and the journey needs to be approached with caution and patience. Both forms can be described as BIM, but the gap between them is such that the significance of the term in one case is vastly different from the other.

BIM will continue to be used as a shorthand way of describing digital modelling, but it may be more helpful in discussion if we use terms that more precisely describe the nature of the model being considered.

1.1.2 Integrated practice

Integrated practice or integrated project delivery (IPD) are terms that are increasingly used to describe a move toward greater collaboration between members of a team that can include design consultants, the contractor and some specialist trade contractors.

Ideally, this integration will begin during the early design stages of the project, where the contributions of all parties can be incorporated with greatest benefit and least cost.

The challenge is to develop effective and affordable ways to form and manage the team, while still maintaining a demonstrable level of competitiveness.

Some of these issues continue to be considered by teams such as the AIA Integrated Practice Task Force and a working group formed by the Australian Procurement and Construction Council (APCC) and the Australian Construction Industry Forum (ACIF).

IPD can, with benefit, be established in an industry based on former technologies, but it will work better if developed in conjunction with high-end BIM.

The adoption of truly effective virtual building, and potentially off-site manufacture, will require the development and adoption of IPD for its effective implementation.

1.1.3 Sharing information

Not all members of the consulting team will be working in the same or compatible software packages and the membership of the consultant team will inevitably change between projects. The challenge then is to facilitate an exchange of information between the consultant team or with the wider IPD team. That challenge has at least two facets.

The first is the range of software being used, which in many cases communicate with each other only with great difficulty or not at all. The International Alliance for Interoperability (IAI) — buildingSMART — has worked for more than a decade to develop a common standard Industry Foundation Classes (or IFCs) for the exchange of information between programs. When fully achieved, it may deliver a degree of interoperability in the construction industry similar to that in the banking world, where any of us can use our credit cards to access money through teller machines owned and operated by a bank other than our own. The concept of IFCs is described below.

The second is the way in which the same software family is used by different practitioners, which can also make collaboration a frustrating and often difficult task. This was much in evidence in the use of 2D CAD in the industry over the past 30 years, and created problems that were avoidable if practices had widely adopted a common methodology for the way that the tools were used.

These guidelines are intended to provide the beginnings of the conversation and collaboration across the Australian construction industry that might lead to the development and adoption of common standards that are truly 'national' and facilitate much better flexibility and opportunities for collaboration in BIM than would otherwise be the case.

1.1.4 Industry Foundation Classes

Industry Foundation Classes (IFCs) were developed to reduce the technical risk in projects by supporting the exchange of information on building projects between the various participants through the life cycle of a project. The development of IFCs has been driven from the software development side of the industry. Software vendors realised that supporting a single standard for information exchange would reduce their development costs considerably (through not having to support a range of exchange standards), and would assist the purchasers of software by improving the content and quality of information that could be exchanged. They were called Industry Foundation Classes because they were intended to support the entire *industry*, by acting as a *foundation* for software development and information exchange, through the definition of standard *classes* within software.

The vision for the capabilities of the IFCs can best be described with an example.

> *Take a concrete column. This may be initially positioned by the architect's sketch designs as part of a notional building structure within the model. This information will then be passed across to the structural engineer, who will import the information on the structure into structural analysis software.*
>
> *The structural design will then be refined and the final information for the size of the column, grade of concrete and reinforcement configuration will be added to the construction documentation.*
>
> *The estimator can then attach unit rates to the formwork, concrete and reinforcing steel for the column, which will be included in the cost estimate for the project.*
>
> *The constructor will also use the quantities for formwork, concrete and reinforcing steel, together with productivity factors to generate a Gantt chart for the project, including the column.*
>
> *The constructor could then use the combination of Gantt chart (sequence and duration of tasks) to generate a 4D (space + time) visual animation of the construction process to allow the various subcontractors to coordinate the construction activities.*
>
> *Ideally, the IFC model for the project will be updated through the construction process and an 'as constructed' model will be provided to the facility manager on handover. This could form the basis for management of the facility throughout its life, and could be updated as various components and systems are updated.*
>
> *This could then be used to plan the refurbishment and eventual demolition of the building.*

It should be noted from the above description that the IFC model of a project will contain information about the components that make up a building, the processes used to construct and maintain it, and the various organisations that have played roles in this process. Geometric information is only a part of the total information that is retained and is stored as part of the 'object' definition within the IFC model, together with all of the other information necessary to support the operations described above.

1.1.5 Changing context of project documents

The transition from drawings to BIMs as the means of design collaboration requires consideration of the nature of the new digital environment.

How have we worked in the past? In the traditional process, we use certain types of documents to 'carry' the information needed by a project partner. For example, manual drawings or 2D CAD describe a building by independent 2D views (drawings), plans, sections and elevations. Editing one of these views requires that all other views must be checked and updated if necessary, a clumsy and error-prone process that is one of the major causes of poor documentation today. In addition, the data in these 2D drawings are graphical entities only (e.g. line, arc, circle).

The work practice of sharing drawings has not evolved past converting them from hard copy to digital documents. Although we can take advantage of the graphics in 2D CAD data much more easily (at the receiving end), the process is primarily a drawing type, suited for contractual estimating and construction, being used as a means for sharing building design information. Specifications are produced in a separate process to fully describe a building.

For example, a reflected ceiling plan defines the architectural concept chosen for the ceiling, and becomes a framework for the several services consultants who need to coordinate their fittings and fixtures with the layout.

BIM provides us with the potential to integrate the entire project information into a digital database specifically for built facilities instead of the disjointed hard copy currently used. This database is an integrated description of a building and its site comprising objects, described by accurate 3D geometry, with attributes that define the detailed description of the building part or element, and relationships to other objects (for example 'this duct is located in the storey LEVEL 9' of a building).

Digital modelling technology has a huge impact on the nature of practice. The building models created can still provide traditional drawings, but can produce far more information that can be used for other purposes in automated processes.

The major difference is the use of the intelligent content of BIM, where objects are defined in terms of building parts and systems (e.g. spaces, walls, beams, doors, building storeys). Instead of sending a plan (the most common document used to inform a project partner of the scope of the topic under consideration), we can now use a model.

1.1.6 Implications for project delivery with BIM

Three areas of current practice will be affected by building modelling implementation.

Technology implications:

- Software and hardware limitations
- Implementation of the new technologies (e.g. web portals, GIS, laser scanning)
- Need for development of greater interoperability and integration of softwares for the whole project life cycle
- Development and demonstration of industry-ready exchange protocols
- Handling of very large model file sizes and techniques for sharing information

Process implications:

- Changing work practices and relationships (e.g. IPD vs traditional practice)
- Need for guidelines of common industry practice (e.g. use of exchange protocols and data content)
- New jobs created with different skill sets and responsibilities
- Value added to the models in different time frames
- Greater focus on information management over whole project life cycle, not just the construction phase
- Co-location of project team for critical phases of design collaboration

Policy implications:

- Need for industry standards
- Government or organisation commitment and resourcing for BIM implementation

- Risks of sharing model data and the need to protect intellectual property, legal, insurance, risk, responsibility issues and cost
- Quality Assurance (QA): can others trust your model and data?
- New definitions of services and fee splits, with levels of model detail and categories of information to be specified

1.1.7 Project collaboration process

Virtual Building is worth adopting even if only used by a single discipline, but its greatest productivity benefit is gained when used in multidisciplinary collaboration, with the interoperability of different softwares.

A principal objective of collaboration is to allow partner disciplines to take responsibility for a specific aspect of the project. For example, a services engineer measures the performance of the architectural design and sets environmental measures. The architect has had some preliminary dialogue about the structural system, and now an analysis is needed to refine structural concepts, set out, member sizes etc.

Contrast this with the use of a conventional 2D drawing with limited types which is used to inform the collaborator. This requires extensive one-to-one discussions, and information additional to the set of data required to carry out the task.

Process definition is weak in the industry at present due to:

- its unrecognised value
- the almost impossible task of achieving it in the absence of common industry languages
- current work practice agreements
- the lack of robust tools that support the definition and auditing of data.

Productive use of BIM is dependent on the development of defined processes.

A list of possible generic objectives for collaboration will seek to:

- use a reference/master model as the basis of a discipline design
- measure the performance of selected criteria
- analyse the behaviour of systems, usage etc.
- coordinate a subsystem with the master model
- support an industrialised manufacturing/ assembly application.

In each case, the receiver has a defined role to perform and the collaborators both need to ensure that the required information is available.

There is also a need to define the 'how' of data exchange. The ability to export and import building model data between different propriety softwares, based upon agreed standards and protocols, is required. Only then can the richness of the data and its relationships be maintained, during repeated exchanges.

This is a big challenge for the industry.

1.1.8 New methods of practice — 'integrated project delivery'

IPD describes new ways of working together. The use of building modelling can assist IPD through an earlier engagement of contractors and subcontractors in project delivery through collaboration, alliancing, 'lean construction' or other 'non-traditional' methods.

Productivity benefits come from the collaborative generation, sharing and re-use of project data.

This will mean that project teams will be structured in different ways; work patterns changed with redistribution of effort to earlier design phases 'design vs design development/coordination'; risk and responsibilities shifted to different participants and different project stages; client expectations and re-configuration of fees due to project information created at different phases.

Design process changes

Digital Modelling can greatly enhance the productivity and quality of the design and construction industries to support traditional practice through greater visualisation and communication, higher quality documentation and integration of project data. BIM uptake is worthwhile even if only used this way.

Construction process changes

Digital modelling enables more accurate off-site fabrication; finer detail construction scheduling; coordination and communication with subcontractors, designers, owners and authorities;

less need or no need for shop drawings and as-built documents produced by updating the 4D model used for scheduling and construction management as the building is constructed.

Maintenance and operation process changes

Project information is available in an accessible and structured format; greater digital linkages with other business processes are possible, and higher quality digital information which has not been manually re-entered.

1.1.9 The guidelines context: Why the need for guidelines?

The purpose of these guidelines is to assist in and promote the adoption of BIM technologies in the Australian building and construction industry, and try to avoid the uncertainty and disparate approaches that created inefficiencies with the implementation of 2D CAD over the past three decades.

The guidelines are also part of a larger CRC for *Construction Innovation* program that seeks to encourage increasing digital modelling practice in the whole building and construction industry.

There are two related CRC for *Construction Innovation* research projects:

- 2007-01-EP Interoperable Standards Development
- 2007-03-EP Collaboration Platform Project (BIM Model Servers)

Formative basis for the guidelines

The guidelines represent a broad approach to the task — more a 'Managers Guide to BIM' — outlining the process changes necessary for industry implementation, rather than a prescriptive standard. The document seeks to promote the development of consistency within the industry which is also 'simple and flexible'.

The guidelines are not a 'standard' that codifies industry practice in a formative standard, like the more comprehensive USA, Norwegian, Danish and Finnish standards. Australian industry BIM usage has some way to go before it can be considered to be a mature technology, and so the guidelines should be seen as a first step towards unifying industry standards of practice.

The guidelines have been informed by lessons learnt from organisations and projects that have implemented integrated digital modelling, including the associated case studies; research; and feedback from seven industry workshops held between July and November 2008 in five Australian capital cities.

The guidelines provide information to assist in creating well-structured IFC and non-IFC-compliant digital models that will allow the sharing of data between disciplines; for the procedures and formats of data exchanges between disciplines; and for digital model management, coordination, merging and use of aggregate project digital models.

Outputs of the Australian Institute of Architects Integrated Practice taskforce have been included in the jointly developed BIM practice diagram — 'Towards Integration'.

To be successful, the process of developing and adopting appropriate principles will depend on the active support and participation of the members of the industry in a collaborative and flexible way.

The focus of the guidelines is the process implications of BIM implementation

The process implications are the most pressing for the industry to address, but the technology and policy implications, although also urgent, will be framed by how new BIM tools are employed and new modes of practice emerge using new processes. This will be an iterative, creative process.

1.2 The potential of digital modelling

The object-orientated model is more valuable because the properties and relationships within the objects enable useful information to be derived directly or by simulations or calculations.

Figure 1.1: BIM example — key concepts

(Image courtesy of J Mitchell)

Figure 1.1 illustrates a project comprising a building on a site including storeys, which contain spaces and building elements such as walls, doors, windows, slabs and columns. It is not just 3D geometry, but is rich in data embedded in the properties of the objects.

The building model:

- allows the integration of a number of discipline models to enable coordination and clash detection of the 3D building geometry
- is a database which enables the geometric representation and building information to be connected in new ways (e.g. specifications potentially can be generated directly from the database using information included with the individual objects in the model)
- can be used to create a 4D construction scheduling and planning model, linking objects with construction activities to test construction strategies, buildability and sequence options. Cash flows and progress payments can be monitored through a 5D model linked to the 4D construction model
- can be updated with 'as-built' project information for building operation and facilities management (FM)
- improves the quality of design decisions by facilitating multidisciplinary collaboration in more frequent and faster design iterations and option development
- quickens the decision-making process through better communication of information that is available earlier and is more accurate, to shorten the time for design and construction
- reduces on-site waste by enabling more off-site fabrication, and optimisation of design solutions
- enables new business and procurement models to be considered
- facilitates developing and comparing design options for environmental sustainability during the formative design stages and reporting on expected design performance.

Digital models can help to resolve the puzzles of constructing buildings, like the Lego instructions that show specific objects, with particular relationships, added at a construction stage, in a particular location.

The practice focus changes from drawing or specification production to creating information for incorporation into a database for the project life cycle.

Therefore the quality and consistency of this database is crucial to BIM implementation.

1.3 Quality of models: Well-formed model building

For a model building to be of good quality it needs:

- to be well structured — where the appropriate tool is used to create the objects; objects are geometrically precise; and the model is structured for intended analysis or exchange
- to have the appropriate information required by the receiver
- to be verifiable.

Model checkers are a new type of tool for BIM that exploit the intelligence of BIM objects, to verify model quality (a 'spell checker' for building models).They can confirm that models are consistent either to internal office standards, external client standards or to statutory regulations.

For example, model checkers can compare design model options and highlight variations, or analyse architectural and structural model alignment of geometry, location, openings etc.

See Appendix 1 *Model checking and auditing* for an in-depth explanation and examples.

1.4 Types and uses of models

A range of different types of building models can be created that are used for varying purposes.

Pre-design, briefing or massing models:

- For space planning and program compliance/ code checking, where only the external form of the model is used for volume definition or planning approval

Design models:

- Visualisation models that represent detailed properties of the building — shape, materials, lighting — and are models which may also simulate interaction and movement
- Models used to simulate and verify building properties such as: thermal performance, energy use, structural calculations, acoustics, heat flows, Life Cycle Costing (LCC), Life Cycle Analysis (LCA) and environmental sustainability
- Building services models: system analysis/ simulation
- Design coordination and clash detection
- 4D scenario planning — staging of work for large complex projects, or continued use of adjacent spaces being refurbished and emergency simulations
- Optimisation, virtual prototyping or optioneering
- Operation simulation and space management.

Construction models:

- Clash detection, 4D construction sequencing/ scheduling, prefabrication coordination, 5D predicted cash flows

Fabrication models:

- CNC manufacture, construction sequence, temporary works, off-site fabrication and procurement

FM models:

- Asset management, resource use monitoring, operation simulation.

1.5 Model usage over whole building life cycle

The consideration of CAD/BIM use has normally only been associated with the design phase of project delivery.

Models can be created and used over the range of project phases in a building's life cycle. Fundamentally, they enable sharing between consultants, sharing with the construction team, sharing with the owner/facilities manager and generally with any stakeholder in the project that has a need for information. The 'building digital database' can be applied to the earlier pre-design stage as well as the construction and post-construction stages, where there are considerable potential benefits. The planning, design and construction stages of a project might be three to four years duration, in contrast to the operation and use of a building at 50 to 100 years. So an accurate and durable database can be a powerful and valuable management tool.

Common or shared information that is required by a number of participants needs to be identified and the responsibility for its creation and maintenance allocated and managed. This will help to avoid duplication and variations of the same object and its associated data, which may create errors and inconsistencies in the project database. The structure and quality of the data is vital and has to be integrated to enable its efficient use and re-use over the project life cycle. This object data will change and develop as the project progresses, when more detailed information is required for increasingly complex analysis/simulation and communication.

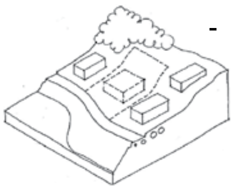
It is also likely that the 'ownership' and responsibility for some data will be passed on to other participants as the project progresses. For example, an architect may initially add columns and plumbing fittings to a model, but 'hand them over' to the structural engineer and hydraulic engineer respectively for their specialist contribution.

1.6 Model development phases

Ideally, building models develop over time with increasing levels of detail and complexity, but in a different way from 'traditional documents'. There is a need to re-define the type and detail of information required as models develop and when this data is likely to be required.

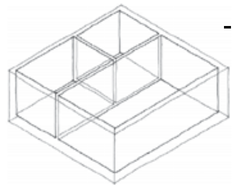
Model development, as a linear development will seldom occur, can be described in the following general phases:

Phase 0 – Briefing/Pre-design



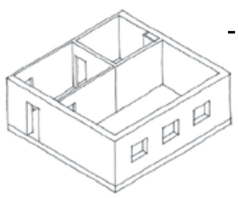
- Clarification and formalisation of the different requirements and restrictions of the project at design brief stage and proposed delivery time frame
- Client requirements: room schedule and functions, capacity, sizes and relationships. Budget and financial constraints
- Legal requirements: zoning, Building Code of Australia (BCA), regulations, infrastructure, environmental requirements
- Site constraints: soil etc
- Preparatory BIM of existing buildings, structures and services on site
- Detail level: coarse 3D massing model, information in document form: legal, analysis, design briefs, building model may contain ground, surrounding developments, GIS information, extent of existing and new infrastructure, supply networks, basic services etc.
- Costing: project feasibility and project budgets
- A capability is emerging that enables the transfer of basic functional requirements into an initial model and the subsequent audit of the spaces and functions provided in the model compared to the briefed requirements

Phase 1 – Conceptual design



- Clarification at an early stage of the project of the overall concept and functional properties of possible project solutions, updated project brief
- Building's overall form, structure and relationships to surroundings, plus rooms and their relationships
- Volumes of building's external geometry in simple format
- Checks volume can contain rooms specified in room schedule: interaction between modelling volumes and rooms
- Able to extract areas and volumes at overall level for estimating, analyse estimate of gross and net areas differentiated by function (usable vs circulation areas), and analysis of area efficiencies (area/ plant spaces)
- Can be used for early negotiations with authorities
- Can be used for simulation of light and shade on building and surroundings
- Can be used as basis of design competition for consultants
- Detail level: building, rooms, function, geometry/location
- Costing: cost planning.

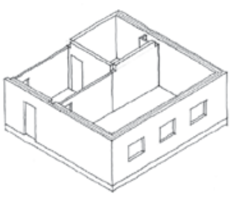
Phase 2 – Schematic design



- Basis for decisions on selecting conceptual solution — the model to reflect the functional and physical structure of the building at an overall level
- Layout of rooms and building elements in general (e.g. footings, walls, structural floors, roof)
- Building elements have geometric shape and location, building envelope

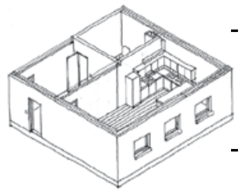
- Used to develop basic structure for assessment of building's overall physical and functional properties, used for spatial coordination between disciplines
- Used for preliminary assessment of evacuation, fire, simulation of indoor environment, lighting, thermal, acoustic performance
- Can be used for early tendering
- Building objects shown in simple outline, without specified attribute data (e.g. a 'generic' wall object used, not a '270 double-brick cavity wall with exterior face brick and interior render and paint finish')
- All openings in walls, structural floors and roofs shown in general detail
- Detail level: building elements, geometry/location, preliminary building property data
- Cost: benchmark cost planning, estimating, design cost checks, elemental cost , planning objects at increasingly granular levels (2–4), preliminary Life Cycle Cost Plan
- FM: model of existing buildings at Phases 2–3 where detailed construction information is not required for FM purposes.

Phase 3 – Developed design



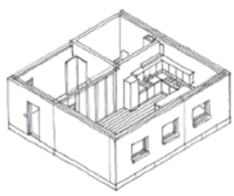
- Basis for the authorities' consideration for approval; coordination tool for the parties in the project; confirmed project brief
- Sufficient information for approval by authorities
- Building elements given attribute data (e.g. door with specific 'fire rating')
- Use for structural resolution of conflicts
- Objects specified as construction types with structural make-up in principle — cavity walls specified and shown
- Detail: building elements, preliminary finishes, building property data
- Basis of basic 4D/5D model
- Cost: Updated Cost Plan, Updated Cash Flow, Updated Life Cycle Cost Plan
- FM: model of existing buildings at Phases 2–3 where detailed construction information is not required for FM purposes.

Phase 4 – Contract documents



- Basis for invitations to tender, estimating, tenders and construction planning
- Information of building elements detailed for tendering and quantity take-off
- Need to be able to extract parts lists and descriptive bills of quantities (BOQ), produce drawings where necessary corresponding to traditional drawings: general assembly, details
- Used for builder as basis for production planning
- Final coordination of all disciplines with checks for clashes, discipline model consistency
- Detail: building elements, final finishes, building property data
- Cost: Updated Cost Plan, BOQ, Detailed Object Definition.

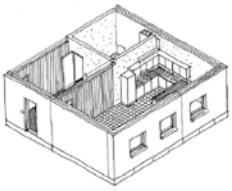
Phase 5 – Construction



- Basis for construction
- Used for construction planning, scheduling (4D)
- Contractors, subcontractors and product suppliers information required
- Previous performance requirer replaced with specific attribut data, and new data added – supplier, guarantees, time

- Detail: building elements, finishes, production/process, product data
- Cost: priced BOQs, quantity take-off, quotation systems, 5D, contract administration

Phase 6 – Post construction/Facilities management



- Setting up ‘as-built’ documentation
- Model with updated building elements, components and properties
- Data used from discipline models for FM including operation, maintenance, renovation, extension
- Detail included in the model at this stage: building elements, finishes, function, geometry/location, building elements properties, construction, product data, operation and maintenance manuals
- Cost: maintenance and replacement modelling, and management information about cost of plant and equipment, maintenance, warranties, operation instructions etc.

The adoption of modelling will change some of the traditional processes. The distinction between schematic and developed design is blurring, and it is anticipated that before long we will simply have a design stage. Even then, the boundaries between design and documentation and the boundaries between disciplines will become less distinct.

1.7 Object data levels

The objects that go to make up a virtual building will vary in their level of detail. As the project proceeds, building objects may be represented with more detailed geometry and with additional or different information attached to the objects. Consequently, more detailed objects replace generic objects and can then provide more accurate analyses and simulations of building performance.

Highly detailed objects are unnecessary, undesirable and expensive in terms of storage space at initial stages.

‘Detail levels’ is a useful concept for obtaining agreement about content of objects at different stages. This will be necessary when defining the extent of information required at formal exchanges.

Level A

- Strategy and performance criteria based on volumes and areas
- Planning activities, concept development
- Non-geometric, briefing data or line work, areas, volumes zones etc.
- Block model
- Conceptual cost allowance (e.g. $ per m^2 of floor area, $ per hospital bed, $ per parking space)
- Total project construction duration or phasing of major elements
- Environmental requirements

Level B

- Generic objects in visualisation/concept models to allow for ‘digital prototyping’
- Generic elements shown in three dimensions with maximum size, and assumed system types
- Preliminary time scale ordered for appearance of major activities
- Estimated cost based on measurement of generic element (e.g. generic interior walls or doors)
- Specific room requirements can be attached
- Approximate quantities of materials for preliminary environmental analysis

Level C

- Specific objects in detailed model, engineering design for digital prototyping
- Specific elements confirmed 3D object geometry, dimensions, materials, capacities, connections
- Time-scaled, ordered appearance of detailed assemblies

- Estimated cost based on measurement of specific assembly (e.g. specific wall type: 70 interior steel studs with 10 painted plasterboard both sides)
- Precise quantities of materials with percentages of recycled/locally purchased materials
- Accurate analyses and simulations based on specific building assemblies and engineered systems for engineering calculations, visualisation clash detection, construction sequencing, cost planning and estimating

Level D

- Detailed objects in production model for shop drawing/fabrication for purchase, manufacture, installation, specified fabrication and assembly detail including construction means and methods (cranes, man-lifts, shoring etc.)
- Specific manufacturer selections
- Precise analyses and simulations based on specific manufacturer and detailed system components, committed purchase price of specific assembly
- Manufacturing logistics procurement

Level E

- As-built objects — for operation and FM, actual record costs, purchase documentation
- Commissioning and recording of measured performance
- Maintenance and operation requirements
- These object detail levels may correspond closely with model development levels in 'traditional' practice, but should be varied to suit alternative project delivery methods

1.8 Modelling implementation

The use of modelling can be adopted for projects in differing ways. The Australian Institute of Architects (AIA) diagram, 'Towards Integration', which has been developed jointly by the AIA's Integrated Practice Taskforce and the CRC for *Construction Innovation*, seeks to describe these possibilities graphically in defined stages. This is intentionally a simplification of what is a complex and evolving process to assist in developing awareness of modelling implementation. It is also a vocabulary to assist common understanding, and has already been a valuable communication tool for the range of professionals in the building procurement, design and construction industries.

It is intended and expected to develop over time.

The diagram is arranged in four major stages, each with two subdivisions.

Stage 0 – 2D documents

0A Manual drafting
0B CAD 2D drafting

Stage 1 – Modelling

1A 3D CAD modelling
1B Intelligent 3D modelling

Stage 2 – Collaboration

2A One-way collaboration
2B Two-way collaboration

Stage 3 – Integration

3A Local server
3B Web-based server

Stages 0A, 0B and 1A represent pre-BIM and are not addressed in the guidelines. A large part of industry practice is still operating at this stage.

Stages 1B, 2A and 2B are the main focus of the guidelines and describe the first stages in the adoption and use of BIM. They also represent that part of the industry which is implementing BIM. The evidence is that most practitioners are currently at stage 1B.

3A and 3B describe technologies and processes hosted on model servers which are not addressed in detail in these guidelines. They are considered separately in the CRC for *Construction Innovation* Research Project 2007-03-EP Collaboration Platform Project – BIM Model Servers (see Appendix 4: *Model servers* for a brief description).

These model servers are yet to be implemented in the Australian industry, but are currently being used for research at UNSW and QUT.

Towards Integration diagram

TOWARDS INTEGRATION

Taking the Australian construction industry forward

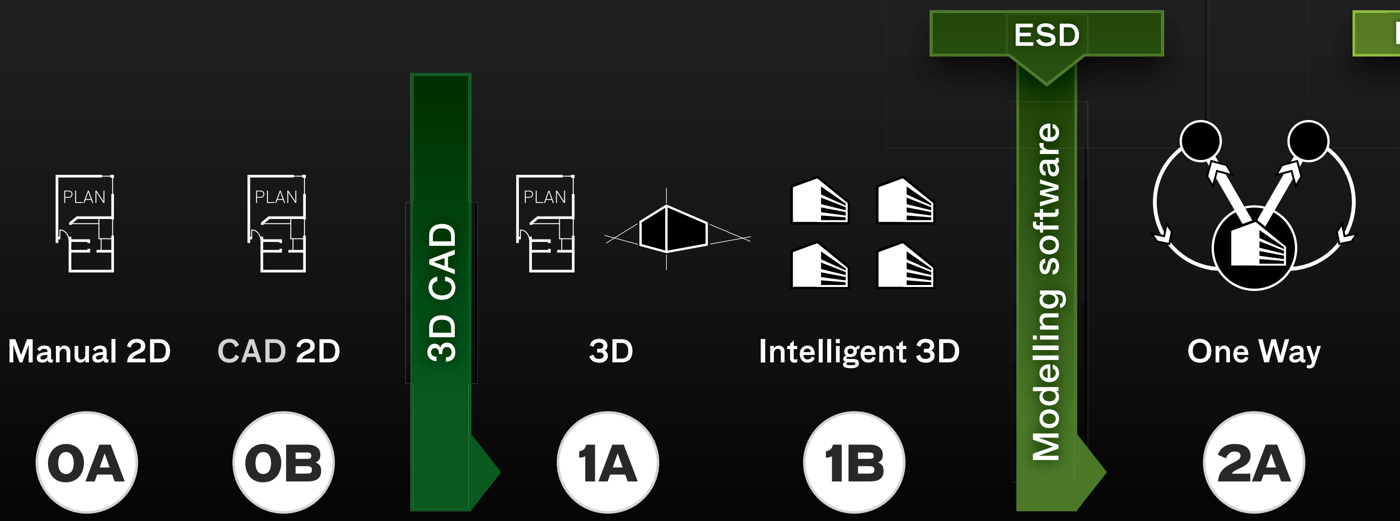
WHERE WE WERE	WHERE WE ARE

0 – 2D
Manual and CAD based (2D or 3D)

1 – MODELLING
Single-disciplinary use of object-based
3D modelling software within one discipline

2 – COL
Sharing o
between t

Representation | Pr



BUSINESS MODEL

ISOLATED | **COLLABORAT**

Legend
Communication type
traditional
digital

UPTAKE

TOWARDS INTEGRATION

	NEXT STEP	WHERE WE ARE GOING

LLABORATION
f object-based models
wo or more disciplines

3 – INTEGRATION
Integration of several multi-disciplinary models using model servers of other network-based technologies

ototype | Full Information Capture

Efficiency

Single platform/IFC

Project Economics

Two Way

2B

Interoperability

Local Server

3A

Distribute Information

Building Project

Lifecycle Economics

BIM

Web Server

3B

Collect Information

Information Management Repository

Life of Building

TRUST

VE	INTEGRATED

Australian Institute of Architects

CRC Construction Innovation
BUILDING OUR FUTURE

1.8.1 Digital modelling: 1B – Intelligent 3D modelling

High quality single discipline model

This well-managed model is for internal use, and to produce traditional documents for coordination with other consultants and stakeholders. It enables better capture, integration and cataloguing of project information as it is being created. Efficiencies are leveraged by using BIM software to its capabilities and to enforce resolution of design to greater detail.

A well-constructed model will reveal building issues in early phases that can be addressed immediately, rather than leaving them to be resolved during the construction phases. This requires modelling procedures and standards, so that building model objects are digitally created and connected in consistent ways.

Better visual communication is possible through quick and accurate creation of views, especially 3D views and sections, for all project participants and automated drawing production and coordination.

Automated model checking is possible in authoring software or with specialist model checking software to identify geometric clashes or inconsistencies to assist with QA (e.g. Solibri Model Checker and Navisworks can also check by using project specific 'rules' or parameters).

Widespread industry capability at Level 1B can have a significant effect on the quality of project coordination and documentation.

To achieve broad adoption of BIM at this level of capability would be a significant advance.

Requirements of models

- Appropriate BIM tools used for all objects (e.g. all walls created with Wall Tools)
- Precise geometric sizes and locations for all objects
- Objects fully populated with correct properties and attributes
- Information embedded or linked in appropriate and consistent manner

Products possible

Traditional views/drawings/documents can, if required, be automatically extracted and internally consistent: automated 2D plan, sections, elevations, details, automated schedules, quantities, e-specifications, 4D construction scheduling, 3D visualisations, perspectives, sun studies and animations. Extracts are possible for quantities, areas, volumes etc.

Challenges

While good progress is being made in the adoption of modelling in the industry, there are a number of significant challenges that will constrain future developments until they are resolved. Some of those challenges are:

- lack of an adequate classification system for Australian building information (see Section 1.10.5 *Emerging building information classification system*)
- lack of design library objects with well-constructed information rich objects in open format (see section 1.10.3 *Need for Australian object libraries*)
- lack of manufacturers information in usable format with 3D geometry and attached data. No agreed industry minimum properties of objects defined (e.g. window properties: 3D geometry, model number, cost code, 'U' value, fire rating, specification, AS standards, warranty, installation instructions).

Example 1: An architect who already uses BIM software for 'traditional documentation', 3D visualisations and 2D document production, develops BIM capabilities to construct an accurate, well-structured 3D model, using correct object modelling tools, embedded with object data that can be extracted for a range of purposes. The 3D geometry has data and 'intelligence' built in. The objects are semantically rich with relationships which are an essential part of the object's properties (e.g. a wall object can have defined ways of adjoining another wall object). A wall 'hosts' window or door objects within it, as it does in real construction, and exact dimensional relationships can be defined. Coordination of the design and detailing is enhanced by the visualisation of the design and the intelligent relationships enforced by the software.

Example 2: An HVAC subcontractor receives 2D documents and creates an intelligent 3D model that is used for detailed routing of ductwork, coordinating the plant room layouts of plant, ducts, pipework and cables. This model is used to generate a schedule of ducts with identification numbers (IDs), quantities and costs. The 3D model is then sent to a CNC machine to cut and fabricate the ductwork and bar code IDs are added to facilitate site delivery and handling. Large scale 3D perspective views can be issued to the site installers to aid understanding, and minimise site errors, especially for complex plant room set-outs.

1.8.2 Digital collaboration: 2A – One-way collaboration

One-way exchange of a BIM model file is exported to other participants for visualisation, communication, assessment, analysis, simulation or discipline design.

The feedback to the authoring discipline would be conventional feedback for design and coordination in a traditional format (e.g. paper/digital drawings, email, or sketches requiring no digital model return). The original model is updated in digital isolation from other discipline models, and so model coordination is not an issue.

Purposes of digital exchange

- Visualisation: high model quality is not as important or necessary for initial graphic communication
- Dimensional coordination: basis for 3D geometry use and set-out; model geometry quality is critical for coordination
- Analysis: LCA, environmental or estimating analysis software use. Quality and detail of model and embedded information is critical (e.g. sun studies, lighting analysis with correct information included)
- Model merging: for checking/clash detection

Some coordination is required to select compatible file formats, versions, data structures etc, and the agreed formats make it easier for quality control and definition of responsibilities and ownership.

Partial models are defined for individual discipline requirements (e.g. no need to export whole architectural model to structural engineer, so a selection of object data is exchanged).

***This is a big step forward from* 1B – Intelligent 3D modelling**

Requirements

- Well-made model as per 1B – Intelligent 3D modelling
- Agreed purpose of exchange
- Correct and complete model for the purpose and project phase
- Agreed project settings and parameters:
  - File naming
  - File structure
  - Model divisions/separations — model arranged in a convenient way for other discipline usage (e.g. separate multi-level building into storeys and define the divisions: top of structural slab, or bottom of structural slab)
  - Coordinated system and building reference point
  - Software/exchange protocol (e.g. dwf, IFC)
  - Requirements of other software — objects, space/room and site data etc.
  - Verification of model quality by model checker
  - Model transfer method — file, database, model server
  - Definition of partial model data requirements; data required 'downstream'
  - BIM information levels to be exchanged
  - Expected information that will survive or not get changed by exchange
  - Notification of errors, conflicts, clashes
  - Agreed template file with project-specific parameters for more consistent and reliable results

Examples

- A partial architectural model is exported to a structural engineer to share project dimensional and geometric set-out and object properties.
- A model manager imports two or more discipline models to perform clash detection/ coordination and reports back issues, but with no digital model export to the original authors.

- Structural engineer exports model to steel shop detailer/fabricator for detailed design and fabrication

Challenges

- Software incompatibilities/interoperability problems – incompatible versions of software
- Chance of loss of some embedded object data or geometry errors
- Model needs to have an agreed structure for geometry and associated data
- QA definitions
- Need to change collaboration methods and relationships
- Ownership, risk and responsibility for exchanged data

1.8.3 Digital collaboration: 2B – Two-way collaboration

The common BIM model file data is shared by two or more project participants in an iterative collaborative process. A significant amount of coordination is required to establish compatible file formats, versions etc. and the correct selection of objects and their mapping settings.

The iterative design process is greatly enhanced by access to analysis softwares and increased feedback. This can produce better decisions and tighter integration of disciplines.

A project could be made up of a number of discipline models that, when combined, better describe the whole (e.g. discipline models that share project geometry and object properties for visualisation, communication, assessment, analysis and simulation contribute to better discipline design and coordination of aggregate project model).

Purposes of digital exchange

- 3D geometry used for clash detection for Design Phase
- Creation of Project Life Cycle BIM Model
- For construction/fabrication for limited trades only for coordination and clash detection
- For analysis or simulation of building performance

This is a major step forward from 2A – One-way collaboration

Requirements

- Well-made model as for 2A – One-way collaboration
- Agreed purpose of exchange
- Correct and complete model fit for the purpose and project phase
- Agreed project settings and parameters:
    - common coordinate system
    - common building reference point
    - model management/coordination
    - definition of partial rights/access to model
    - definition of partial models

Challenges

- Identification/control/documentation of authorship/ownership of amended model
- Has it been amended to conform to agreed standards/requirements to allow import back into original software?
- Is it compatible?
- Defining project standards and enforcing them
- Software incompatibility/interoperability problems
- Chance of loss of some embedded object data
- Need to change collaboration methods and relationships
- Round tripping — what works, what gets lost, what gets corrupted?
- QA definitions
- Handover definitions
- Authorship, ownership, risk and responsibility of exchanged data

A project, in practice, might have some disciplines collaborating at different levels (e.g. architectural and structural at Level 2B, and all other discipline collaboration at level 2A).

1.9 New types of jobs and skills

New skills and knowledge are required to create, coordinate and manage the process of modelling, as seen in the case studies. These new skills and roles are still emerging and are as yet hard to define. There will be opportunities for those able and willing to shape new services that progress the contribution of models to the intended outcomes.

The role and contribution of experienced technical staff capable of generating and manipulating models in any discipline has grown and is likely to continue to do so for the immediate future. While not rivalling their professional partners, they have a growing responsibility for the creation, communication and analysis of the information that is at the heart of the model.

1. **Generic skills for modellers and discipline model managers**
    - Creation of models and object
    - Editing models
    - Coordination and merging contributions for team members
    - Analysis: managing structural analysis and design softwares, extraction of quantities for estimating/cost planning or ordering of materials, thermal assessment, LCA, sunlight and lighting studies and interference checking
    - Simulation: solar studies
    - Viewing: building coordination on site
2. **The role of the project model manager**
    - Coordination and management of project models. This is much more than a re-badged CAD manager as there are new processes and relationships to manage and new challenges in the integration of multiple disciplines into a common model.
    - Project model manager tasks:
        - establish and manage project standards and protocols
        - report to design manager or discipline manager
        - check and merge models, write custom project rules for model checking
        - implement QA
        - archive model files
        - establish and manage the structure of team and technology
3. **The role of the information model manager**
    - Coordination and development of organisation modelling standards and practices across projects and project teams
    - Coordination of the scope and structure of models
    - Licence to promote modelling outcomes and maintain company knowledge base
    - Information focus from architect (e.g. R rating, embed information on bits of the model)
    - Maintain project and object product database into the future

1.10 Challenges for BIM implementation (issues beyond the guidelines)

1.10.1 Disruptive vs evolving implementation

This is the ‘human factor’ that has significant impact for industry, especially at the management level. A quote from the case studies

> ‘... that BIM cannot be implemented through a gradual progression from legacy CAD to BIM. Some indicated that adopting BIM concepts and technologies requires a mindset of ‘revolution’; a process that cannot evolve from replicating legacy CAD standards and procedures. BIM is perceived as a ‘disruptive technology’ that requires quite significant changes to the design and documentation philosophy. This disruption will necessarily include some ‘pain’ which needs to be absorbed and mitigated over time and through deliberate effort.
>
> It follows that adopting BIM may necessitate ‘leaving behind some CAD advantages’ like customised CAD libraries, scripts and other established documentation standards. This shedding of legacy data and procedures is considered — by some interviewees — as a prerequisite for successful adoption of BIM principles and processes.

Management has to be aware of both the opportunities and challenges associated with BIM.

1.10.2 Model users' differing views and expectations of model information

BIM, being such a broad concept and encompassing all participants in the building industry, will bring a diverse range of views, experiences and expectations. Therefore an awareness of the requirements of other parties is necessary.

A wall, for example, is seen in very different ways by the following:

- architect: layout, size, finish, colour, texture
- structural engineer: load bearing or non-load bearing
- mechanical engineer: enclosure objects with physical thermal properties
- quantity surveyor (QS): quantity extraction, object specification and cost
- contractor: item to have fabricated off site or assembled on site, with cost, delivery time, construction time, sequencing
- subcontractors: a number of subcontractors may contribute to a single wall — structural framing, lining, plastering, painting, electrical, hydraulic services
- FM: surface to maintain as part of a room or building.

1.10.3 Need for Australian object libraries

Accessibility to product information is emerging as a crucial issue for the successful adoption of BIM by industry. This constraint has been most obvious with design practices that first adopt BIM when they discover that libraries of building elements, furniture and equipment etc. rarely suit their needs. This has led to many consultants creating their own, time consuming, library objects and then finding it difficult to exchange data. Information can be lost, partially lost or corrupted when exchanged, and this can diminish faith in BIM. For example, a curtain wall system after exchange might be in the correct location and height, but doors within that system might end up in different locations, thus corrupting the integrity of rooms/spaces, and the links in the hosting model's database.

Internal tools in the BIM software have generally good shape editors, and users add rudimentary material properties. However, these libraries are restricted to only a few aspects of product usage that are primarily focused on material or cross-sectional (or presentation) attributes that support documentation needs and correct finishes for visualisation.

While current BIM users have developed their own libraries (from conventional product literature and media), the advent of IFC-based collaboration had made these limitations an even more critical impact as comprehensive material, structural, thermal behaviour and acoustic performance attributes are missing to support their corresponding disciplinary analyses.

The model objects will need to:

- be sponsored, endorsed or created and be maintained with specification details by product manufacturer, bureau, or third party company. They should be controlled and checked before being added to open libraries. Governments could be the generator and custodian of the libraries
- conform to accepted local classification system
- support performance-based specifying and monitoring: use of parameters and/or filter sets, provide QA for specifiers to be checked against project brief, and display if changed for checking
- support code compliance software
- support e-commerce — web enabled for coordination, tendering, ordering, tracking delivery, installation, progress payments and maintenance requests.

Accommodate levels of object data

Any object will need to accommodate an increasing level of detail appropriate for successive project phases.

For example, cost and schedule data for a reinforced concrete column:

Level A – m^2 (not differentiated from building and spaces)

Level B – column – generic

Level C – column – specific

Level D – column – detailed for construction

Level D.1 – formwork
Level D.2 – reinforcement
Level D.3 – concrete
Level D.4 – finish

Level E – column - existing

1.10.4 Product information and specifications

A further issue arises globally in terms of language, terms and work practice. These issues, combined with the specific selection of individual properties, present a very complex environment regarding the meaning of terms, the applicability of properties to particular element performances and the relationship between these properties.

An International Framework for Dictionaries (IFD Library) is an object reference library which an open international standard implementation of ISO 12006-3, and seeks to define 'what' we are exchanging. It can be used to get more detailed information in and out of a construction design model. This is currently being implemented in Norway, USA, The Netherlands and Canada and is likely to have great potential for application in Australia.

1.10.5 Emerging building information classification system

Consistent with the need for product libraries, there is a parallel requirement for clear and accepted standards for building information.

See also NATSPEC Draft TECHreport June 2008 'Information classification systems and the Australian construction industry', which recommended compliance with ISO Standard 12006-2: *Organization of information about construction works – Part 2: Framework for classification of information*.

The building information classification system needs to be extensible, simple and multi-level, and allow connection to automated and semi-automated specifications and BOQ.

A draft schema proposed by the Queensland Department of Public Works defines a 'BIM Classification Code', in a structure derived from Australian Institute of Quantity Surveyors (AIQS) codes, with up to five levels of increasing detail.

This BIM code would be added as a category of data to every modelled object to enable data to be extracted in an automated and consistent process.

This schema allows extraction at different levels for progressive cost planning and estimates and quotation systems for contractors and subcontractors. There is the opportunity for this coding to be mapped to specifications systems like NATSPEC. It can also assist in asset management and, with a time component, be used for predicting cash flows, with 'benchmark', 'actual' and 'complete' reporting.

This is an ongoing area of important, urgent research, development and consultation.

1.10.6 Information database management

The longevity of digital models presents an increasing problem as authoring software is upgraded at relatively frequent intervals (1 to 2 years) compared to the life cycle of buildings (50 to 100+ years). If the database is to be used for operation and management, issues of the file type, format, version and media used for storage need to be resolved.

Retaining superseded versions of software to view or edit the models is problematic as it may not be compatible with current hardware and operating systems, or even trained staff familiar with older software. Upgrading the digital database by regular 'maintenance' to current versions of proprietary software is a probable solution. Non-proprietary file formats may be an alternative viable long-term solution.

The key issue is to maintain the data richness over time, and be able to add or update the data.

1.10.7 Management of file sizes

Management of large data files for projects presents problems for existing computing facilities, and file sizes are growing as more information and/or disciplines are added to the building model. The structure of the data and how it is embedded in files or linked from other files need to be addressed.

Model server technology aims to deal with this.

1.10.8 Sharing information

Communicating information between independent offices is a challenge and will continue to be so for some time. A potential answer may rest with the wider use of model servers as a common database of all of the discipline models, and their integration into a more complete project model.

1.10.9 Legal, insurance and practice impediments

Digital practice has an enormous effect on a range of consulting services. Issues of risk, fees, responsibilities and insurance become important.

1.10.10 Slow adoption in industry

Many voids exist in practice as industry is yet to make full use of the possibilities that new software technologies have provided. There appears to be little multidisciplinary BIM, and very little over the whole building life cycle.

Compliance checks required by government agencies for building code, energy and sustainability could assist the adoption of virtual building if assessment software could import, analyse and report on a digital model.

1.10.11 Software to address local requirements

Minimum building performance is becoming mandatory, as for thermal performance, energy and water use, natural ventilation and sustainability. Software is needed that can leverage the data richness of digital models to assess and report the anticipated performance of buildings to local standards and codes.

1.11 Emerging developments in BIM

There will be new or extended applications of digital modelling in the following areas.

4D and 5D modelling for optioneering/ optimisation Simulations are possible that provide rapid feedback to aid iterative development processes. Virtual building simulation also allows for fire training, security, emergency response planning, evacuations, web cam link of maintenance crew back to base for coordination, and games style software interface for interactive simulation of building by prospective users.

Facilities management (6D) Monitoring and maintenance is possible by integration of the digital building model database with other management systems: work orders, scheduled and emergency maintenance.

Rule-based design Corporate knowledge used to develop design rules for building types, to enable generation of the design and evaluation by automated reporting of design conflicts or violations and recommendations of solutions.

Sustainability LCA and the use of eco-profiling for comparison of design proposals.

BOQs and specifications Automated or semi-automated extraction from models for BOQ and specifications will be based on developed object libraries.

New business processes 'Lean construction' is enabled and will bring different timing for engagement of subcontractors. Web-based project data for e-commerce, web-based tendering and quoting with procurement supply chain changes strengthened.

Increasing off-site fabrication Models will provide efficiency gains through improved quality, less wastage, safer on-site environment, 4D coordination for site delivery and installation sequencing.

Model servers Development of model servers for data management, data exchange management and information quality management.

2. Model creation and usage

2.1 Modelling overview

The creation, use and management of digital models involve a number of distinct activities, which can be grouped into three areas.

Model creation

Discipline models

Exchange

Aggregate models

Model quality

Model checking

Model use

Visualisation and communication

Data extraction

Document production

Simulation and analysis

These activities are not necessarily performed in this order, and many of them will be done several times over, and require methodologies different to traditional practice to be effective. Model checking, data extraction, exchange and simulation and especially analysis, are either new or are significant developments in the use of digital building information that require serious reconsideration for practice.

2.1.1 Model creation

A clear distinction has to be made between models that are created by a single discipline for their own purposes and aggregated models which combine the contribution of two or more disciplines in some meaningful and useful way. Both discipline and aggregate models can be exchanged and exported for a range of purposes, as described below.

Discipline models

Discipline models are built, not surprisingly, by an individual discipline, and often for their own purposes. If the rules adopted for model building and object definitions for single disciplines are considered, structured, appropriate and consistently applied, then there is the potential to better exchange and extract data and share as required.

Single discipline models may be differentiated by discipline and purpose.

Within the building industry, the first digital models were probably built by architects using ArchiCAD and were of limited utility. Certainly they enabled the form of the building to be explored more fully and were helpful in sharing the ideas with clients and others, but when it came to the preparation of documentation for construction, 2D CAD systems were the tool of necessity.

Nevertheless, these early models were the foundation of what is achievable now, and more importantly, the motivation for what will be done in the future. Increasingly stakeholders, apart from the design disciplines, are independently building their own models, at their own cost and for their own purposes.

Structural steel detailers have been modelling for some time in the preparation of documentation for the fabrication of steelwork, which can be taken from the model to CNC machines to cut, cove and drill the steel.

Mechanical services trade contractors are increasingly building their own models for air-conditioning ductwork, which also can be loaded onto fabrication plant for the cutting, folding and joining of the ductwork. In some instances, they will build their own model from 2D drawings supplied by the consultant team to resolve potential clashes and avoid the waste caused by the need to rework ducts to avoid structural elements.

These models can be, but are not necessarily, exchanged, and they remain the responsibility of the discipline specialist, who retains ownership, and the rights of users of the model are limited.

The responsibility for content and modification of each discipline model remains with its author.

Discipline models can be used for the production of traditional 2D drawings, particularly for the tendering and construction stages.

For example, in the case study of Northlakes Police Station, there were initially eight IFC discipline models at the design stage. The models and their approximate sizes were: architectural (22 MB), civil (12 MB), structural (9 MB), mechanical (9 MB), hydraulics (4 MB), electrical (4 MB), fit-out (11 MB) and landscape (8 MB).

Where a discipline model continues over the life of the project, it will increase in the level of detail and the extent of object types and object attributes.

To be truly useful for collaboration with others, models need to contain at least an essential number of object types for simulations, analyses, visualisations and data extraction for the take-off of areas, properties and quantities by other disciplines.

Exchange

There are many benefits of exchanging digital building models. A number of choices must be made concerning the format, formality, status and purpose for exchange.

Formats of exchange: Many formats of data are exchanged and shared in the architecture, engineering and construction (AEC) **industry**. The range of formats include: image or raster, 2D vector, 3D surface and shape, 3D object exchange, GIS and XML. The data and the structure of the data contained within these file formats varies considerably, so it is critical to select the most appropriate format for its intended use.

Formality of exchange: Exchanges can be of a 'formal' or 'informal' nature. Formal exchanges of discipline models require definition of content, format, QA status and timing of exchange. Informal exchanges can occur as necessary to facilitate the communication and coordination process.

Status of exchange: The exchange of a model can be for reference, where the responsibility for consistency remains with the issuer and the recipient is responsible for working with the correct updated version.

Alternatively, a model can be for handover, where the issuer is responsible for the content at handover and the recipient is responsible after that for its maintenance and use. For example, a main contractor hands over an 'as-built' model for FM use.

The purpose for exchange can be of three basic types: visual communication; digital investigation, collaboration and use; and common project database.

Visual communication: Visual communication is possible using digital files for marking up and querying by other project participants. The format for these exchanged files can be 3D PDF or DWF, and they provide for a greater level of visual investigation of the building design as the model can be rotated by the viewer, its objects visibility filtered and object properties queried, rather than the 'fixed views' of traditional documentation. There is no editing of the original model by the receiver, so there are no interoperability issues. The information in these files is used as a basis to assist in project coordination feedback to create separate discipline models. 3D PDF and DWF files can also be opened by free viewing software and is used by clients and other project participants. This form of exchange is currently widely used in industry, and digitally replicates the transfer of information previously held in paper documents.

Digital investigation, collaboration and use: Digital model or partial digital model files can be passed to other participants, and include object information as well as the graphical views of the model as described above. The content of the model file can be viewed and queried as described before, but can also be edited or used for analysis and coordination. For example, an early architectural model might have rooms or spaces with dimensions and properties that can be used directly by thermal assessment software to give initial feedback on building performance, rather than the engineer having to re-create the geometry and relationships.

Another example could be the structural engineer using a partial architectural model for 'digital set-out' information of their discipline model to coordinate grid set-out, column locations, wall layout etc. Partial models created from discipline models normally contain a selection of data from the discipline model for the targeted receiver, to avoid unnecessary, redundant or overlapping data and keep file sizes to a minimum.

For this type of file-based exchange, there are four main methods for data to be passed between applications:

1. direct proprietary links between applications

   Examples: ODBC, COM, GDL or MDL

2. proprietary file exchange formats mainly for geometry

   Examples: DXF, SAT, STL and 3DS

3. public product data model exchange formats Examples are IFC or CIS/2.

4. XML-based exchange formats (eXtensible Markup Language)

   Examples: gbXML, OGC and IFCXML.

The choice of exchange method will vary depending on the software to be used, the types of data required to be exchanged and the purpose for exchange.

Although method 3 — 'Public product data model exchange' — is not yet seamless or error free, it appears to hold the most promise for long-term industry application (refer also to Appendix 5 for a look at some IFC export and import requirements).

This form of exchange is the basis for 2A – One-way collaboration and 2B – Two-way collaboration, as described in the 'Towards Integration' diagram (page 13), and is not yet widely used in industry.

Common project database: A common project database or model server stores, manages and maintains the project discipline models that may have been created in a range of software. This form of exchange is a basis for 3A – Local model server and 3B – Web-based model server, as described in the 'Towards Integration' diagram (page 13), and has only started to be used by industry in Australia. This type of exchange is outside the scope of these guidelines (refer to CRC for *Construction Innovation* Research Project 2007-03-EP Collaboration Platform Project).

Aggregate or combined models

An aggregate model might be described as the assembly of a number of discipline models or the construction of a single model that incorporates the contribution of a number of disciplines. These models are much more useful and can be the vehicle for coordinating the documentation for the project.

Examples of aggregate models can be architectural + structural models, or architectural + structural + HVAC models. Not every discipline has to be in the aggregate model.

The North Lakes Police Station case study project had eight discipline models combined into an IFC aggregate model of about 150 MB for collaboration, tendering and construction purposes.

Aggregate models can be used to minimise conflicts and ensure consistency and quality of design documentation and coordination within each party; specifically to test for geometric interferences between objects; as a communication tool to show structure and stage of overall design development; as a basis of 4D/5D construction models; and as a basis for an operations and maintenance model.

Building aggregate models is where the challenge starts in earnest for the industry.

Aggregate models can be created in propriety software like ArchiCAD by 'hot-links' or Revit by 'links'; where other discipline models are imported. This provides basic visual checking.

Aggregate models can also be created by specialist softwares which have many advanced features for model merging, checking and coordination (see section 2.1.4 *Model checking* below). For example, Navisworks is a multifaceted package that supports a very large number of file import formats, while Solibri Model Checker supports IFC import and export.

Whatever software is used, it is essential to coordinate the structure of the discipline models before merging into the aggregate model. Files to be imported into an aggregate host file need compatible file structures, project coordinate systems and common building reference points.

The individual discipline model's data remains separate within the aggregate model and can be substituted by updated versions when necessary.

Where there is a large project, discipline models may be split into parts for ease of management, but coordinated through an aggregate model. For example, an architectural model can be split into basement, podium and tower models, and other discipline models likewise.

Accessibility of the aggregate model must be controlled and stored on an accessible server, web portal etc. with a viewer program for analysis and visual checking of conflicts of components. Partial access rights can be given for viewing only or for viewing *and* editing.

Version control of the aggregate model and its constituent discipline models is essential.

The process to create an aggregate model would include the following steps:

1. Select objects to export from discipline model to create a partial model.
2. Export in appropriate, agreed format.
3. Import into aggregate model (e.g. ArchiCAD with hot-linking, Revit with link files, Navisworks or Solibri Model Checker).
4. Check coordinates and correct insertion point.

2.1.2 Model quality

Model checking

The new facility to combine a number of discipline models assists project coordination and identification of conflicts. New software can 'check' or 'audit' models in a semi-automated process for geometric inconsistencies and other criteria.

Some proprietary authoring software has built-in model checking facilities like geometric interference checking. This helps to identify objects that clash in 3D space to assist design resolution and model quality in discipline models. The selection of objects used for checking can be filtered to target issues with particular categories of objects, for example, major structural objects like beams, floors and walls.

Purpose-made model checking software is able to audit and verify model quality for a much greater range of criteria such as:

- model structure: building definition and set-out of building storeys
- data on building storeys: if objects are related to building storeys
- space compliance with project parameters: minimum area and heights for rooms
- duplicate coincidental model objects or redundant objects
- incorrect object use
- clash detection: geometric object clash detection
- interdisciplinary model coordination
- version comparison of models
- code compliance: egress, accessibility and code checking
- custom rule checking for unique project design criteria
- quantity take-off.

See also Appendix 1 'Model checking and auditing' for more detailed explanation and examples.

Model checking is useful for monitoring the quality of a model as it is being built and can be performed at any time. It is highly recommended prior to model exchange as part of the project's QA.

2.1.3 Model use

Visualisations

Digital models provide a far greater range of formats to 'view' the building database, as compared to traditional 2D documents as partially described above in 2.1.1 *Model creation – Exchange*.

Digital graphic representations become more useful in the planning and design coordination process through communication with other parties by being able to test and verify design solutions for structure, spatial relationships and building geometry. New forms of graphics allow us to show site installations, animations, walk-throughs and 4D simulations, photo-realistic images, sun studies through static and dynamic images (see also *Simulation and Analysis* on page 25). Interactive presentations, using gaming interfaces, will provide other means for clients and users to 'test the building design' before sign off.

Data extractions

Data extracts from models are not necessarily geometric, but can be quantities of objects and associated data. Consistent use of construction types and correct tools is important, and discipline models should be quality checked before extraction. Data extracted from discipline models can be in list format in files to be imported into spreadsheet, for post processing.

Examples are:

- areas/spaces, volumes, lists of object types and object attributes
- quantities for cost planning and estimating
- schedules for rooms, windows, doors, furniture, equipment and prime cost items. These can be structured for building owners to check design submissions against project briefs.
- interference checks of 3D geometry (clash detection report)
- code compliance checks against regulatory requirements.

Document production

A major challenge for those moving to modelling has been the need to return to 2D CAD systems for the preparation of tender and construction documentation. It is now possible to extract selected 2D views from the model, but it is still a limited use of a potentially more powerful tool.

It is possible to include embedded 3D views of building details for inquiry purposes of object properties, but this is still less than ideal. An even better option may be to share the aggregate model with tenderers, contractors and trade contractors for use with appropriate viewers. This can provide a much richer and more flexible means of communicating the intent of the design team, but does require well-built models and a supply chain capable and willing to shift to a different way of communicating. This can provide information about both the building and construction process (e.g. site access and logistics, construction options).

Simulation and analysis

BIM provides the opportunity to run simulations and analyses to test and verify design solutions using discipline or aggregate models. There is a large range of building performance that can be assessed such as:

- thermal, heating and cooling analysis
- energy consumption
- structural analysis
- environmental impacts, carbon emissions
- LCA
- LCC
- acoustic analysis
- eco-profiling of building material options
- daylighting and lighting design
- air flow and ventilation
- sun studies, solar potential, shadow and reflection studies
- egress, evacuation simulations
- 4D construction sequence
- 5D cash flow predictions
- FM maintenance schedule.

The rapid assessment results that digital models make possible allows for more frequent design iterations that result in greater design and coordination resolution, which then give more certainty to the whole project team.

The output from simulations may not necessarily result in an amended model, but may provide performance data to aid team collaboration and for individual disciplines to amend their own models.

A multidisciplinary example: Thermal, lighting and LCA analyses

Increasing industry and community expectations for a higher level of building performance require disciplines with overlapping responsibilities to collaborate more closely, for example, the architectural choices of materials which influence the thermal performance and daylighting in buildings. This will have an impact on the amount of external energy required for the building to perform to client requirements. This essential interdisciplinary dialogue is greatly enhanced by the appropriate use of digital models that enable rapid analyses of diverse parameters of design alternatives to achieve desired performance and environmental ratings.

As an example of the process, consider an architectural BIM and thermal analysis collaboration.

The input data for thermal analysis typically comprises:

- building layout including the configuration of spaces (rooms)
- building carcass, with the thermal properties of construction elements including walls, floors, roofs/ceilings, windows and doors with values assigned by the thermal analysis package, by building material references (e.g. the CIBSE Product Catalogue) or created by the user
- functional space use and occupancy from room data information included in the model
- building systems data including lighting, HVAC
- other building services system loads that may impact on thermal analysis are the responsibility of the appropriate specialist engineer
- utility rates to calculate life cycle costs
- weather data identified by geographic location and orientation from the site entity.

The architect's building model should thus reflect these exchange requirements specified by the process definition between the partners and the understanding of input requirements for the thermal analyst. This data is typically collected in a specific layer combination, so that it can be exported as data without other extraneous information.

Based on this scenario, Custom Rule Sets can be developed to ensure that all the data expected in the model exists and is consistent. The architect, with a defined data scope, can now export the relevant sub-model file for the engineer's analysis with all the building carcass elements — walls, slabs, roofs, windows and doors — including thermal properties to calculate heat loads. The emerging work process will have the architect sending the thermal engineer a model with the carcass, space usage and sufficient building element material specifications. User experience suggests that this information is very difficult to find in current product literature, and even difficult to find in specialist building science or related technical references.

2.2 BIM project definition and set-up

To enable digital collaboration using BIM, a number of major decisions have to be made. Some of these mirror or replicate decisions in traditional project collaboration, but others are new, due to the opportunities or requirements of digital processes and the changed relationships of project participants. There is also the need to standardise where possible the information needed for specific tasks within the building life cycle, so that information is available when needed and of the appropriate quality. Project definition includes selection of exchange protocols and details specific discipline requirements; the role of the model manager/coordinator: the project modelling schedule; and project-specific requirements.

These major decisions involve 'who?', 'what?','why?' and 'when?'

The interrelated questions are:

1. Who is involved and their responsibilities? For whom are the models intended?
2. What models are required? What range of discipline models is needed, and if an aggregate model is to be created, why is it required?
3. When are they required? At what project stage are the models needed?
4. What data is needed in the models and at what level of detail?
5. How will the models be exchanged and in what format?
6. Who is managing the process? Is there a need for a project BIM manager?

These have to be addressed on a project-by-project basis. There is no ONE solution.

2.2.1 Who is involved?

The choice of discipline consultants will be based on the contracting method adopted and the type and complexity of the project.

Contracting method requirements

A decision on the form of contract to be used for a project will have a significant impact on the selection of participants and their relationships in the model creation and coordination process.

Alternatively, a decision to commit to a well-developed and aggregated model can equally contribute to the decision on the procurement strategy to be adopted.

With the traditional design–document–tender–build, lump sum contract, the main contractor and subcontractors will become involved after design; design coordination and documentation have been completed. They will probably have tendered on 2D drawings and will be responsible for the production of shop drawings. There can be some variation on this method, but they will generally involve the shift of some roles into the documentation process and the realignment of some risk.

With Design–Construct contracts, the main contractor and subcontractors are involved much earlier and accept responsibility for design, or more often, design development and documentation. They may be provided with an architectural model or an aggregated model, but will continue the development and use of the model only to the extent that is of value to their role and responsibility.

Different opportunities exist with managing contractor forms of procurement. Some specialist trade contractors are well advanced in their modelling capabilities and have much to contribute to the detailed decision making in the design process. Engagement with both a managing contractor and some specialist trade contractors in the design development and documentation stages can be of benefit to the outcome for the project. This arrangement is consistent with a model IPD currently being considered by APCC and ACIF.

Project type and complexity

The range of disciplines in a project is determined by its type and complexity on a project-by-project basis, irrespective of the contracting method mentioned above.

For example, a large complex project might have 8 to 10+ disciplines involved in the design and documentation stages, where a BIM project coordinator/manager and specialist building services or environmental expertise is required.

Alternatively for a small, simple dwelling there may only be architectural and structural disciplines needed, that may only have two individuals collaborating on modelling.

2.2.2 What models are required and why?

The purpose and use of models determines the types of discipline models to be created and how they will be used such as: visualisation and communication, coordination and collaboration, data extraction, document production, and the range of analyses and simulations that are expected to be performed.

As disciplines will normally have overlapping property data requirements, so the identification of the authors of the data and their responsibilities is important. Model objects may also be passed on to others for their discipline purposes as the project progresses and become their responsibility for development and specific detailing (e.g. partial architectural model handed over to landscape architect; or hydraulic fixtures from architect to hydraulic engineer).

The decision needs to be made concerning which design models do not form part of contract documents (e.g. models that are the basis for design iteration, analysis and collaboration, but are discarded because they are 'working models').

2.2.3 When are the models needed?

The information level within discipline models is progressively developed over project phases and determines the following:

- object types included
- attributes attached to objects
- geometric accuracy of defined objects
- extent of detail required by each discipline
- required outputs for each stage.

Project phases may be defined in a variety of ways. An international approach based on the General Process Protocol is the basis of current and future international standards, which covers the whole building life cycle, from briefing to demolition.

See also Appendix 2 *Information Delivery Manual.*

2.2.4 What should the models contain?

The phase and purpose of the building model raise two important questions: What objects should be in the models; and what data should be within those objects?

Objects to model

- Those spatial volumes or parts or areas of the project modelled in each model and those not
- Expected content of each model and required level of detail at project milestones
- Content includes:
  - geometric and spatial data
  - object property data (e.g. fire rating)
  - object construction data (e.g. how assemblies are broken down)
  - cost and schedule object parameters.

Objects to be modelled and those objects not to be modelled have to be defined. For example, it may not be suitable to model detailed joinery or room trim elements, but they can be mentioned as properties in a room schedule.

The table below shows an architectural example from Project Services, Queensland Public Works for the Schematic and Developed Design project phases, including table of objects to be modelled or not modelled and the associated data that is to be added.

Building elements	Modelled	Data in object parameters	Comments
Walls: - linings - finishes - skirtings	✓ ? 	 ✓ ✓ ✓	Modelled at correct dimensions and profiles for the structural component of the wall. Linings and finishes to be nominated in the room family parameters. Cost codes applied.
Windows and doors: - frame - jambs - architraves - trims - sills	✓ ✓ ✓ ✓ ✓ ✓		These components should be able to be modelled as simple geometry. Generally suitable for 1:100 scale. Fine detail added as footprint details where required. Cost codes applied.
Ceilings: - cornices	✓ ×		Ceilings are system families and do not allow additional parameters, therefore cornices will not be included with the ceiling information.
Roof: - downpipes - gutters - fascias - cappings - flashings	✓ ✓ ✓ ✓ ✓ ✓		All of these components can be modelled and identified as true elements. Cost codes applied.
Stairs: - finishes - balustrades	✓ ✓ ✓		Fully modelled to correct size and shape. Cost codes applied.
Built-in joinery	✓		Fully modelled to correct size and shape.

Data within model objects

As models develop with more types of object added, the data within objects in the model will be updated or replaced as the design, documentation, construction or management matures.

For example, a window might be defined progressively with object properties during the building life cycle in the following manner:

> **Briefing/Concept Design Stage: (Levels A & B)**
>
> room, size, orientation, operation, material
>
> **Developed Design Stage: (Level C)**
>
> room, size, orientation, operation, material, glazing, design 'U' value, design SHGC, transmittance, air filtration, STC rating, fire rating,
>
> **Construction Stage: (Level D)**
>
> room, size, orientation, operation, material, glazing, actual 'U' value, actual SHGC, transmittance, air filtration, STC rating, fire rating, manufacturer, model number
>
> **FM Stage: (Level E)**
>
> room, size, operation, material, glazing, manufacturer, model number, warranty, maintenance and service document

The above example highlights the need for agreed sets of properties within common model objects that can be relied on for robust and efficient quality exchanges.

Property sets (Psets) for objects have been developed by IAI buildingSMART as part of the IFC, registered by ISO as ISO/PAS 16739, and are currently in the process of becoming an official International Standard ISO/IS 16739. These form part of IAI buildingSMART's Information Delivery Manual (IDM) that seeks to define industry processes based on business requirements that define exchange requirements for building data.

See Appendix 3 for a detailed window property set example.

There are great capabilities at present for the sharing of significant data within models. Industry agreement is required to define property set content to unlock this potential (e.g. manufacturers to provide product data that supports analysis and verification processes — initially the architectural, structural and building services disciplines and then QS, sustainability and thermal analysis disciplines. This varying growth of detail will also greatly benefit contractors, subcontractors, owners and facility managers.

It is possible that there will be properties that are relevant to Australian practice that are not part of the IAI buildingSMART Psets. For example, there is a strong case for a supplementary Pset for windows that covers those properties, so that all project participants will have confidence that their required data is part of the window objects exchanged.

A sustainability Pset or Psets should be developed for software such as LCADesign, to assist the analysis and simulation process.

The development of consistent, flexible and shared objects and the associated information or properties is one of the more challenging and potentially rewarding issues in the development of really useful integrated models.

2.2.5 How are the models to be exchanged?

The method and requirements for model exchange will be defined per project. It can range from informal model exchange discipline to discipline for design development iteration to formal scheduled handovers. Whatever methods are selected, it is advisable to test and verify exchange procedures at the start of the project to resolve any technical or procedural errors and adapt exchange process documentation.

The following areas also need to be defined.

Levels of BIM implementation

The 'Towards Integration' diagram (page 13) is useful to help define the form of digital BIM collaboration exchange that is appropriate. Each discipline's collaboration should be specified as either traditional, one-way or two-way collaboration; and whether a project model server will be used.

This will have an enormous impact on the structuring of the project collaboration.

Exchange formats and file sharing

The process for exchange/sharing model files can be done in different ways depending on the project team. A neutral or proprietary exchange format needs to be selected for each proposed data exchange. Exchange can be by email or storage media (e.g. CD/DVD).

Alternatively, a central repository, formal collaboration project website, model server, or FTP site can be used, where user accounts would have to be created and managed with user rights assigned at varying status levels.

Project-specific requirements

There are a range of selections that have to be made on a project-by-project basis to aid collaboration as follows:

- software selection and specific design review software for 3D design coordination
- discipline templates based on selected software
- definition of discipline-specific data requirements where exchange is normally a partial model
- project reference point: site and project set-outs and each building model
- sectioning divisions of the model
- break-up of architectural components
- library objects
- file and folder structures
- discipline model label data
- definition of dimensional accuracy and contractual use of models
- QA
- risk/allocation of responsibilities.

2.2.6 Who will be managing the process? The role of the project model manager

The question as to who ultimately manages the aggregate project model can vary according to the phase of the project.

For the design stage of a project, the responsible person will often be the architect or architectural model manager who is accountable for the project from inception until passed to another party. They can be considered to be the 'project database manager' or 'BIM manager', not just a 'CAD manager', as they coordinate the integrated building information and not just the form of the information provided by all the disciplines.

The project model manager would create a project coordination schedule of key modelling activities, project data, exchange requirements and format, specified software, documentation requirements, and required discipline models to define a formal process for coordination and collaboration between designers, contractor and subcontractors.

Coordination and collaboration process

1. Define what models are to be created and their purpose.
2. When models are to be created, schedule initial delivery of model to project model manager.
3. Define discipline-specific data requirements and document for the team and systems to be coordinated (e.g. structural/HVAC).
4. Schedule for updating each discipline model and presentation of versions of each model and its constituent models, ideally incorporated into construction schedule.
5. Describe who has responsibility and control discipline model coordinators and responsibilities — define expected content of each model and required level of detail at project milestones. Objects included (e.g. text or no text).
6. Provide feedback to the client on the content of the model.
7. Manage and monitor data exchanges and updates: user, date/time, history, log, digital signatures.

8. Check discipline models before merging into project aggregate model.
9. Merge discipline models into aggregate model.
10. Check and audit aggregate model coordination (clash detection).
11. Identify and document conflicts/clashes.
12. Establish timing and general meeting process for coordination of 3D models, timing of meetings and the documents to be coordinated.
13. Develop protocols for addressing design questions.
14. Define and document solutions.
15. Upload or export updated full models or partial models for discipline viewing and use.
16. Verify the models as approved and ready for fabrication.
17. Track amendments, version control of documents, storage and location of project documents.
18. Create and maintain project database which could include a project website, or separate collaborative digital environment.
19. Back-up, archive and restore data to maintain a copy of each file received to ensure model security and for QA coordination.

2.3 An example of set-up guidelines for a large scale multi-building project

2.3.1 Site

A master precinct site directory may need to be created due to the complex nature of site works and the number of different consultant requirements. This folder would contain the total precinct site CAD data, including the 2D and 3D survey, master site model and the new master 3D site model. Individual building project sites would be extracted from the master site. These would be stored in the individual project directories and modified as required. These cut down sites would then be re-inserted into the master precinct site.

Disciplines required to work on the total site services would model the immediate site services in the individual hub sites. Site services outside of the individual hubs may need to be 2D documentation using the master site model as background reference.

Site model

Site set-out: In the case where no 3D site model is available, the site has to be modelled from the 2D surveyors drawing as a base. This 2D drawing would be imported and the site established using shared coordinate system. This means that the site model coordinate system will match the surveyor's coordinate system. True north remains true north.

A 3D topography surface would be created from the initial site using the same (surveyor's) coordinate system.

The result is that every 2D and 3D model produced would have the same coordinate system.

A method for managing very large sites with multiple buildings:

1. Import 2D surveyor's drawing file at true north and northing and easting survey coordinates.
2. Create 3D topo surface of existing site from the existing 2D survey and at the same coordinate system.
3. Create 3D new topo surface from the existing 2D survey and at the same coordinate system. The new site will need to have appropriate smaller site models cut out to allow integration of the new modified site models from the individual building sites.
4. Master site plan — link 2D survey drawing into master site file.
5. Building files — link into master site and location using shared coordinate system.
6. Site files — extract small manageable portions of the 3D topo surface from the master site for project use.

2.3.2 Architectural modelling

Care is needed so that only necessary objects are modelled. In other words, the project can only realistically be modelled at somewhere between 1:100 and 1:50 scale. This concept could best be described as cutting a 1:50 section through the model, which would produce a favourable result at 1:50 scale with limited 2D elaboration of construction elements.

Aim to model as close as possible to 1:50 scale for the total project.

What data and requirements do the architects need from the consultants for modelling (e.g. model elements within consultants' linked files to be tagged or labelled in such a manner to allow architects to not display text or tagging)?

What data and requirements do the consultants need from the architects (e.g. properly constructed rooms)?

Setting out buildings

Each building file is to be modelled using the base architectural template and the coordinate location established using a shared coordinate system. This allows the building models to be aligned to the master site and allows project north and true north to be used throughout the project without disturbing the integrity of the 2D and 3D data.

Large complex buildings

Splitting the models of large complex buildings has the advantage of allowing maximum use of each section of the model. Architectural modellers can work on the internal core model file or the external fixtures, (e.g. sunscreen components) without necessarily suffering the disadvantage of working on a large complex model file. Additionally, various files can be loaded and unloaded into memory as required for modelling.

Splitting does have the disadvantage that ultimately all building models will need to be loaded into a single file for review, checking and output. This may require other strategies.

An 'aggregate architectural model' file can be created from these linked files:

1. exterior shell model file (see details below)
2. exterior fit-out model file — external fixtures: sunscreens, awnings etc.
3. internal core model file — internal walls & built in furniture
4. furniture model file — internal furniture
5. site model
6. external works.

The exterior shell model to contain:

1. building floor slabs and associated footings and beams
2. exterior structural walls
3. exterior curtain walls
4. exterior doors and windows
5. exterior and interior structural columns
6. roof structure and roof
7. ceilings
8. internal structural elements: columns, structural walls
9. lift core
10. minimal finishes necessary for SD & DD output and CD documentation if required.

Smaller buildings

Smaller buildings are unlikely to face the same file size issues and can be modelled within a single architectural model file for each building (exterior shell, exterior fit-out and internal core models in one).

The site and furniture components can still be modelled in separate files and linked into the master building models.

NOTE: The above splitting methodology is a worthwhile office practice to develop on smaller projects to enhance in-house collaboration skills and capability building for use on larger projects.

Worksets

Worksets can be used on building files. Worksets are primarily used to control linked file accessibility, data segregation and managing workflow.

Because the master building file can be separated into smaller manageable files, fewer worksets are required. There can be an issue with the number of worksets and speed of opening and working on the files. Structural engineer modellers could have a number of worksets in the architectural files.

Possible worksets for architectural and structural models per floor —

Architectural	Structural
Building exterior shell:	
A_Shared Levels and Grids	S_Shared Levels and Grids
A_Basement	S_Basement
A_Ground Floor	S_Ground Floor
A_First Floor	S_First Floor
A_Second Floor	S_Second Floor
Internal core:	
A_Shared Levels and Grids	S_Shared Levels and Grids
A_Basement	S_Basement
A_Ground Floor	S_Ground Floor
A_First Floor	S_First Floor
A_Second Floor	S_Second Floor
Roof:	
A_Downpipes	S_Roof
A_Roof Accessories	and as required
Site:	
A_External Works	
A_Landscaping	
A_Site Structure	
A_Pathways and Ramps	
A_Roads	

When to stop modelling

Don't model objects unless they are necessary.

Limit modelling finer elements which would not normally be shown at smaller scales.

Avoid modelling skirtings and cornices.

Only model finishes that appear on a significant number of views, for example, roof flashings, capping, barges and any construction finishes that are necessary for elevations, roof plans and 3D views etc.

Only model casework with the shape and profiles of the furniture to correct dimensions, and simple doors and drawers. Handles should be modelled using very simple geometry.

Wall linings in multi-layer walls can be modelled separately to the core structural wall but don't necessarily give the break-up for cost planning and estimates. This could be of some use for construction scheduling and progress claims, but would be a significant impact on workflow and processes.

More can be achieved modelling content using simple geometric shapes (e.g. rectangles, squares) Curved surfaces increase processing markedly. Try to eliminate unnecessary curved surfaces.

Model objects/families

Model objects/families should be modelled using the minimum content necessary to achieve a realistic representation of the modelled component without unnecessarily complicated or intricate detailing.

The following are recommended guidelines to use when creating model objects/families:

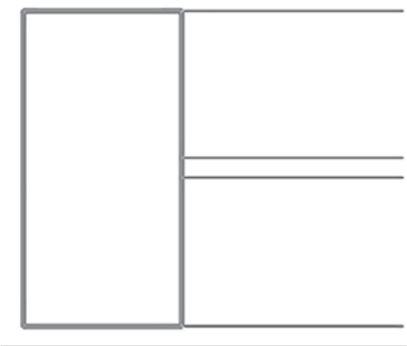
- Avoid the use of web available objects/families.
- Avoid using nested objects/families if it can be done in a single family. Nested objects/families create larger file sizes. However, they do allow

for greater flexibility when manipulating the family components.

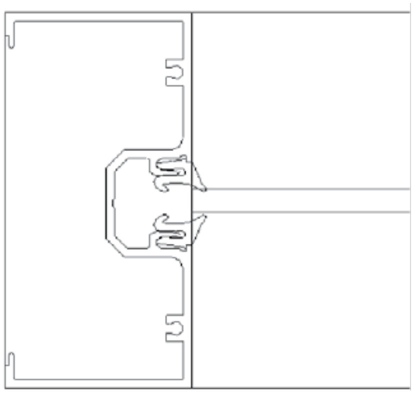
- Check object/family file sizes regularly. If over 500 kB, there is reason to investigate.
- Set appropriate origin points.
- Keep components as simple as possible. Don't use complicated profiles. Complex geometric shape and modelling create significant problems with file sizes.
- Consistently use agreed naming conventions for objects and subcategory names.
- Clean out all unwanted data, particularly 2D imports and subcategories prior to loading into the model files.
- Include cost planning codes from QS as well as manufacturers data etc. to be stored in family parameters.
- Rooms/spaces should have wall finishes and skirtings defined in the system family parameters.
- Room/space tags to include room names, room number and floor finishes.

Model object examples of geometric detail

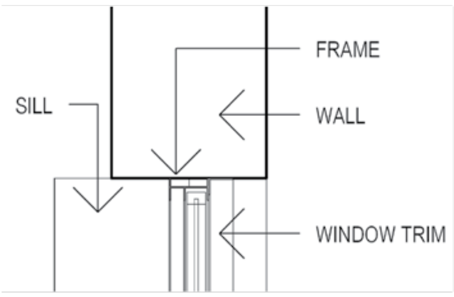
Suggested model detail



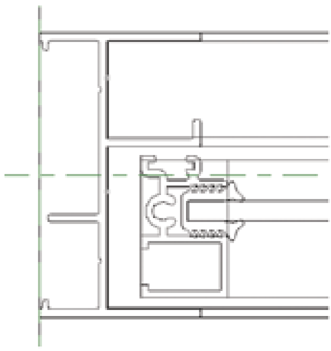
Avoid modelling this detail



Suggested window detail level



Avoid this window model detail



(Images courtesy of Project Services, Qld Department of Public Works – QDPW)

2.3.3 Structural modelling

Determine if structural modellers will work directly in the architectural models or copy/monitor.

Structural modellers may be working in the main building models. Content of structural families/objects needs to be constantly reviewed to minimise their file sizes.

Concrete columns, slabs and footings:

- Model structural components at correct dimensions and profiles
- Reinforcement not to be modelled in the architectural models
- Finishes to be nominated in the family parameters
- Cost codes applied

Structural steel:

- Model portal, brace, purlin and girt structural components at correct dimensions and profiles
- Cost codes applied
- Nuts and bolts will not be modelled in the building models
- Model only significant plates

2.3.4 Mechanical, electrical and plumbing (MEP) modelling

Consider splitting the mechanical services of pipework and systems into two files. Avoid loading large linked architectural models into memory.

2.3.5 Electrical modelling

Generally because of limited pipework, electrical models are easier to produce. Switches, light fittings and cable trays are modelled and located in the model. Wiring in the model is completed using 2D line work. In-ground services are modelled in the site model files.

2.3.6 Hydraulics modelling

It may be necessary to split the hydraulics systems into two separate model files to allow greater flexibility in workflow and to avoid delays caused by processing large amounts of MEP pipework in a single file.

Consider two models, possibly:

- stormwater and sewerage
- trade waste and hot and cold water supply.

3. Discipline modelling, analysis and simulation

3.1 Project definition, planning and pre-design

It is necessary to create a very large amount of data for every building project. This building project data has traditionally been created and collated in disconnected ways and formats, like paper-based graphics or text and varying digital-based formats created in a range of unrelated software that are not interoperable. Reliable and efficient use of building data by building owners, managers and occupants is greatly enhanced by the use of BIM technologies. The ability to create, collate and manage information in an efficient and convenient process throughout the building life cycle is becoming achievable.

There is also a strong connection between the types of information required at the initial project briefing stage, and at the operational and management stage of a building (refer also to '3.7 Facilities management' below). For large institutional building owners, the corporate knowledge gained from previous projects can be codified more efficiently into briefing/design guidelines for future projects with BIM, where templates or proformas for different types of buildings (e.g. hospitals, offices, schools, universities) are created to aid in the documentation of the building requirements.

This enables the development of 'rule-based' design, where project parameters can be used to help create and then verify the design options against the brief. For example, relationships of items: adjacencies, items attached to other items (e.g. windows, doors, equipment or furniture attached to rooms); a defined property (e.g. minimum or maximum dimensions); or particular access requirements like disabled access.

BIM software can help to make the transition from the client brief where the equivalent of room data sheet information with spatial requirements is linked to sketching software to create massing models with 'conceptual bubble diagrams' showing areas, volumes and relationships. These can then be 'plugged in to' architectural software with the ability to track and validate design iterations.

Project information requirements will vary at inception based on the client; type, scale and complexity of the project; new or existing buildings etc.

The most common types of information required at the project inception/definition phase are:

- spatial requirements/functional areas, rooms/spaces/finishes schedules
- spatial relationships
- performance requirements and targets (e.g. Green Star rating) or degree of sustainability required
- site-specific features and restrictions.

These general requirements are defined more specifically in the model through the object hierarchy:

- project:	contact information, overall budget and area
- site:	physical location, size, address, site survey, characteristics
- buildings:	footprint on the site
- storeys:	a specific floor or level of the building
- group:	a zone or department which can be a number of spaces or rooms
- space/room:	a volumetric entity within a building with a name, size, relative location etc.
- opening:	a door or window
- objects:	entities within a space (e.g. furniture, fixtures, equipment).

Early analyses of a 3D model containing the above objects can include checking or validation of design options to the brief requirements, building code compliance, visual feedback, cost analyses, sustainability analyses and solutions tracked against project criteria.

BIM technologies can also assist the investigation of the 4D (time) considerations of timing, scenario-based planning or staging of the project, and also the 5D (cost) considerations of cost, cash flow and project control quantities.

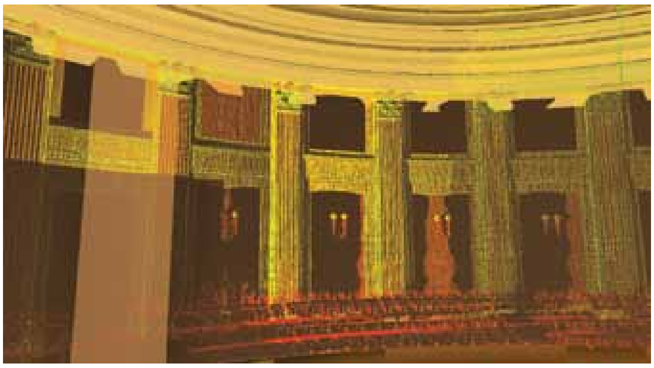
3.1.1 Document existing site conditions

The definition of the scope and scale of a project can be contingent on the establishment of the existing site conditions.

The ability to capture the site, existing buildings and infrastructure is important, especially where the building has heritage significance. Refer to figures 3.1 and 3.2. below and the Brisbane City Hall case study.

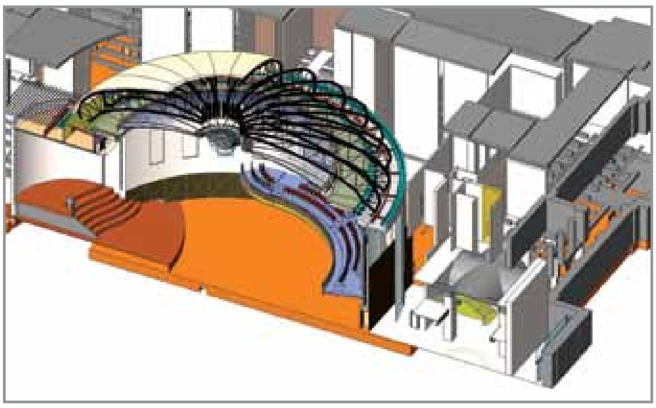
The use of on-site laser scanning to capture existing building geometry to inform and validate the digital model provides confidence for project brief development and 4D-scenario planning to stage renovation works on complex sites where new services need to integrate with the existing building fabric. This is a very powerful and effective tool when integrated with BIM.

Figure 3.1 Brisbane City Hall internal laser scan



(Image courtesy of Brisbane City Council)

Figure 3.2 Brisbane City Hall partial digital model merged with laser scan



(Image courtesy of Brisbane City Council)

3.2 Architectural modelling

The architectural model most often forms the basis for the other discipline models by establishing the room/space layouts and dimensional set-out.

It can be created in phases 0 to 4 as described below.

3.2.1 Phase 0 – Briefing and pre-design

BIM is not necessarily used at this stage, but the design brief described in a space program in electronic form, to be updated design and quality requirements planning and used for comparison.

The space program's minimum content in table format, to include room-specific net areas, dimensions and/or shape, special requirements, function and users of space, principal connections, adjacencies and impacts on other spaces (contents of room data sheets).

Performance criteria such as: indoor climate, sound insulation, lighting, loads, strength, safety, fire rating, thermal performance.

Mechanical and electrical services, furniture, fittings, equipment, space divides, indoor sub-structure, finishes schedule.

Some data is unlikely to be modelled in any phase. For example, paint finish would be included in the finishes schedule but not as 3D-modelled objects.

Site BIM/existing buildings

The detail of site data may vary considerably. Where the proposed building is new on a greenfield site, the site BIM model would be relatively simple.

For renovation/refurbishment projects, the detail of the existing buildings could be modelled to different levels depending on the extent of proposed work, and the purpose of the model.

A detailed site model with existing buildings can form the basis for FM, and later for renovations and extensions.

Laser scanning, as mentioned above, is used to capture detailed building elements for verification of the digital model.

Spatial allocations to be identified for building services and structural elements. The site model would have a main reference point and also define the location of any buildings on site with a reference point: x,y,z coordinate, northing, easting, AHD and rotation angle.

3.2.2 Phase 1 – Conceptual design BIM

Model to show the building envelope modelled as a minimum and internal elements not necessary.

Building modelled as spatial groups as space objects and arranged in storey or separate BIM files.

Height of spaces to correspond with designed room height.

Design alternatives investigated for spatial groupings, massing, building site location.

A conceptual estimate is possible at this phase.

Each space modelled as separate object. Space program expressed in functional spaces. Various ways of grouping in fire compartments, apartments, departments.

Space objects of different area types may overlap (e.g. room and gross area objects may overlap). Spatial reservations created for MEP systems and structure.

Modelling of spaces

Space tools used to create 3D object enclosed by walls, slabs that if moved will update space sizes automatically (area and volume).

Height of space objects to correspond with designed room height, measured from floor level to bottom of slab above or to bottom surface of ceiling, whether flat or raked.

Spaces of multiple storey height modelled separately on each storey.

It is very important to maintain space identifiers (number and name) as they are used for comparison of design alternatives, spatial cost estimations, energy analyses, and FM applications. Space identifiers need to survive import and export to avoid modelling errors through overlapping or duplicated objects.

Areas and volumes

Areas and volumes calculated from 3D geometry of space objects, and need to be linked to space identifiers and room categories.

If spaces modelled without wall thicknesses, they must be separated for assumed partition thickness.

Room area: area enclosed by inner surfaces of walls less area of columns, load bearing walls and flues within the space.

Gross area: outer surface of external walls and height of designed room height, used for space analysis and calculations, and detection of possible missing or overlapping spaces.

Other areas:

- volume (spaces, spatial groups, gross area)
- volume information contained in 3D geometry of space objects
- total building volume used for quantity take-off, cost calculation etc.

Checklist for conceptual design BIM

- BIM in agreed format
- BIM includes defined storeys
- Spaces defined separately in each storey
- BIM includes gross area objects
- All spatial groups include names and types
- Spaces match with gross area in each storey
- BIM includes spatial reservations for MEP
- Spaces do not overlap
- All spaces have global unique identifiers (GUIDs)

3.2.3 Phase 2 – Schematic design BIM

Model to reflect functional and physical structure of the building at an overall level.

All objects to be created from correct BIM tools.

Model to contain layout of spaces/rooms and building elements using generic objects that have geometric shape and location without specified attribute data (e.g. footings, walls, structural floors, roof).

Building location and orientation shown on the site.

All openings in walls, structural floors and roofs shown in general detail, with function of windows and doors shown.

Objects modelled using nominal dimensions.

Material information for surfaces not needed in space objects.

Figure 3.3 Visualisation model of 8 Chifley Square

(Image courtesy of Mirvac)

3.2.4 Phases 3 and 4 – Developed design and contract document BIM

- Material information linked to spaces through space number and name, also room painting, and other specifications
- Building elements with type information as per building specification may have specific supplier
- Each storey modelled separately, thus multi-storey walls and spaces modelled separately on each storey

Required information content:

- *Elements of the building*: ground gloor, ground floor slabs, structural frame, load-bearing walls, columns, beams, floor slabs, attic floor slabs, structure frame stairs, facades, external walls, windows, external doors, external decks, balconies, canopies, roofs, roof sub-structures, roofing, glass roofs, skylights, hatches
- *Elements of internal space*: space dividers, partitions, glass partitions, balustrades, internal doors, specific doors, space stairs, suspended ceilings, standard fittings, specific fittings, standard machine and devices

Modelling of building objects

- Walls to be modelled using wall tool from slab to slab to storey heights, with internal and external walls distinguished. Walls and spaces to be related. Walls of multiple storey height modelled separately for each storey
- Doors and windows to be modelled using door or window tool, with type and fittings information, connected to walls. Consistent and stated dimensioning to either frames or openings. Doors and windows associated to spaces and changed when either edited
- Glass and curtain walls. Solid wall that hosts glass or curtain walls or facades must be modelled first, then doors and windows added. There should be no gaps between host wall and openings. Multiple storey height curtain walls modelled by storey with appropriate openings each storey
- Slabs (ground floor, floor and attic floor) to be modelled using slab tool. The joining of slabs to walls modelled so that slab ends on surface of load-bearing wall for consistent data for quantity take-off and cost calculation. Floors modelled to extend to the inner surface of the external wall
- Roofs, beams, stairs and columns to be modelled using correct tools
- Columns modelled by outer dimensions including surface structure

Information required by architect from other disciplines:

- *Civil engineer*: platforms, roadways, parking, ground levels, cut and fill, site drainage
- *Mechanical engineer*: plant layout outlines, vents, exhausts, plant, ductwork, air ducts, air returns, intakes, penetrations
- *Electrical, fire and data engineers*: cables, penetrations, external lighting, distribution points on site plan, distribution point on floor plan, electrical symbols on floor and ceiling

plans, light fittings, alarms, emergency lighting, external alarm panels, detectors

- *Hydraulic engineer*: sewer lines, access covers, associated services, building drainage, hot water service, downpipe positions, vents, solar collectors, sprinklers, service ducting
- *Landscape architect*: paths, ramps, stairs, planting beds, furniture, existing trees
- *Structural engineer*: pads, piers, columns, joints, setdowns, access ladders, structural steel details
- *Interior designer*: furniture layouts, built-in furniture, lighting, ceiling bulkheads

Checklist for architectural models

- Model in agreed format including defined storeys, with components defined separately using correct objects and belonging to appropriate systems
- BIM includes required building elements
- Building elements modelled using correct objects and as agreed
- No excess, overlapping or doubled components
- No significant clashes or within identified tolerances between objects
- Model includes gross area objects
- Space names and types are as agreed
- Space areas match brief/space program
- Spaces, walls and columns match with the gross area
- Spatial reservations included for MEP services and structure
- Space height defined (including suspended ceilings)
- Shape and size of spaces matches with walls
- Spaces do not overlap
- All spaces have GUIDs

Possible architect's toolbox in the future

Pre-design
e.g. Affinity, Codebook International

Conceptual modelling
e.g. SketchUp, Generative Components

Design modelling
e.g. ArchiCAD, Revit Architecture, Bentley Architecture, Vectorworks

Model analysis and design tools
e.g. Ecotect, LCADesign, IES-VE-Ware

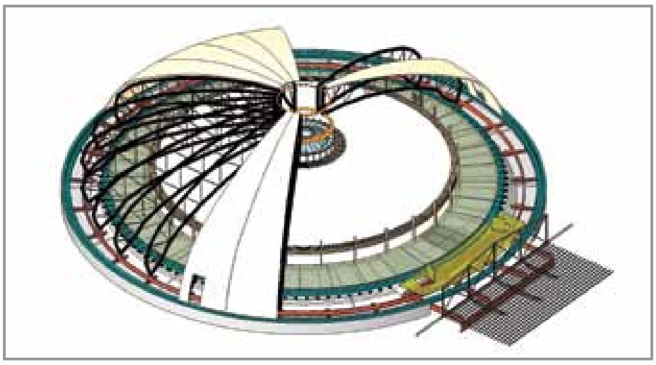
Model merging and checking
e.g. Solibri Model Checker, Navisworks Manage

Model viewing
e.g. DDS Viewer, Solibri Model Viewer, Navisworks Freedom

3.3 Structural modelling, analysis, design and production models

Phases 0 and 1 – Pre-design, briefing and conceptual design

Figure 3.4 Brisbane City Hall existing roof structure model



(Image courtesy of Brisbane City Council)

Phases 2 and 3 Structural analysis model

Data required from 3D object-orientated BIM (normally a partial architectural model):

- site
- site context
- building/room functions
- dimensions
- material properties
- loadings for equipment
- spatial allowances for structure.

Information required by structural engineer from other disciplines:

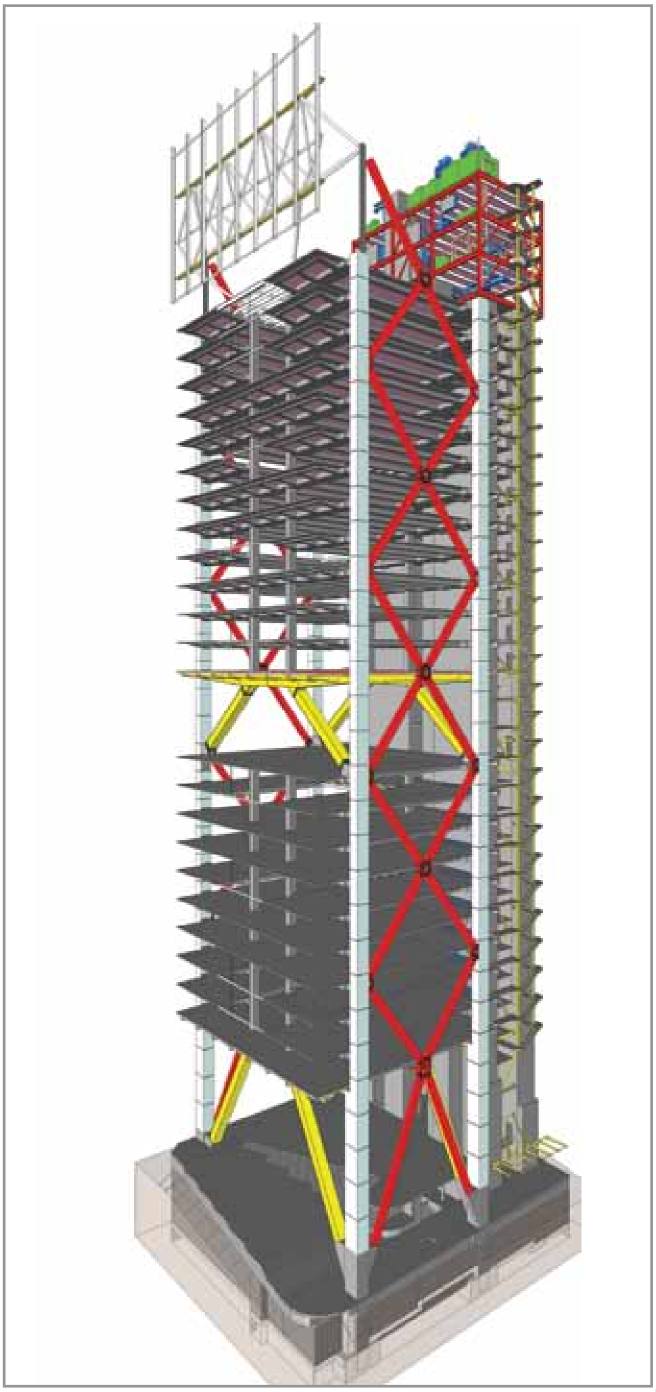
- *Architect*: building grid lines, slab outlines and penetrations, slab setdowns, wall outlines, loadbearing and non-loadbearing, external and internal walls, windows and doors, sizes and locations, columns, stairs, ramps, roof outlines and configuration, skylights, roof vents and penetrations
- *Mechanical engineer*: duct penetrations in slabs and roofs, plant equipment layout and loadings

- *Electrical engineer*: electrical pits in slabs, electrical cable ducts and conduits in slabs
- *Civil engineer*: retaining wall layout, set-out from architectural model, extra properties added to structural objects, structural connection rules and relationships: beam to beam, beam to column, wall to column, beam to wall, slab to wall, columns, beams, slabs, braces, walls, footings, piers, piles, trusses, loading for functions, autocheck for member support. Structural analysis model is not normally exchanged but used for investigation of structural options

Data exported to architectural model of adjusted sizes for:

- interference checking of 3D geometry
- revisions tracked
- auto connection of analytical and physical models.

Figure 3.5 Structural model of 8 Chifley Square

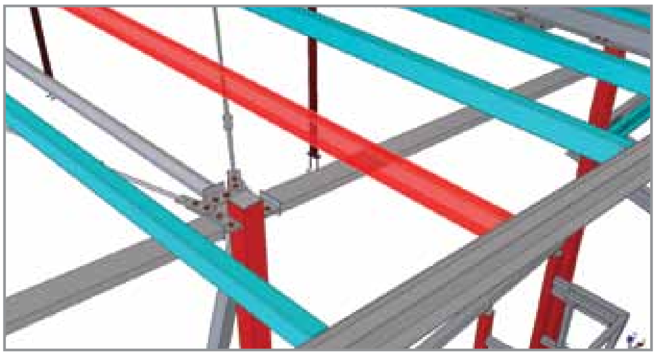


(Image courtesy of Arup)

Phases 4 and 5 – Contract documents and construction

- Fabrication and construction model is used for material procurement; fabrication design and details; quantity take-off and estimating; scheduling of construction sequence; tracking of elements, with use of RFID and barcoding; transportation, site handling; finishing/QA, inspections and approvals

Figure 3.6 Northlakes Police Station steel fabrication model



(Image courtesy of Project Services, QDPW)

Phase 6 – Post-construction/facilities management phase

- Models used to update for renovations, calculate suitability for alternative usage and loadings, or demolition requirements

Checklist for structural models

- Model in agreed format including defined storeys, with components defined separately using correct objects and belonging to appropriate systems
- BIM includes required building elements
- Building elements modelled using correct objects
- No excess, overlapping or doubled components
- No significant clashes between objects
- No conflicts between structures and penetrations in arch/structural models
- MEP penetrations and reservations included in structures

3.4 MEP modelling, analysis, design and production models

Phases 0 and 1 – Pre-design/briefing and conceptual design

- Import architectural and structural conceptual design models

Data required:

- site
- site context: orientation, geographic location
- building, building storeys
- rooms, room names
- enclosed volumes including roof/attic spaces, ceiling spaces, floor spaces, ceiling grid, partition layouts
- base structure — columns, stairs, structure, walls, bulkheads, ducts, openings, glazing
- floor to slab height, ceiling height
- furniture/workstation/equipment/joinery layouts, and occupant numbers

Conceptual design stage

- basic room concepts
- basic layout for rooms and testing of relationships
- analyse ceiling heights
- specification applied to room spaces
- model check and setup
- check rooms are enclosed volumes (air-tight)
- assign rooms to zones
- check for clashes
- obstructions or shaping devices
- design performance targets
- areas: floors, ceilings, external walls, internal walls, total glazing
- ratio volume to area
- area ratios: floor/ceiling, total wall/floor, external wall/floor, window/wall

Revised conceptual design stage

- analyses of glazing
- alternatives for skylights and resultant daylighting factors
- basic HVAC systems modelled to establish base figure for energy use

Phase 2 – Schematic design

Data required for HVAC analysis:

- 3D geometry
- building type/function of spaces/rooms
- geographic location and associated climate data
- design thermal parameters (comfort ranges for summer and winter) performance targets, hours of operation

- building construction and materials for main objects: ground floor slab, upper floors, external walls, interior walls, exterior windows, interior windows, roofs, skylights, doors, openings
- Australian standards and codes.

Early schematic design:

- calculation of heating and cooling loads to provide recommendations for design changes. Analysis can be in a number of stages based on whole building or room by room calculations
- lighting layouts created
- daylight sensors to control artificial lighting
- yearly energy usage for lighting, heating and HVAC systems
- design options with costings
- lighting results for rooms passed to architect for checking to client brief specifications.

Figure 3.7 Joint Contact Centre thermal analysis model

(Image courtesy of Project Services, QDPW)

Later schematic design:

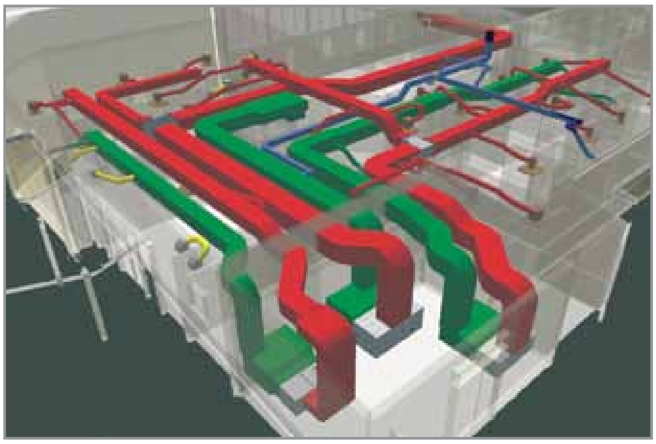
- refined detail model with rooms in smaller HVAC zones
- construction details of shading devices, walls, doors, windows added
- detailed operational profiles modelled
- energy results with increased accuracy
- different combined lighting/HVAC systems modelled for comparative assessment
- costing options of Green Star brief requirements for 4, 5 or 6 star building.

Phase 3 – Developed design

Design model and detailed design model:

- use of manufacturers' specifications
- detailed design of revised system
- coordinate with other discipline models for clash detection
- re-calculate thermal performance
- hard and soft clashes
- minimum clearance for installation, operation and maintenance
- air and pipes systems
- detailed manufacturers objects required for pumps, chillers, registers etc.

Figure 3.8 Northlakes Police Station detailed HVAC model



(Image courtesy of Project Services, QDPW)

Information required by other disciplines:

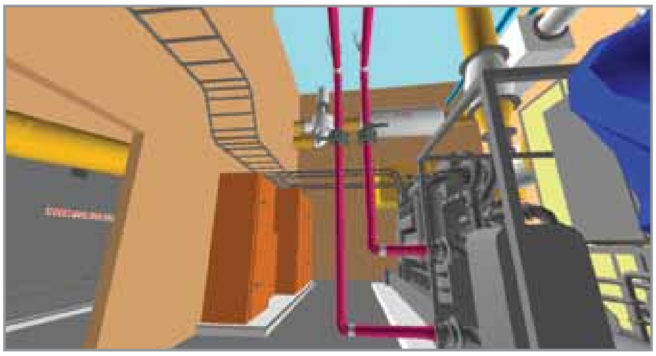
- *Architect*: plant layout outlines, vents, exhausts, intakes, plant, ductwork, air ducts, air returns, ducting, intakes, plant profile outline, ductwork, penetrations
- *Structural engineer*: ducts which penetrate slab(s), ducts which penetrate roof(s)
- *Fire services engineer*: supply diffusers, exhaust grills, ductwork (supply), ductwork (exhaust), switchboards, major pipe runs
- *Electronic engineer*: plant layout outlines, vents, exhausts, intakes, ductwork, air ducts, air returns, switchboards
- *Hydraulic engineer*: plant room layout, tundish locations, hot water ring mains, hot water units, air-conditioning units, major pipe runs, all text on separate layers, hose cock locations.

Phases 4 – Contract documents and Construction phases

Fabrication model for CNC manufacture and installation:

- detailed design for automated fabrication
- costing of objects and their installation
- bar coding for management of delivery and installation, stock control
- detailed graphics and model available for installers
- group objects for production and installation logistics: unique ID for each object, group ID for installation, production group ID for collection of identical or largely similar parts for fabrication and procurement
- confirmation of penetrations by site laser scanning before manufacture.

Figure 3.9 Detailed HVAC ductwork, services and pipework in plant room



(Image courtesy of Triple M, Brisbane, QLD)

Phase 6 – Post-construction/Facilities management

Services models contributing to the FM model:

- warranties, operation manuals, energy consumption, maintenance and replacement management
- monitor usage to design parameters.

Checklist for HVAC system model

- Model in agreed format including defined storeys, with components defined separately using correct objects and belonging to appropriate systems
- System names and colours are defined systematically
- No excess, overlapping or doubled components
- Components fit into their spatial reservations with no significant clashes between HVAC, architectural, structural, hydraulic and electrical models

3.5 Cost planning and quantity take-off

Phases 0 and 1 – Pre-design/briefing and conceptual design phases

Required data extracted from the project brief or early design model:

- site
- site context
- building function
- room data: areas, finishes, services, functions, relationships
- equipment, furniture, fittings
- existing building and siteworks.

Cost parameters/control quantities measured characteristics for systematic comparative analysis and cost modelling such as gross floor area, net floor area, volume, gross exterior wall area, window area, roof area, services etc.

Other information to be considered but not normally part of the model's database:

- cost per square metre and unit rates, site preparation and other site costs, professional and statuary fees, temporary works, other objects that can't feasibly be modelled so they can't be automatically extracted (e.g. paint).

Phase 2 – Schematic design

Cost planning based on generic objects, with partial visual analysis of 3D architectural model at an elemental level.

Preliminary estimates from specialist consultants for HVAC, electrical, hydraulics etc.

Generic object properties

Link to costing database

Phase 3 – Developed design

Merged discipline models used for cost planning based on specific objects and assemblies for design cost checks

Updated specialist consultants' estimates for HVAC, structural, electrical, hydraulics, fire etc.

Specific object properties: name, GUID, geometry/location, physical properties, manufacturer, product data, phase code, cost code

Quantities and properties semi-automated extraction for estimating software

Use of classification system recognised by a range of project software

Comparison to earlier model iterations and design options

Phase 4 – Contract documents

Final project model for tender documents, BOQ, detailed object properties and finishes for tendering.

Phase 5 – Construction

5D use of model to assist construction management, procurement, progress claims, partial completions, verification of progress, and tracking of cash flows.

Model objects may have to be broken down to allow assessment of partial completions (e.g. a concrete column divided into formwork, reinforcement, concrete, strip, finishing).

Phase 6 – Post-construction and facilities management

Project model that has been edited during the construction phase can be used for maintenance modelling, tracking replacement costs, monitoring of LCC and tax depreciation calculations. Models are also used for space management and refurbishment planning.

3.6 Construction models

It is helpful to differentiate between types of models by their purpose.

Construction models can be created for different purposes (e.g. planning models, as-being built models and as-built models).

Construction Phase planning models can enable:

- Investigation of what-if scenarios, using animations and other traditional graphics to optimise construction timing and sequence. Animation of site and temporary objects (e.g. cranes, hoarding, scaffolding and vehicles) is possible
- Integration with manufacturing, procurement supply chain, by tracking of construction activities, including off-site fabrication
- Tracking and reporting of cash flow and cost control and management
- Integration of design model with site laser scans for accuracy checks of services penetrations
- Use of machine guidance technologies through the use of GPS and robotic site surveying
- Tagging of building elements with RFIDs (**R**adio **F**requency **ID**entification tags) for faster, more accurate feedback of project status
- Site safety planning and management
- Differing contractual styles that allow integration of design models with subcontractor models, either in traditional post-tender practice or integrated pre-tender practice
- Where main contractor has the design coordination role, modelling facilitates the earlier identification of spatial conflicts, quantity take-offs, construction scheduling, planning and off-site fabrication
- Modelling coordination methodologies for construction phase models vary depending on the content and use of models. The two examples below show the extra input required for producing 4D models

3D construction coordination process

1. Combine/merge discipline models, convert files if necessary
2. 3D viewing to aid communication, filtering of data and querying of object properties
3. Interference checking and clash detection
4. Selection of objects or sets of objects to check and report to, tolerance levels defined etc.
5. Quantity take-off
6. Cost estimation

4D construction coordination process

1. Link 3D model (from above) to construction schedule
2. Establish work breakdown and flow
3. Establish installation sequence
4. Re-organise or re-structure 3D objects if necessary, and add temporary works
5. Refine schedule
6. Re-link 3D objects and construction schedule activities: demolish, construct, temporary status
7. Refine 4D model
8. Present animations etc.

Challenges

- There are a range of significant challenges for the efficient and effective use of construction phase models that will have to be addressed:
- Subdivision of 'design objects' for fine detail scheduling of 'construction objects'
- Integration with cost estimating, FM, project management and construction management software
- Automated linking and updating of objects to construction schedule
- Integration with off-site fabrication, where object status to be acknowledged even though no 'object' on site yet

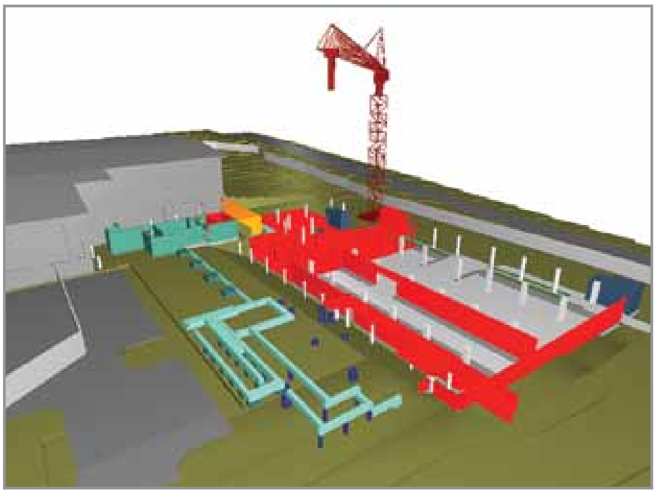
Model object information required for construction models as a minimum

- Accurate detailed 3D model, graphic views of building components, ability to extract quantity and object property information
- Model temporary works objects: scaffolding, hoardings, cranes, formwork for construction sequencing etc.
- Specification information for all objects
- Analysis data for performance levels and project requirements: structural loads, heating and cooling loads, lighting design levels
- Construction status of each object: to track and validate progress
- Database of productivity performance and cost data

Type 1: Pre-construction model, conceptual or strategy models

- Conceptual model for design and spatial analysis; feasibility of construction with tender program and used for tendering/bidding presentations and demonstrations
- Strategy models for design and construction methodology, to identify and resolve issues at an early stage to aid communication, coordination and clash detection

Figure 3.10 Pre-construction planning model from Queensland State Archives



(Image courtesy of Project Services, QDPW)

Content

- Construction schedule data with task durations reflecting an overall estimated construction period and only major interface points specified
- 3D geometry derived from design models: architectural, structural, building services, not necessarily with detailed properties
- Elements modelled as design spaces and programmed as construction zones or activities

Type 2: Logistics models and structural models

- Detailed model and construction program to effectively demonstrate construction methods, process, sequence, and relationships between elements and activities, to aid construction planning and scheduling; and to determine preliminary cash flow

Content

- All of Type 1 data
- 3D geometry with detailed properties
- Site context, traffic plan, mechanisation, site facilities, health and safety, temporary works and overall building construction sequence
- Structure and façade broken down into individual models as per the parts of buildings such as foundation, substructure, superstructure, envelope and the roof
- Elements are modelled semi-detailed and programmed as multiple activities
- Zone-based program not location-based planning
- Non-building temporary works objects added such as: scaffolding, cranes, site sheds, hoardings
- 3D geometry re-arranged to suit trade break up and/or construction sequencing
- 4D tags linked to Gantt chart/programming software
- Model object properties can include object recipes and performance data to automate scheduling
- Different degrees of detail for structure, services and finishes

Type 3: Detailed construction schedule models

- Construction planning and scheduling of each detailed object for programming of individual activities
- Emphasis is on task duration, the length of time each individual task will take to complete and the interface with those tasks and contractors that have a direct correlation to the activity being programmed
- This level of detail is necessary for interior or fit-out models where all the elements are modelled as individual activities
- Building services models broken down into different models as per types of services such as ductwork, pipework, electrical, fire protection, drainage, communication, etc.

Content

- All of Type 2 data
- Objects can be assigned an individual task to match construction sequence (e.g. single concrete slab divided into separate concrete pours; or columns on a floor level may by formed and poured and stripped on different days)
- Models can include the demolition and excavation sequence and other temporary works such as the location and movement of cranes, access ramps, the position and movement of temporary hoardings, pedestrian walkways, storage and set-down areas, temporary cabins and site offices, scaffolding, hoists and much more. These items often are relocated during the construction process and can provide the basis of investigation of alternatives

Type 4: 'As-being built' models

- Construction management tool to track the progress of the project by updating the model, to aid procurement and the determination of cash flow
- This requires a significant effort to accurately and frequently update the model, but it then becomes a major construction management tool
- Procurement requires the tracking of elements fabricated off site with the on-site progress. Normally the off-site objects are not part of 'the model'
- An updated 4D model aids cost planning, analysis of cost claims, and comparison of baseline costs to actual costs incurred. The assessment of the state of object completion within a 4D/5D model can be used for checking regarding on-site progress (e.g. concrete columns: formed, reinforcement installed, poured, stripped, finished)

'As-being built' models

These models are better classified as FM models. See following section 3.7 *Facilities management/ as-built* models

3.7 Facilities management/as-built models

Content

- 3D geometry derived from design and/or construction models
- Maintenance history

Types of FM models

The purpose of the FM model will depend on its application for existing buildings or for new buildings

Phases 0 and 1 – Input into client brief

Feedback during design and development of the model can be used to verify compliance with the original brief, or variations to the brief, such as: rooms/spaces, areas, finishes, functions, performance specifications, budget

The issue of property set definition of data sets for exchange is also important for FM. In the USA, COBIE — Construction Operations Building Information Exchange — has been developed for this purpose, so that the 'format facilitates the delivery of building information during planning, design, construction, and commissioning for delivery to facility owners and operators'. It does this by using the IFC schema.

Phases 2 to 5 – Project delivery/design stage FM model

- Model of site, and/or existing buildings and siteworks
- FM model at a schematic/developed design level where detailed information for construction is not required. Data to include: spaces/rooms, areas, volumes, function, occupants, zones/departments, performance criteria, performance improvements, energy usage monitoring targets, LCA and costs targets

Phase 6: As-built FM model, monitoring/ analysis FM model

Operation and maintenance

- As-built FM model with inventory, equipment, maintenance schedule, that can be used for monitoring of energy use and performance against design criteria; maintenance and condition management for both preventative and emergency maintenance

Models can also be used for portfolio management by owners by real-time reporting of building performance, link to maintenance manuals; and for tenants for space usage, occupancy costs, internal rents/costs, spatial conditions, energy and comfort monitoring.

This is an emerging area that needs investigation and expansion, but where significant financial and efficiency gains are possible.

Appendices

Appendix 1: Model checking and auditing

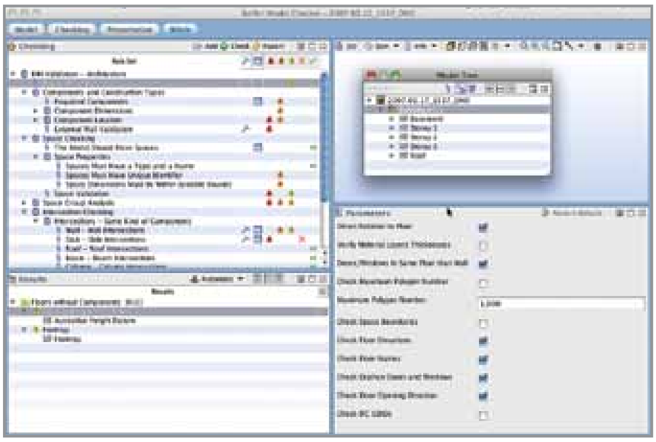
Model checkers can compare models against many standard and customisable rules.

One model checking software is Solibri Model Checker (SMC).

Rules are grouped in RuleSets, a number of which are predefined, e.g. *BIM Validation – Architecture.* Examine Figure A1.1 below. The rules examine model structure, required objects, construction types, spaces (rooms) and their coding and classification, and intersection checking. This represents a comprehensive selection of key parameters that ensure a model is consistent and logically sound, that is, well built.

Model structure

Fig: A1.1 Building model logic



(Image courtesy of J Mitchell)

The selected example checks that a model has a valid model structure, with a building definition and a set of building storeys. The rule, *Model Structure,* requires that objects have a direct relationship to a storey, and SMC finds that two storeys (AHD and Footings) have no components. In this model, the model builder has included a reference storey *AHD* at 0.00, representing the real survey height.

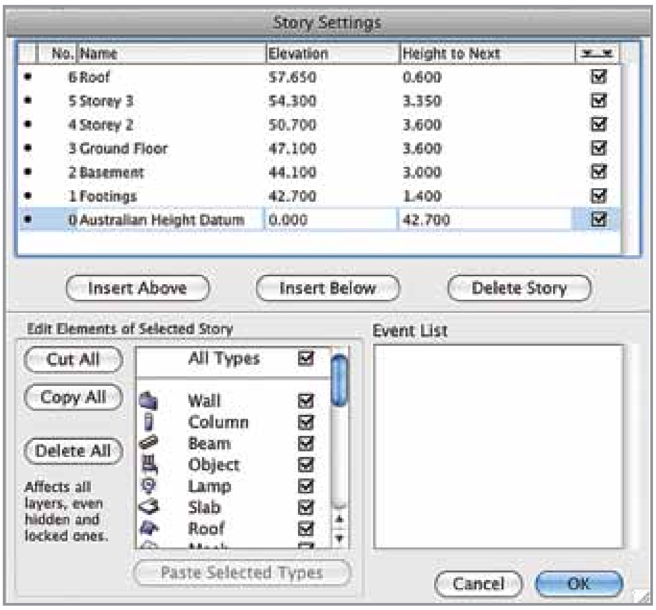
Data on building storeys

SMC allows us to accept or reject auditing results. In this case we can ignore (accept) that result, as we want our models to reflect real elevations for every component of the building. The second storey *Footings* is part of the agreed model storey set-up but there is no structure defined for the model at this stage. So we can also accept that result.

However, many models include artefacts that are being used for database set-up in the BIM tool (e.g. referenced files, or as holding places for options or templates or standard parts). In the IFC model exchange, the storey structure is a key element of the model and *must be consistent for all the partners of the shared project*.

In this case, Solibri ignores the storeys without objects (perhaps it shouldn't, as we would like confirmation that there is a storey with nothing on it!), but if we look at the source model we see the full structure.

Fig: A1.2 Building Storey Settings



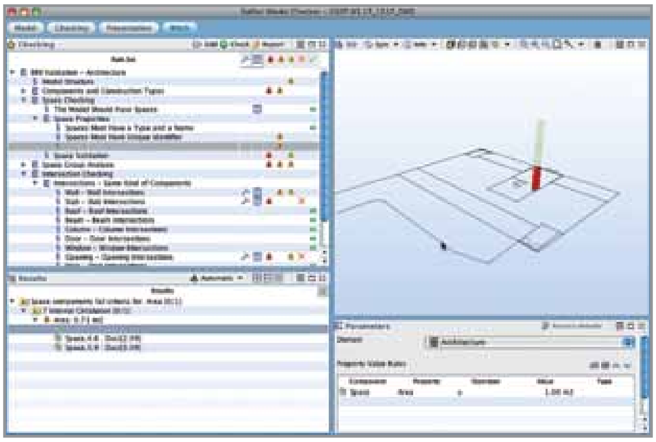
(Image courtesy of J Mitchell)

This first example also makes clear the concept that a rule has a specific context, which may vary from project to project, and thus the same rule may have different consequences. The rule may report issues that are perfectly acceptable, but we still use the semantics of the model — intelligent objects related to each other, and the power of the computer to comprehensively audit the model to check for discrepancies.

Space compliance with project parameters

A second example of a rule in this Rule Set is *Space dimensions must be within sensible bounds*. The constraints defined are that the space area must be greater than 1.00 m^2, and the height must be greater than 500 mm. These reflect a reality that a space (or room) of 300 x 300 mm is very small, and less than 500 mm in height is a potentially impossible space (but a plenum in a ceiling used for return air could be lower!).

Fig: A1.3 Space checking example



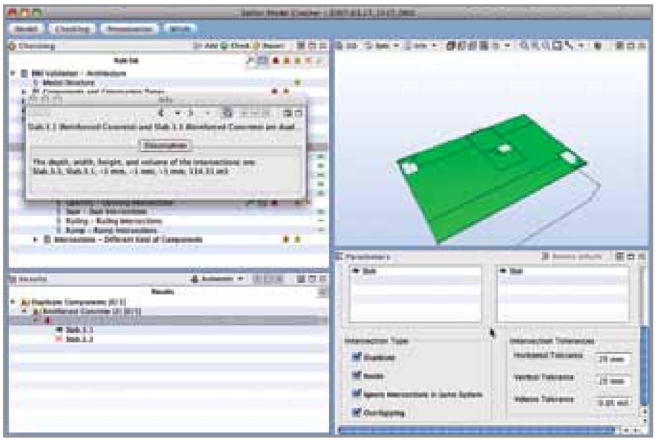
(Image courtesy of J Mitchell)

The application of that rule is seen (Figure A1.3 above) where three spaces have been identified, all the same profile, actually a duct. Here the space *is* suitable for its task, an electrical cable riser, so we can elect to ignore the report.

Duplicate and coincidental model objects

Another example illustrates a common error in model building, that of duplicate components, often very difficult to see in the authoring BIM software.

Fig: A1.4 Duplicate building elements example



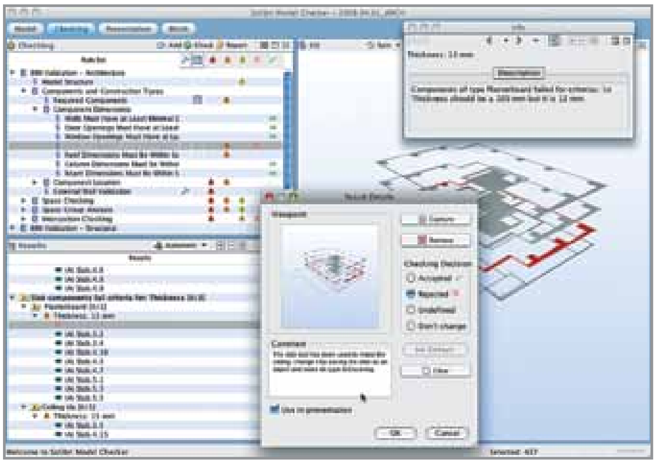
(Image courtesy of J Mitchell)

Here there are two instances of the slab (ID 3.1 or 3.3) at the ground floor. SMC identifies it and we can specify that the model author deletes the appropriate duplicate.

Incorrect object use

Another common instance of poor model building is incorrect use of objects.

Fig: A1.5 Incorrect object use example



(Image courtesy of J Mitchell)

Here a slab tool in the BIM application has been used to model a ceiling. The default export for this object is ifcSlab, so the semantics are incorrect and, if left as is, will lead to incorrect interpretation, quantities, specification etc. Another clue is the Slab type of 'Plasterboard', which should alert a modeller to an unusual instance of a plasterboard *slab*!

While it looks adequate, the model is incorrect and should be fixed.

In the Result Details window we see the auditor's instructions to the modeller. This is how SMC manages feedback, and from this result and all others in the audit, a report is automatically generated in pdf and other formats for delivery to the appropriate project personnel.

Clash detection

The next examples look at the most common issue in a model — clash detection — which can be checked even in the early stages of a project where there may be a need to coordinate building services systems with architectural elements or structure.

Clash detection falls into several categories or types:

a. errors of location (the responsibility of the discipline modeller) 'hard' conflicts — physical conflicts between components, or 'soft' conflicts — interferences between components and access spaces or violations of clearances

b. design coordination (a shared responsibility)

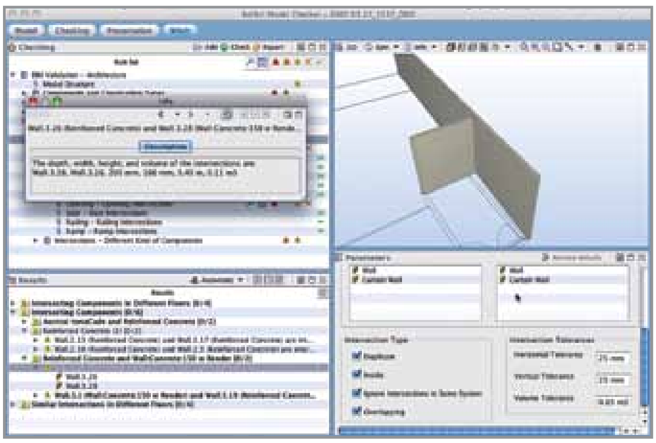
c. interdisciplinary design resolution (interdependent resolution of detailed design development to support another discipline)

Instead of waiting for the builder to discover these errors on site, we now check and resolve the problem 'virtually' before we start on site, ensuring lower RFIs, lower costs and a more predictable result.

a. Errors of location

In this type the clash is an error of location largely the result of poor model building.

Fig: A1.6 Element intersection checking example



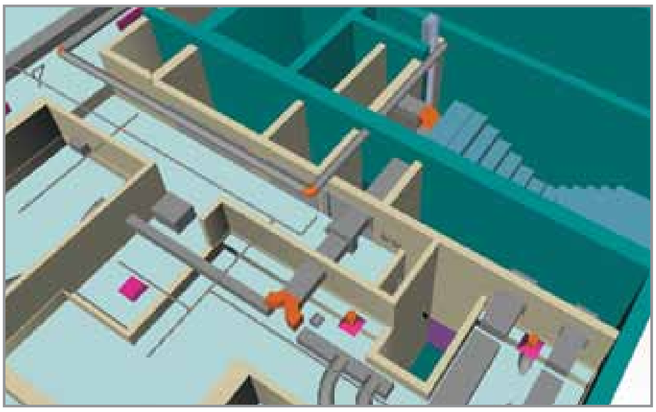
(Image courtesy of J Mitchell)

The report identifies dissimilar material specifications for the two walls and calculates the intersection properties. The *Parameters* pane shows the rule settings. (Note you can alter these on the fly, but if you want to re-use it you must update or specify a new rule using the Rule Set Manager).

The *Info* dialog reports the properties of the intersection — i.e. a depth intersection in plan of 200 mm.

The walls are in the basement storey and part of the external wall and stair structure. In this case it is an error and we can tag it (as we did in the previous example) with an instruction on how to fix it.

Fig: A1.7 Services modelling example



(Image courtesy of J Mitchell)

This example has four sub-models, included above: architecture, structure, HVAC and sprinklers. The branches to the main duct do not match the elevation at the bifurcated duct bends, (lower centre) and this model building issue is found often with modellers new to 3D object modelling.

Now that we can see the full 3D context it should be possible to reduce these errors to an absolute minimum if not completely.

b. Design coordination

In this second type of clash, the clash cannot be resolved by the model owner alone; the respective parties have to agree on a solution that typically involves re-routing services networks, adjusting the size or proportions of components, or modifying the carcass building elements or the architectural layout.

Fig: A1.8 Services coordination example

(Image courtesy of Project Services, QDPW)

In this case study example we can verify if the design is fully coordinated. Figure A1.8 above is a multidisciplinary IFC model built by Project Services, Brisbane merging architecture (ArchiCAD), structure (Tekla), electrical (Revit MEP), and hydraulic and mechanical (DDS) services.

SMC's rule checking highlights that a circular exhaust vent has interfered with 'Z' purlins and penetrated the roof sheeting. The resolution of this clash requires design input from all parties including the architect to resolve it effectively.

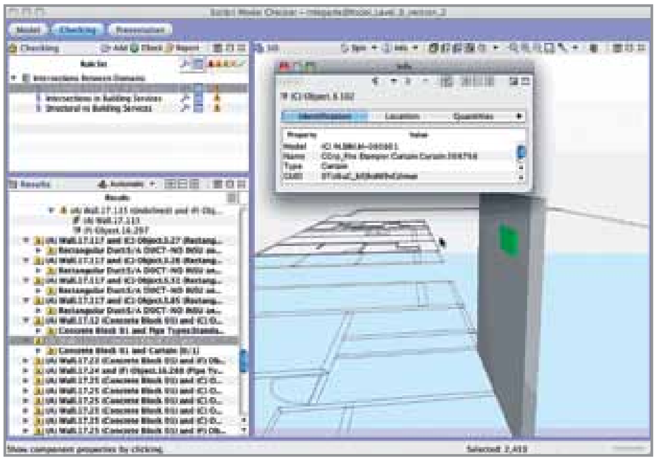
Experienced professionals know that in multidisciplinary work (in complex building types such as hospitals for example) a shared solution is required, as individual modifications often have a strong impact on the other systems.

These last two clash types improve our modelling skills, clarify our understanding of object modelling, and greatly improve the quality of a single or multidisciplinary model.

c. Interdisciplinary model coordination

In this final type of clash, the model checker identifies a point of interdependency between systems in the building.

Fig: A1.9 Interdisciplinary design resolution



(Image courtesy of J Mitchell)

The example above shows a fire damper correctly located in a fire-rated wall, but SMC reports it as an error. In this case, the structural engineer needs to provide a penetration, meanwhile checking that it does not cause a structural or related problem.

For services systems, penetrations are pervasive in the building carcass, and where these penetrations are located in structural elements and fire-rated walls, or become exposed, they need careful design resolution.

The integrated model makes visible what is often very hard to see in traditional 2D documentation; plinths for plant, detailed structure to support other systems, outlets for serviced equipment (simply a toilet, or a more complex steam steriliser), boxing in for pipe runs etc.

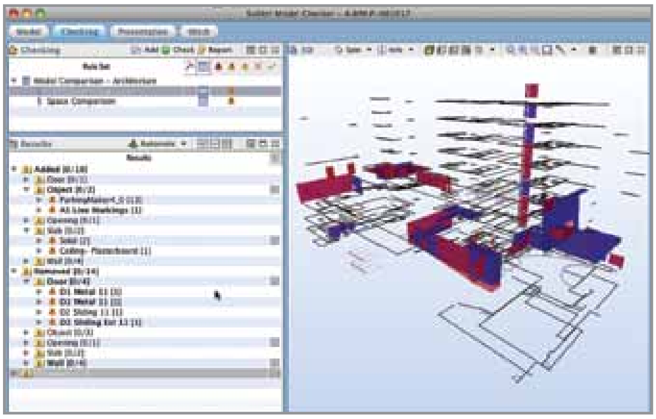
Auditing tools bring outstanding benefits in this area, and alone will justify making this tool and addition to a designer's BIM toolset.

Version comparison of models: Reporting versions

As the progress of a multidisciplinary project gathers pace during the detailed design and documentation phase, regular updates of the models are posted for exchange among the project team. What has changed since the last version? In today's drawing-based methods, participants are used to expecting mark-up 'clouds' to show where changes are.

In a model, where 2D annotation is not a normal part of a model-based exchange, how are modifications advised to project partners?

Fig: A1.10 Comparing versions of the model



(Image courtesy of J Mitchell)

SMC has a Rule Set expressly defined for this purpose — *Model Comparison — Architecture*. Similar definitions are available for building services and structure.

Changes to a model can be of three types:

- new objects (blue)
- deleted objects (red)
- modified objects (purple)

New objects may sometimes be visually identified; but objects that have been deleted are far harder to check, and modified objects, even more so. A significant advantage of this technique is to have a thorough identification of object changes in a new version.

For each object of each type, full details of the change are provided and significantly enhance the collaboration process.

In this architectural model, SMC has grouped the changes into the three types. Colour coding (red deleted, blue new, purple modified) aids understanding, and the *Info* dialog describes the selected object detailed changes.

This auditing speeds up model development and improves the interdisciplinary design development.

Code compliance — egress, accessibility and code checking

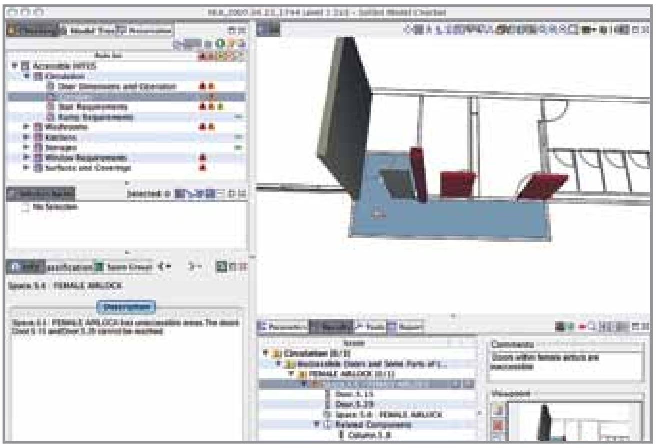
We have shown so far checking for basic geometry, material and spatial aspects, relationships and multiple domain contexts. The step to auditing a model for code checking is now much more obvious.

We have in place the basics for an automated code checking system:

- a model of a facility that has all the potential data needed to support analysis
- a model that integrates all the relevant object types and systems
- standardised codes.

With appropriate software, we can now determine if the model complies with codes such as a development application, building approval or, for example, a NSW BASIX compliance.

Fig: A1.11 Accessibility for wheelchairs



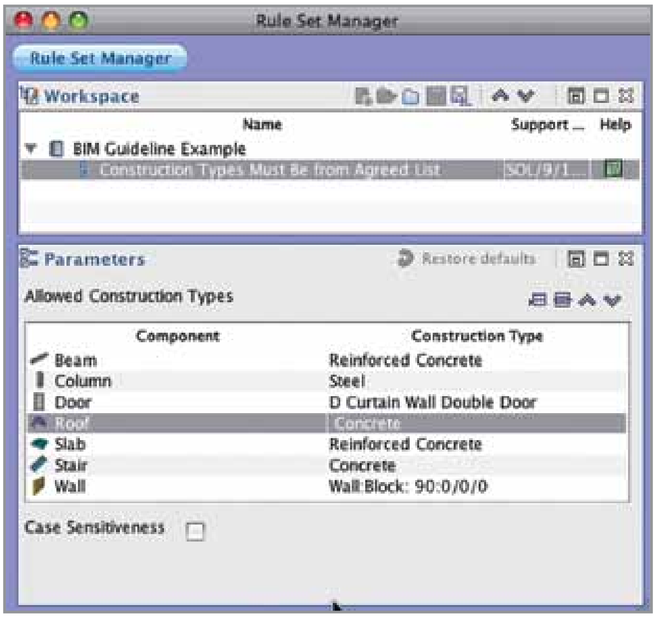
(Image courtesy of J Mitchell)

In this example we have used one of the egress and accessibility Rule Sets. The airlocks to the toilets have failed as the space does not allow wheelchairs to pass each other in the corridor. The space (5.6 Female airlock) has two doors (5.15 and 5.29) which cannot be accessed. These tools quickly and universally check building models, *before* being submitted for approval, and provide designers and users with reliable solutions which otherwise too often require a complex manual verification.

Developing custom Rule Sets

SMC allows users to customise RuleSets to support organisational, project, discipline or building object specific auditing of the model.

Fig: A1.12 Defining a new rule in the Rule Set Manager, and the domain settings



(Image courtesy of J Mitchell)

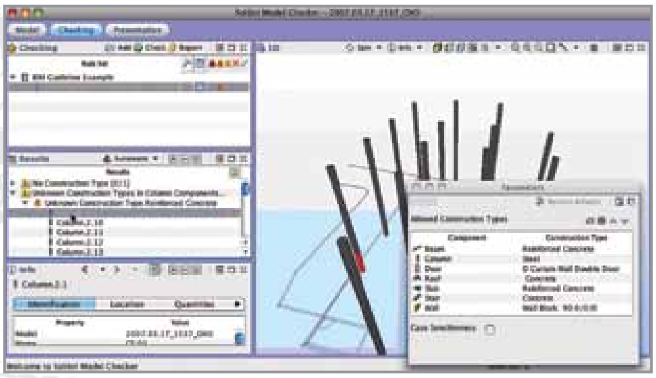
We have defined a custom rule *BIM Guideline Example* (Figure A1.12 Rule Set Manager pane above) where we want to verify that certain building components (walls, columns, doors etc.) have specified construction types.

The allowable *types* in this case are the names of the building elements, defined in the BIM application libraries. You may define a project-specific set that you want to be used by all the disciplines involved on the project.

Or it is possible to make domain specific rules using the Domain list (right hand image in Figure A1.12 above). We have chosen 'Architecture' domain in that example.

We now select the Rule Set for checking in the model and see the results:

Fig: A1.13 Custom Rule Set results



(Image courtesy of J Mitchell)

Based on the types we have defined, we find many errors. We expected steel columns and have reinforced concrete. The stairs in this model have no defined type. For any typical building model, this auditing highlights errors quickly and precisely and further improves the quality of the final mode.

Appendix 2: Information Delivery Manual

IAI buildingSMART has developed a schema that defines a set of information that needs to be exchanged to support a particular business requirement at each stage of a project, and provides a description of the information in non-technical terms.

The Information Delivery Manual (IDM) targets both BIM users and solution providers. For BIM users, it provides a simple to understand, plain language description of building construction processes and the requirements of information to be provided.

The development of the IDM is based on open data standards. It provides requirements to BIM solution software companies as it identifies and describes the detailed functional breakdown of the exchange process, and describes IFC capabilities needing to be supported for each functional part in terms of the entities, attributes, property sets and properties required.

See http://idm.buildingsmart.no/confluence/display/IDM/Home

IDM components:

The IDM has five components:

1. Process maps

See http://idm.buildingsmart.no/confluence/display/IDM/A+-+Process+Maps+%28PM%29

2. Exchange requirements

See http://idm.buildingsmart.no/confluence/display/IDM/B+-+Exchange+Requirements+%28ER%29

3. Functional parts

See http://idm.buildingsmart.no/confluence/display/IDM/C+-+Functional+Parts+%28FP%29

4. Business rules

5. Verification tests

1. Process maps

Process maps describe the flow of activities for a particular business process and enable understanding of the configuration of activities that make it work, the actors involved, the information required, consumed and produced.

Examples:

- cost modelling
- energy analysis
- FM
- HVAC engineering
- service life planning
- structural engineering

2. Exchange requirements

Exchange requirements are a set of information that needs to be exchanged to support a particular business requirement at each stage of a project and provide a description of the information in non-technical terms.

Examples:

- Building model (basic)
- Cost model (order of magnitude), (preliminary appraisal), (approximate estimate), (detailed estimate), (actual cost)
- Energy analysis model (programming), (zones), (demand), (energy)
- Service life (design), (reference), (estimated), (residual)
- Structural design (outline conceptual), (scheme), (analysis model), (coordinated), (response model), (specifications)

3. Functional parts

Functional parts are a unit of information, or a single information idea, used by solution providers to support an exchange requirement at a particular project stage.

A functional part is a complete schema in its own right, as well as being a subset of the full standard on which it is based.

Examples of functional parts with detailed properties:

Set project context:

GUID, Owner History, Default Units, Representation Context, Extended name, Project description, Project Phase, World co-ordinate system, Co-ordinate space dimensions (2D or 3D), True north relative to WCS

Owner history

Owning User, Owning Application, Creation Date, Change Action, Last modified date, Last modifying user, Last modifying application, Current state

Model site

GUID, Owner History, Name, Description, Placement, Shape Representation, Composition Type, Contained Elements, Extended Name, Reference Elevation, Reference Latitude, Reference Longitude, Land Title Number, Buildable area, Maximum building height, Total planned area for site, Perimeter, Area, Volume, Classification

Model building

Building site, GUID, Owner History, Name, Description, Extended name, Building origin, Shape Representation, Composition Type, Contained elements, Postal Address, Elevation height, Elevation above terrain, Occupancy Type, Area, Volume, Total Height, Perimeter, Gross Area, Net Area, Gross Volume, Net Volume, Main fire use, Ancillary fire use, Sprinkler protection, Sprinkler protection automatic

Model building storey

GUID, Owner History, Name, Description, Extended name, Building storey origin, Shape Representation, Composition Type, Contained elements, Entrance level, Above ground, Sprinkler protection, Sprinkler protection automatic, Gross area planned, Net area planned

Model space

GUID, Owner History, Name, Description, Extended name, Function, Flooring level, External or Internal, Origin, Shape representation, Composition type, Contained elements, Occupancy type, Maximum number of occupants, Floor Area, Perimeter, Volume, Classification, Height, Ceiling area, Wall area, Floor covering, Wall covering, Ceiling covering, Skirting board, Publicly accessible, Handicap accessible, Concealed flooring, Concealed ceiling

4. Business rules

Constraints that may be applied to a set of data used within a particular process.

Used to vary the result of using a schema without having to change the schema itself, e.g. localising an international standard.

5. Verification tests

Testing software to verify the accuracy of its support for exchange requirements.

Appendix 3: Window property sets example

An example: Property sets or Psets defined by IAI for a window are:

Pset_WindowCommon: common property set for all window occurrences

Reference	Reference ID for this specified type in this project (e.g. type 'A-1')
FireRating	Fire rating for this object.
AcousticRating	Acoustic rating for this object
SecurityRating	
IsExternal	Indication whether the element is designed for use in the exterior
Infiltration	Infiltration flowrate of outside air
ThermalTransmittance	
GlazingAreaFraction	
SmokeStop	

Pset_DoorWindowGlazingType: specific property set for the glazing properties of the window glazing, if available

GlassLayers	Number of glass layers within the frame, e.g. '2' for double glazing
GlassThickness1	Thickness of the first (inner) glass layer
GlassThickness2	Thickness of the second glass layer
GlassThickness3	Thickness of the third glass layer
FillGas	Name of the gas by which the gap between two glass layers is filled
GlassColor	Color (tint) selection for this glazing
IsTempered	Indication whether the glass is tempered
IsLaminated	Indication whether the glass is layered with other materials

IsCoated	Indication whether the glass is coated with a material
IsWired	Indication whether the glass includes a contained wire mesh
Translucency	Fraction of the visible light that passes the glazing at normal incidence
Reflectivity	Fraction of the visible light that is reflected by the glazing at normal incidence
BeamRadiationTransmittance	Direct solar radiation transmittance that passes the glazing at normal incidence
SolarHeatGainTransmittance	Total solar heat transmittance that passes the glazing at normal incidence
ThermalTransmittanceSummer	Thermal transmittance coefficient (U-Value) of a material
ThermalTransmittanceWinter	Thermal transmittance coefficient (U-Value) of a material

Pset_DoorWindowShadingType: specific property set for the shading properties of the window glazing, if available

ExternalShadingCoefficient	Radiation transmission coefficient of the outside shading device
InternalShadingCoefficient	Radiation transmission coefficient of the inside shading device, symbol 'b-value
InsetShadingCoefficient	Radiation transmission coefficient of the shading device inside the glazing, symbol 'b-value'

Appendix 4: Model servers

Model servers are yet to be implemented in the Australian industry, but are currently being used for research at UNSW and QUT. Both are using EDM. They aim to support all the information that is required within a building project and the subsequent life of the building. The amount of information that will need to be stored is very large. Model servers use advanced database systems to manage the necessary information in a timely manner. Additionally, no one person will be interested in **all** of the information. The information can be filtered to meet the needs of particular people within their normal working roles. This ability to store all of the information, but only present the relevant information at any particular time is a core function of the model server. Model servers will also support new types of functionality, such as e-commerce, supply chain management, version control, merging of refined/revised information with the server model, access management (privacy).

ftp

ftp (file transfer protocol) is an old technology (pre-World Wide Web) but a reliable one that supports the sharing of files and directories over networks, including the internet. In simple terms, one or more directories on a network accessible hard disk are made visible across the network. People can then access the directory(ies) and files to perform various operations. The range of operations they can perform depends on the permissions assigned to the user account. The most open access is provided through an 'anonymous' account. The convention is that the user then gives their email address as the password, but this is not essential. User 'anonymous' is normally only able to read listings of the files in a directory and copy files that are already in the directory. This is for obvious security reasons.

If an ftp site is going to be used to support collaboration on a project it is usual to give each person (or possibly company) their own user name and password. This will allow read and write access to directories where they are to store their files and read-only access to directories where other disciplines have uploaded their files.

There will be one designated person who is the site administrator who can do anything to the files stored on the ftp site. This administrator can control who can upload or download files, read directory listings etc.

A structure for an ftp site could be as follows:

Server
    ftpDirectories
        Project1
            Architectural
            Civil
            Hydraulic
            Mechanical
            Structural
            ...
        Project2
            ...
        Project3
            ...

There are dedicated ftp client programs that support the use of ftp. These can copy multiple directories, set permissions etc. A standard web browser is appropriate for infrequent use, supporting drag-and-drop of files if the user has the appropriate permissions. A URL (uniform resource locator) is referencing an ftp site if 'ftp://' is at the start of the resource name.

Appendix 5 : Export examples

Revit IFC import/export configuration

Mapping specification

The partial mapping below from the **exportlayers-IAI-IFC.txt** file shows how Revit BIM objects are mapped to the IFC model entities. IFC entities are always preceded by the prefix 'ifc' and the complete list of entities can be found at http://www.iai-tech.org/, where the IFC specification, IFC2x3TC1 HTML Documentation can be downloaded for reference (approx. 22 MB). There are about 600 model entities which supports a wide range of exchange scenarios, notwithstanding that the sending and receiving softwares may not support a particular entity. Most architectural, structural and building services objects are covered.

In the table opposite, **bold** entries represent direct mapping of Revit objects to their corresponding ifcEntity, for example, Doors: **IfcDoor**; and Ducts: **IfcDuctSegment**.

A second group map Revit object categories to an IFC entity **IfcBuildingElementProxy**. A proxy entity carries the geometry and properties of the exported object, but has no specific entity type. This can either be used to send objects for which there is no object type in the IFC specification, or as a temporary mapping until the correct assignment is set.

Model object types

The objective in the export file is to have all exported objects directly mapped to their proper ifcEntity. If ifcProxy elements are used, it is much more difficult to select them for clash detection etc, as each one has to be visually checked for its building element type.

In the partial example below, there is a mixture of architectural elements as well as building services and structural engineering elements. For a single engineering model export, deactivate the inappropriate categories by setting the Layer name to 'Not Exported'.

Category	Subcategory	Layer name
Air Terminals		**IfcAirTerminal**
Area Polylines		Not Exported
Area Tags		Not Exported
Areas		**IfcSpace**
Callouts		Not Exported
Casework		**IfcFurniture**
Casework Tags		Not Exported
Ceiling Tags		Not Exported
Ceilings		**IfcCovering**
Ceilings	**Surface Pattern**	**IfcCovering**
Color Fill		Not Exported
Color Fill Legends		Not Exported
Columns		**IfcColumn**
Communications Devices		**IfcBuildingElementProxy**

References

Universities, government and industry organisations

AIA: American Institute of Architects, USA
CIFE: Center for Integrated Facility Engineering, Stanford University, USA
COBIE: Construction Operations Building Information Exchange, USA
CORENET, Construction and Real Estate Network, Singapore
CRC for *Construction Innovation*, Australia
FIATECH, USA
Georgia-Tech: Georgia Institute of Technology, USA
GSA-NBIMS: General Services Administration, USA
IAI-buildingSMART. International
NIST, National Institute of Standards, USA
Salford University, UK
Senate Properties, Finland

Regular web-based newsletters

AEC-Bytes
Cadalyst
JBIM: Journal of Building Information Modeling

Technical web-based journals

CIB Publications (International Council for Research and Innovation in Building and Construction)
Itcon Publications (Information Technology in Construction)

BIM-related software listing

Planning, pre-design, early design

Affinity
Aprog
Bluethink House Designer
Codebook International
dRofus
Facility Composer
FormZ
Generative Components
SketchUp

Design

12D
ArchiCAD
Architerra
Bentley: Architecture, Structure, Mechanical, Electrical, Facilities
CAD-Duct
DDS: Electrical, HVAC
Digital Project
MagiCAD
Powel 3D Terrain
PRO-IT
Prosteel 3D
Revit: Architecture, Structure, MEP
Riuska
Robot
Tekla Structures
Vectorworks

Analysis, simulation and visualisation

3D Max
CostX
CRC for *Construction Innovation* Estimator
Ecotect
Green Building Studio
IES-VE
LCADesign
Simurban

Model merging and management

Navisworks
Solibri Model Checker

Construction, 4D and 5D

A3D
Constructor
Navisworks
Synchro
Vico

FM

ArchiFM
Artra
FM Desktop
Rythi
Vizelia

Model servers

EPM Jotne
Octaga

Others

e-specs
Newforma
Team Binder

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Green BIM: Successful Sustainable Design with Building Information Modeling by Eddy Krygiel, Brad Nies and Steve McDowell

BIM and Construction Management: Proven Tools, Methods and Workflows by Brad Hardin

Integrated Practice in Architecture: Mastering Design-Build, Fast-Track, and Building Information Modeling by George Elvin

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GSA BIM Guide Series 2: BIM Guide for Spatial Program Validation – January 2007

GSA BIM Guide Series 03 3D Imaging – January 2009

GSA BIM Guide Series 05 Energy Performance Version 1.0 — February 2009

Profiting From Integration November 2007, Construction Industry Council UK

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Generic Process Protocol, Salford University

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Virtual Technology in Design and Construction: The BIM Process, Letterman Digital Arts Center, A Case Study, Mieczyslaw (Mitch) Boryslawski

ECTP – FIATECH Capital Projects Technology Roadmap August 2007, Matti Hannus VTT

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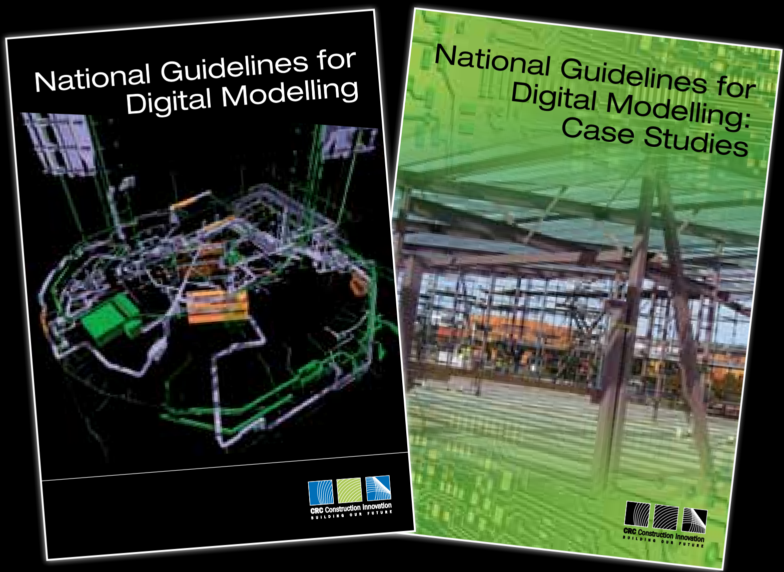

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