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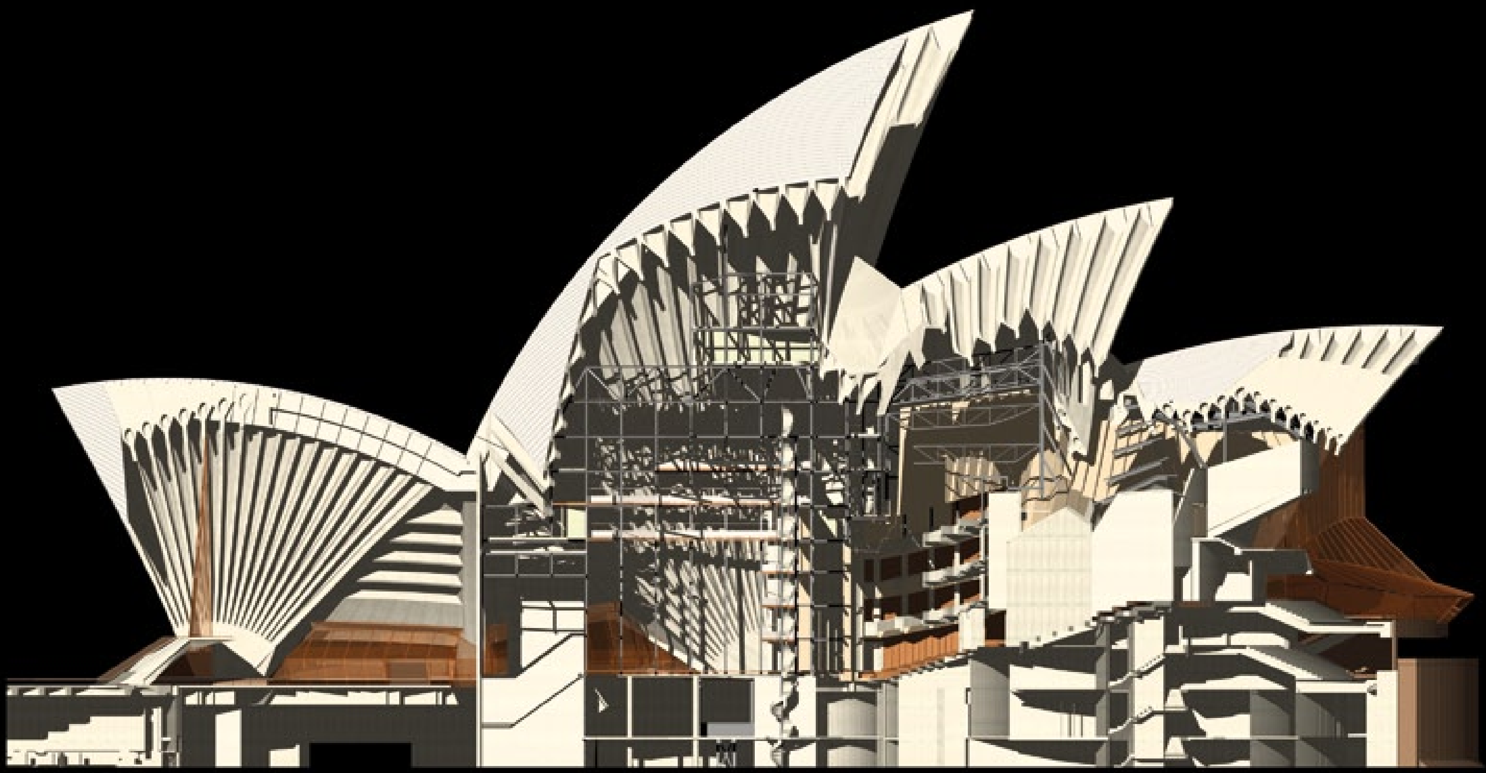

# Adopting BIM for facilities management

## Solutions for managing the Sydney Opera House

# CRC for Construction Innovation participants

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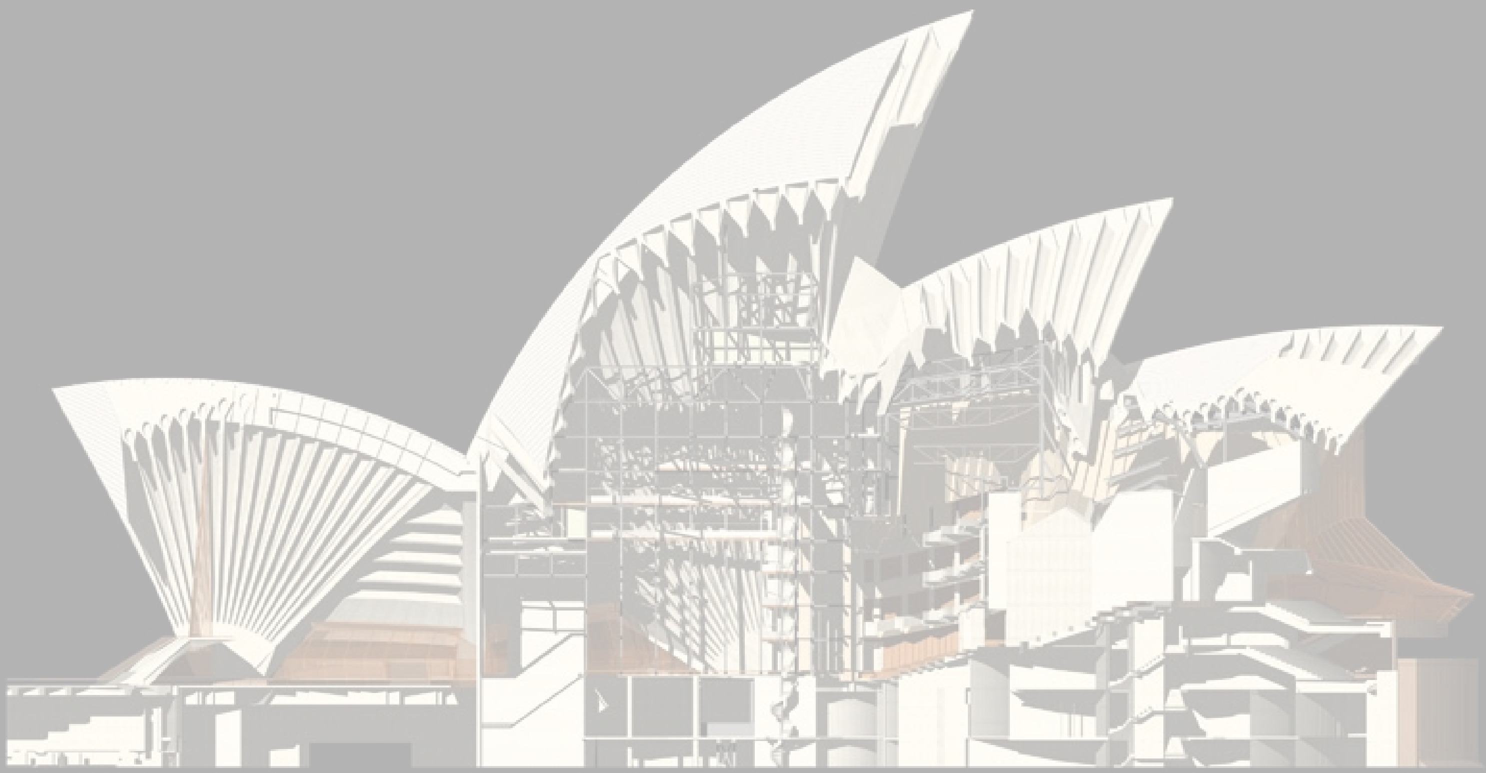

# Adopting BIM for facilities management

## Solutions for managing the Sydney Opera House

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# Contents

# Acknowledgements

*Adopting BIM for facilities management* is based on the digital modelling outcomes of the Sydney Opera House FM Exemplar Project — a joint initiative between the Cooperative Research Centre (CRC) for *Construction Innovation* and the Australian Government's Facilities Management Action Agenda.

This publication is an abridged version of the FM Exemplar Project's *Digital modelling* report, the compilation of which was lead by John Mitchell (consultant to CSIRO). The CRC for *Construction Innovation* also acknowledges Max Winter of WinterComms for review and editing assistance.

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Australian Government

Department of Industry, Tourism and Resources

Without the financial and collaborative efforts bringing together industry, government and applied researchers, this valuable report may not have been successfully delivered to our industry.

## Project partners

Industry

Government

Research

# About the Facilities Management Action Agenda

The Australian Government's Facilities Management (FM) Action Agenda chose Sydney Opera House as the focus of its FM Exemplar Project and partnered with the Cooperative Research Centre (CRC) for *Construction Innovation* to develop innovative strategies across three research themes. The findings have been integrated in order to achieve an FM solution beyond its component parts demonstrating FM as a business enabler.

The Australian Government, through the Department of Industry, Tourism and Resources, seeks to make Australia more competitive by working closely with industry to identify new opportunities for growth. Action Agendas are a means by which selected industries work with the Australian Government to identify and then implement strategies to overcome impediments to growth.

The focus in Action Agendas is on the actions industry can take to achieve its objectives.

The FM Action Agenda had its origins in requests to the Australian Government from the Facility Management Association of Australia (FMA Australia) on behalf of the industry. FMA Australia identified a number of key concerns for the industry. These included recognition of the industry, establishment of a distinct facility management career path, industry-wide innovation, recognition of sustainability as a driver of business in the future, and the impact of regulation in the industry. The FM Action Agenda was announced by the Hon. Ian Macfarlane MP, Minister for Industry, Tourism and Resources, on 19 January 2004, and one of the outcomes of the FM Action Agenda was the FM Exemplar Project: Sydney Opera House, to demonstrate FM as a business enabler.

# About the Cooperative Research Centre for *Construction Innovation*

The CRC for *Construction Innovation* is a national research, development and implementation centre focussed on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, *Construction Innovation* is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. *Construction Innovation* is a seven-year project funded by a Commonwealth grant, and industry, research and other government support. More that 300 individuals and an alliance of 21 leading partner organisations are involved in and support the activities of this CRC.

There are three research areas:

Program A — Business and Industry Development

Program B — Sustainable Built Assets

Program C — Delivery and Management of Built Assets.

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

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

*Adopting BIM for facilities management* is part of a series of publications produced by the Sydney Opera House: FM Exemplar Project. *FM as a business enabler* is the major publication and it presents the collective findings from the *Digital modelling*, *Services procurement* and *Performance benchmarking* reports. It outlines the integration of these streams into an integrated FM solution that demonstrates FM as a business enabler. Refer to the *Construction Innovation* website to obtain these publications.

# Acronym list

| | |
|---|---|
| 2D, 3D | two- and three- dimensional |
| AEC/FM | Architecture, Engineering, Construction and Facilities Management |
| AM | asset management |
| AM/FM | asset management and facilities management |
| BCA | Building Code of Australia |
| BCI | Building Condition Index |
| BFI | Building Fabric Index |
| BIM | Building Information Model(s) |
| BIMSS | Building Information Model Open Standard Specification |
| BPI | Building Presentation Index |
| CAD | computer-aided design |
| CAFM | computer-aided facilities management |
| CCSN | Co-ordinated Controlled Survey Network |
| CRC | Cooperative Research Centre |
| GIS | geographic information system |
| FM | facilities management |
| FMA Australia | Facility Management Association of Australia |
| HVAC | heating, ventilation and air conditioning |
| IAI | International Alliance for Interoperability |
| IFC | industry foundation class(es) |
| KPI | key performance indicator(s) |
| PSET | property set |
| SQL | Structured Query Language |

# Executive summary

The digital modelling research stream of the Sydney Opera House FM Exemplar Project has demonstrated significant benefits in digitising design documentation and operational and maintenance manuals. Since Sydney Opera House did not have digital models of its structure, there was an opportunity to investigate the application of digital modelling using standardised Building Information Models (BIM) to support facilities management (FM).

The focus of this investigation was on the following areas:

- the re-usability of standardised BIM for FM purposes
- the potential of BIM as an information framework acting as integrator for various FM data sources
- the extendibility and flexibility of the BIM to cope with business-specific data and requirements
- commercial FM software using standardised BIM
- the ability to add (organisation-specific) intelligence to the model
- a roadmap for Sydney Opera House to adopt BIM for FM.

## *Major findings and conclusions*

The FM Exemplar Project has established that building information modelling is an appropriate beneficial technology enabling storage and retrieval of integrated building, maintenance and management data for Sydney Opera House. Using this approach yielded several advantages such as consistency in the data, intelligence in the model, multiple representations such as two- and three-dimensional (2D and 3D) reports, an integrated source of information for existing software applications, and integrated queries for data mining. The standardised building model acts as main data structure which can be extended with other data sources as each element of the model such as a wall, furniture, a room, or a grouping of elements has a unique identifier. This unique identifier can be used as a basis for correlating different datasets, thereby opening up query capabilities across different datasets.

The industry foundation classes (IFC, an open building exchange standard) specification provides comprehensive support for asset and facilities management functions, and offers new management, collaboration and procurement relationships based on sharing of intelligent building data. The major advantages of using an open standard are: information can be read and manipulated by any compliant software, reduced user “lock in” to proprietary solutions, and third-party software can be the “best of breed” to suit the process and scope at hand. Standardised BIM solutions consider the wider implications of information exchange outside the scope of any particular vendor, information can be archived as ASCII files for archival purposes, and data quality can be enhanced, as the now single source of users’ information has improved accuracy, correctness, currency, completeness and relevance.

The current availability of FM applications based on IFC-compliant BIM is in its infancy but focussed systems are already in operation internationally and show excellent prospects for implementation systems at Sydney Opera House.

To support the FM processes using the IFC, guidelines and modelling practices have been formalised as a Sydney Opera House specification. This specification describes how information and conventions specific to Sydney Opera House can be incorporated in the BIM. This enables Sydney Opera House to develop a BIM with consistency.

Tests with partial BIM data demonstrated that the creation of a complete Sydney Opera House BIM is realistic, subject to resolution of compliance and detailed functional support by participating software applications.

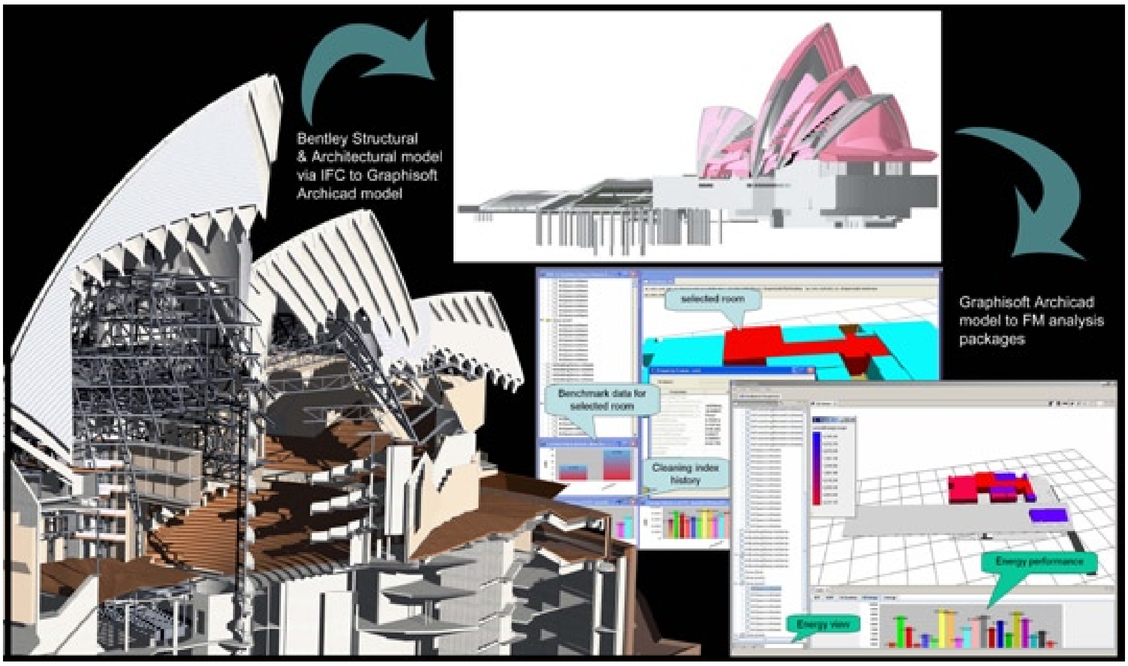
Showcase has demonstrated successfully that IFC-based exchange is possible with several common BIM-based applications through the creation of a new partial model of the building. Data exchanged has been reasonably geometrically accurate, given that Sydney Opera House's structure represents building elements of considerable complexity, supporting rich information describing the types of objects, with their properties and relationships. The unexpected re-use of a structural model of Sydney Opera House for FM clearly demonstrates the re-usability and versatility of the IFC.

The structural model has been imported from an architectural computer-aided design (CAD) system, where the IFC model was enriched with information on elements such as Rooms and Furniture elements based on the Sydney Opera House specification. Based on this enriched IFC file, a showcase system has been developed where the Sydney Opera House information can be visualised and restructured. Facilities performance and cleaning contract data have been inserted and correlated with the IFC model, offering functionality to query and to obtain visual feedback of this correlated dataset.

The following conclusions were made:

- Standardised BIM systems, as integrated information sources for FM delivery including business processes, are feasible.
- IFC offers interoperability between CAD systems, enabling re-use of building information.
- The IFC model is standardised and consequently can be used by a variety of different software systems including FM systems.
- Commercial FM software systems are available using IFC data.
- Other related software such as energy prediction models and on-site monitoring are available using IFC data.
- The IFC model is extensible and can incorporate organisation-specific requirements.
- Integrated datasets can be constructed, offering enhanced query results and enhanced visualisation of (integrated) datasets.

It is recommended that the FM industry adopt IFC to support FM processes such as benchmarking, procurement and service delivery, for the sharing of FM information for asset management (AM) applications, and ultimately to support broader business objectives.




IFC interoperability between different software systems

# Introduction

Sydney Opera House is recognised throughout the world as a building icon of twentieth-century architecture. The Cooperative Research Centre (CRC) for *Construction Innovation* and the Australian Government's FM Action Agenda chose this iconic symbol as the focus of its Facilities Management (FM) Exemplar Project and partnered with industry, government and research to develop innovative strategies across three research themes:

*Digital modelling* — developing a building information model capable of integrating information from disparate software systems and hard copy, and combining this with a spatial 3D computer-aided design (CAD) and geographic information system (GIS) platform. This model offers a visual representation of the building and its component elements in 3D, and provides comprehensive information on each element.

*Services procurement* — developing a multi-criteria performance-based procurement framework for FM service delivery.

*Performance benchmarking* — developing an FM benchmarking framework that enables facilities/organisations to determine key performance indicators (KPIs) to identify best practice and improvement strategies.

This project provides a broad range of practical input from client, consultants and service providers. The project's outcomes will in turn support the industry's FM Action Agenda. The innovative methods delivered by this project should be implemented across the FM industry at the strategic, management and operational levels. Further research on the FM Exemplar Project outputs would assist in developing a broader application of the integrated FM solution to other facility types and benefit the FM industry and the community at large.

Additionally the project aimed to achieve collaboration across these three areas as a basis for demonstrating FM as a business enabler.

This document, *Adopting BIM for facilities management*, is an abridged version of the *Digital modelling* report. The report describes the results of the investigation into digital modelling to support FM at Sydney Opera House. The investigation was instigated as follows:

- analysis of FM/AM (facilities management/asset management) systems at Sydney Opera House
- analysis of state-of-the-art digital facility models
- recommendations for digital modelling for Sydney Opera House
- a showcase of the Sydney Opera House Digital Modelling BIM.

# About Sydney Opera House

As the exterior of unique curved shells implies, Sydney Opera House is a large, very complex structure, housing equipment and activities that are equally complex. The building comprises seven theatres, 37 plant rooms, 12 lifts, and over 1000 rooms. The building has 300 full-time staff with 500–600 part-time staff, delivering over 1500 performance and 1000 other events each year.

The building has a design life of 250 years and a very high quality of construction and finish appropriate for NSW's most prestigious entertainment facility.

The building has a Conservation order and is likely to have a UNESCO World Heritage listing, further complicating the process of change and renewal.

Its early structural and spatial layout was a design challenge for the design and construction team, and innovation was a common theme of the eventual technical solution for many aspects of the final design.

As a consequence, the traditional hard-copy 2D documentation struggled to adequately describe the work to be constructed, and although this may have been more adequately resolved by the geometric capability and accuracy of 2D CAD software, the building's construction unfortunately pre-dated the emergence of this technology.

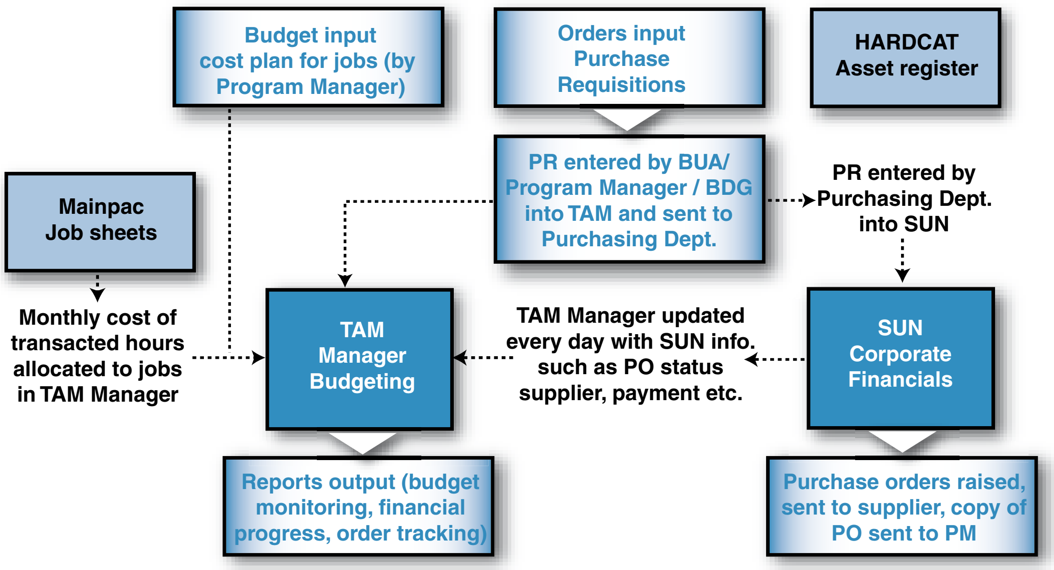
In conducting the research, a number of key concerns became evident at Sydney Opera House:

- The building structure is complex, and building service systems — already the major cost of ongoing maintenance — are undergoing technology change, with new computer-based services becoming increasingly important.
- The current "documentation" of the facility comprises several disparate and independent systems (see Figure 1), and is inadequate to service current and future services required.

- The building has reached a milestone age in terms of its condition, and the ability to maintain key public areas and service systems, the functionality of spaces and the longer-term prospect of strategic management.
- Many business functions such as space or event management require up-to-date information of the facility that are currently inadequately delivered, expensive and time consuming to update and deliver to customers.
- Major building upgrades are being planned that will put considerable strain on existing facilities portfolio services, and their capacity to manage them effectively.

## *Existing AM/FM systems*

Current AM/FM systems at Sydney Opera House are as follows:




| Function | Product | Comments |
|---|---|---|
| Building maintenance | Mainpac | Job sheets, recording labour/hour transactions are managed by the system. Records performance measures such as average time for alterations. |
| Asset register | HARDCAT | The financial asset register, which monitors the value of the asset at any given time. Uses depreciation rates to calculate current value. Annual asset audits are performed through this system. |
| SAM budgeting | TAM Manager | System established in 2000, with data from 2001 to date considered reliable. Setting up and monitoring of major and regular works budgets, order commitments and actual spend. Ensures that projects are completed within the allocated budget. |
| Accounting | Sun | Corporate financial system |
| Building condition | FaPI | SQL database, updated weekly or quarterly with a rating of the presentation of the building. |
| Document management | TRIM | Business document management tool. (Adapted by the Facilities Portfolio as an interface to Sydney Opera House PDF drawings linked to an MS Access database.) |
| Technical document access | Intranet | An Intranet is being introduced to provide universal access to Sydney Opera House technical information. |

**Figure 1** Existing AM/FM systems

# Building Information Models (BIM)

An important consideration in the context of the current dimensionally inaccurate 2D CAD data, and significant upgrade projects planned for Sydney Opera House over the next 5–10 years, is the use of an integrated model (or BIM) of the building to comprehensively support all the asset and facility management operations required by Sydney Opera House.

## *BIM defined*

BIM is an integrated 3D digital description of a building, its site and related geographic information system (GIS) context. A BIM comprises individual building, site or GIS objects, (supported by accurate geometry and represented visually), with attributes that define their detailed description, and relationships that specify the nature of the context with other objects. For example, the duct having an asset code of BSE-DU694 is installed on building storey Level 3 of the building named Block B situated on a land parcel with Lot No 1222546.

BIM is called a *rich* model because all objects in it have properties and relationships, and this information can be used for data mining to develop simulations or calculations using the model data. An example is the ability to perform automated code checking to confirm egress, fire ratings or thermal load calculations.

The principal difference between BIM and 2D CAD is that the latter describes a building by independent 2D views (drawings) such as plans, sections and elevations. Editing one of these views requires that all other views must be checked and updated, an 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, such as lines, arcs and circles, in contrast to the intelligent contextual semantic of BIM models, where objects are defined in terms of building elements and systems such as spaces, walls[1], beams, and piles.

## *Generic attributes of BIM*

The key generic attributes are:

- *robust* geometry — objects are described by faithful and accurate geometry that is measurable
- *comprehensive and extensible object properties* that expand the meaning of the object — objects in the model either have some pre-defined properties, or the IFC specification allows for the assignment of any number of user- or project-specific properties according to a common format; objects can be richly described with items such as a manufacturer's product code, or cost, or date of last service
- *semantic richness* — the model provides for many types of relationships that can be accessed for analysis and simulation, such as "is-contained-in", "is-related-to", "is-part-of"
- *integrated information* — the model holds all information in a single repository ensuring consistency, accuracy and accessibility of data
- *lifecycle support* — the model definition supports data over the complete facility lifecycle from conception to demolition; for example, client requirements data such as room areas or environmental performance can be compared with as-designed, as-built or as-performing data — a vital function for FM.

## *BIM benefits*

The key benefit of BIM is its accurate geometrical representation of the parts of a building in an integrated data environment.

Related benefits are:

- *faster and more effective* processes — information is more easily shared, can be value-added and reused
- *better design* — building proposals can be rigorously analysed, simulations can be performed quickly and performance benchmarked, enabling improved and innovative solutions
- *controlled whole-life costs and environmental data* — environmental performance is more predictable, lifecycle costs are understood
- *better production quality* — documentation output is flexible and exploits automation
- *automated assembly* — digital product data can be exploited in downstream processes and manufacturing
- *better customer service* — proposals are understood through accurate visualisation
- *lifecycle data* — requirements, design, construction and operational information can be used in FM

[1] Technically, a wall in an IFC model is called *ifcWall* etc.

- *integration of planning and implementation processes* — government, industry and manufacturers have a common data protocol
- ultimately, a more effective and competitive industry.

## *Interoperability or building data sharing*

Interoperability is defined as the seamless sharing of building data between multiple applications (or disciplines) over any or all lifecycle phases of a building's development. Although BIM may be considered as an independent concept, in practice, the business benefits of BIM are dependent on the shared utilisation and value-added creation of integrated model data.

To access model data therefore requires an *information protocol*, and although several vendors have their own proprietary database formats, the only open global standard is that published by the International Alliance for Interoperability (IAI) called IFC.

## *IFC protocol*

The IAI is a worldwide alliance of organisations in the construction industry — Architecture, Engineering, Construction and Facilities Management (AEC/FM) — comprising 12 international chapters, from 21 countries with representation by over 550 businesses from private industry and government.

The IAI's stimulus in developing the IFC protocol was the recognition that the greatest problem in the construction industry today is the management of information about the built environment. Although every other business sector has embraced IT and adopted industry-specific standards, the construction industry worldwide has stuck to its trade-based roots and dependence on drawings, with a continuing record of poor quality, low investment value and poor financial rewards.

## *Data sharing with BIM*

The mission of the IAI is to integrate the AEC/FM industry by specifying a universal language that improves communication, productivity, delivery time, cost, and quality throughout the design, construction, operation and maintenance lifecycle of buildings.

The focus on lifecycle has been a key aspect, as the current industry practice does not facilitate the efficient transfer of requirements, design and as-built construction data for the increasingly critical phases of operations and strategic AM/FM.

Building models and open interoperability are necessary complements of each other. Without the IFC sharing standard, data cannot be accessed in an industry-open format; similarly, use of IFC requires integrated model data and cannot work with 2D drawings.

## *Initial developments*

The standard, which has undergone several releases since the first commercially supported version IFC 1.5.1 in 1999, commenced principally in northern Europe with the major (so-called "upstream") CAD vendors implementing IFC support. This development demonstrated the feasibility of modelling the building geometry (or shell) and as such largely covered the architectural layout of a building.

## *Building as a system*

From 2000 to 2003, the model was extended in two important respects. Firstly, a stable platform within the standard was defined, and this was a core element to encourage more vendors to support the protocol by ensuring the initial investment in the software development had a secure future. The second, which was more important for the continuing design and construction aspects of building development, was support for engineering systems, structures (concrete, steel, timber and pre-cast), and building services such as HVAC, electrical, hydraulic, and essential safety measures.

The combination of these developments now underpinned a large number of typical business case processes, and thus attained a level of functional maturity enabling IFC to be adopted as an ISO standard (ISO/PAS 16739) in 2002, the first such comprehensive information standard for building in the world.

The recent extension of the model for GIS data has provided a reliable link between the building and the planning professions, enabling public authorities and governments to manage and to innovate services based on comprehensive, reliable information databases of assets, facilities and buildings, and their land or urban context — the built environment.

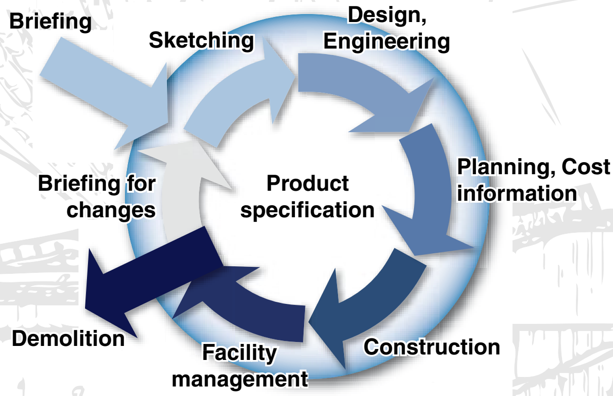



**Figure 2** Information lifecycle (Courtesy of Arto Kiviniemi, VTT)

# FM support in IFC

The capacity for whole-facility lifecycle management has been a central concept in the IFC model specification as seen in Figure 2 (see page 4). The core model is a rich description of the building elements and engineering systems that provides an *integrated* description for a building. This feature together with its geometry (for calculation and visualisation), relationships and property capabilities underpins its use as an AM/FM database.

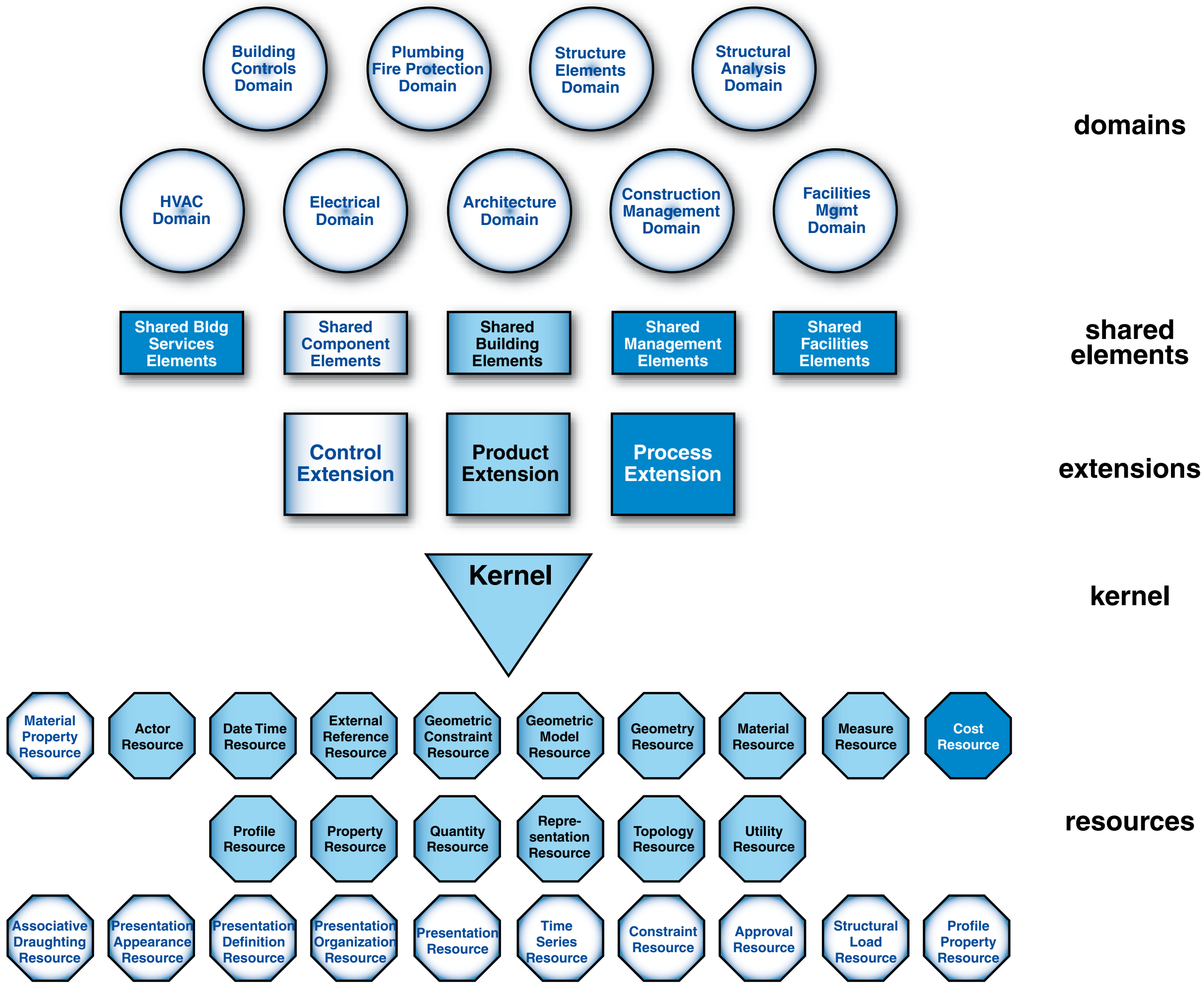



**Figure 3** IFC 2x series Model, Model Support Group, IAI

However, from its first release, the model has supported many other concepts needed for operational AM/FM. Referring to Figure 3, the model is represented as follows:

- *resources* — fundamental concepts, generally taken from the STEP standard [2]
- *kernel* — concepts used globally in the model
- *extensions* — specialisation of resources needed uniquely for AEC/FM domains
- *shared elements* — common concepts used by domains
- *domains* — functionally independent views (or disciplines) of the AEC/FM model.

The model specialises data for use in various domains, e.g. Architecture, HVAC and, for our purposes, FM.

[2] ISO 10303 STEP — Standard for the Exchange of Product Data is the parent standard of IFC, and encompasses support for the manufacturing sectors of shipbuilding, process plant, offshore and building and construction.

## *Some key concepts of the IFC model*

Before describing in detail the more specific concepts that may apply to FM, a number of general IFC concepts (called “kernel” in the IFC specification) will help to set the context.

**IfcProject** — the undertaking of some design, engineering, construction, or maintenance activities leading towards a product. The project establishes the context for information to be exchanged or shared, and it may represent a construction project, but does not have to.

**IfcActor** defines all actors or human agents involved in a project during its full lifecycle. It facilitates the use of person and organisation definitions in the resource part of the IFC object model.

**IfcProcess** An action taking place in building construction with the intent of designing, costing, acquiring, constructing, or maintaining products or other and similar tasks or procedures. Processes are placed in sequence (including overlapping for parallel tasks) in time, and the relationship *IfcRelSequence* is used to capture the predecessors and successors of the process. Processes can have resources assigned to them, and this is handled by the relationship *IfcRelAssignsToProcess*.

**IfcPropertyDefinition** defines the generalisation of all characteristics (i.e. a grouping of individual properties), that may be assigned to objects. Property definitions can be property set definitions, or type objects.

**IfcControl** is the abstract generalisation of all concepts that control or constrain products or processes in general. It can be seen as a specification, regulation, cost schedule or other requirement applied to a product or process whose requirements and provisions must be fulfilled. Controls are assigned to products, processes, or other objects by using the *IfcRelAssignsToControl* relationship.

> EXAMPLE: Controls are space brief, cost schedules, orders, work plan, and so forth.

## *IfcSharedFacilitiesElements*

The *IfcSharedFacilitiesElements* schema defines basic concepts in the FM domain. This schema, along with *IfcProcessExtension*, *IfcSharedMgmtElements* and *IfcFacilitiesMgmtDomain*, provides a set of models that can be used by applications needing shared information concerning FM-related issues.

The *IfcSharedFacilitiesElements* schema supports ideas including:

- furniture
- grouping of elements of system furniture into individual furniture items
- asset identification
- inventory of objects (including asset, furniture and space objects within separate inventories).

## *IfcFacilitiesMgmtDomain*

The *IfcFacilitiesMgmtDomain* schema defines basic concepts in the FM domain.

The *IfcFacilitiesMgmtDomain* schema forms part of the domain layer of the IFC model. It extends the ideas concerning FM outlined in the *IfcSharedFacilitiesElements* schema and management in general outlined in the *IfcSharedMgmtElements* schema. The objective is to capture information that supports specific business processes that are wholly within the domain of interest of the facilities manager. The aim is to provide support for information exchange and sharing within computer-aided facilities management (CAFM) and computer-aided maintenance management applications. The model extent will not support some of the more detailed ideas found in these applications.

The following are within the scope of this part of the specifications:

- Managing the movement of people and their associated equipment from one place to another. All types of move are considered to be within scope ranging from moving a single person from one office to another to the movement of complete organisations between locations.
- The assignment of FM standards according to roles played by actors within an organisation. Assignment of standards is limited to space, furniture and equipment.
- Capturing information concerning the condition of components and assets both for subjective and objective assessment of condition.
- Recording the assignment of permits for access and carrying out work.
- Capturing requests for action to be carried out and the assignment of work orders to fulfil the needs expressed by requests.

The following are outside of the scope of this part of the specifications:

- Work interactions between actors and between space programs.
- Moving or identifying the movement of or identifying the need for (as a result of moving) electrical or telecommunications services or connection points, or the need for new electrical or telecommunications equipment as a result of the move.
- FM standards other than space, furniture and equipment.

## *IfcSharedMgmtElements*

The *IfcSharedMgmtElements* schema defines basic concepts that are common to management throughout the various stages of the building lifecycle. The primary classes in the schema are all subtypes of *IfcControl* and act to manage or regulate the conduct of the project in some way. This schema, along with *IfcProcessExtension* and *IfcConstructionMgmtDomain*, provides a set of models that can be used by applications needing to share information concerning management-related issues.

The objective of the *IfcSharedMgmtElements* schema is to capture information that supports the ordering of work and components, the development of cost schedules, and the association of environmental impact information. The aim is to provide support for exchange and sharing of minimal information concerning the subjects in scope; the extent of the model will not support the more detailed ideas found in more specialised management applications.

The following are within the scope of this part of the specifications:

- Principal types of order that may be used in the project and whose details need to be captured for the project, including purchase orders, change orders and work orders.
- Schedules of costs.
- Association of cost and environmental impact of information to specific objects as required.

The following are outside of the scope of this part of the specifications:

- Transaction details that may be supported by or support electronic commerce.

## *IfcProcessExtension*

The *IfcProcessExtension* schema provides the primary information that expands one of the key ideas of the IFC model. This is the idea of “process” which captures ideas about the planning and scheduling of work and the tasks and procedures required for its completion. It is important to understand that process information can be expressed by classes in exactly the same way as product information can. A process can also have state and identity, the state being determined by the values of various attributes of the processes.

The *IfcProcessExtension* schema extends the primary idea of the *IfcProcess* outlined in the *IfcKernel* schema. The objective of the *IfcProcessExtension* schema is to capture information that supports the planning and scheduling of work and the procedures and resources required to carry out work. The aim is to provide support for information exchange and sharing within commonly used scheduling applications; the extent of the model will not support the more detailed ideas found in more specialised scheduling applications.

The following are within the scope of this part of the specifications:

- Definition of work plans including the tasks that are included within the plan and identification of the resources required by the plan.
- Definition of work schedules, together with the elements that make up the schedule, the time constraints and durations applicable to the elements.
- Identification of work tasks included in plans and schedules.
- Identification of procedures that are considered to not consume time in their accomplishment.
- Identification of the relationship between a process and the resources that are consumed by the process.
- Allocation of resources to work plans, work schedules and work tasks.

### *Strategic asset planning and FM*

The features mentioned demonstrate the comprehensive model functions for asset and facilities planning. In summary BIM/IFC supports:

- integrated FM
- a common operational picture for current and strategic planning
- visual decision-making
- open, universal standards
- automated code and performance checks
- total ownership cost model
- energy simulations, performance
- physical security (CBR, sick building)
- intelligent 4D simulations
- construction management.

### *IFC-compliant software for FM*

A number of IFC-based applications exist internationally (and one locally) for FM applications. For more detail on these, please read the full *Digital modelling* report.

# Building information specifications for Sydney Opera House

Sydney Opera House was chosen as the basis of a case study for the application of BIM for FM purposes. Sydney Opera House is a complex, large building with a very irregular building configuration, which makes it a challenging test.

The work described here supported a complementary task which sought to identify whether a building information model — an integrated building database — that would support AM/FM functions could be created.

### *Sydney Opera House master model data*

The FM Exemplar Project has sought to build up an accurate, reliable, and relevant integrated building model of the Sydney Opera House complex to support operational management, building and service system alterations and additions, and asset and maintenance management.

This was achieved by progressive incremental development of a model using master and sub-models, in accordance with operational, logistic and financial constraints. The master model for Sydney Opera House is divided into a number of logical discipline-specific sub-models.

### *Sydney Opera House sub-models*

In order to manage an incremental development of building information model, sub-models need administrative data so that changes and extensions to the master model can be tracked.

Contractors also identify their organisation's details and designated representative in their IFC exports. Using these basic administrative labels, assertion of building information connected to the master model becomes traceable and consequently more manageable.

The master model for Sydney Opera House is based on a geographical reference grid defined as the "Sydney Opera House Plane Grid", and is being incorporated on all survey information at Sydney Opera House. Sydney Opera House has established a Co-ordinated Controlled Survey Network (CCSN), comprising a set of survey marks throughout the site and buildings with reference to this datum. All model data will be calibrated with these survey marks. All models will be in metric scale 1:1, with units in millimetres to 0 decimal places.

### *Spatial hierarchy*

The master model supports different spatial parent–child hierarchies based on the following entities:

- location zones
- functional spaces
- rooms
- places.

Figure 4 shows the relationships between the entities.

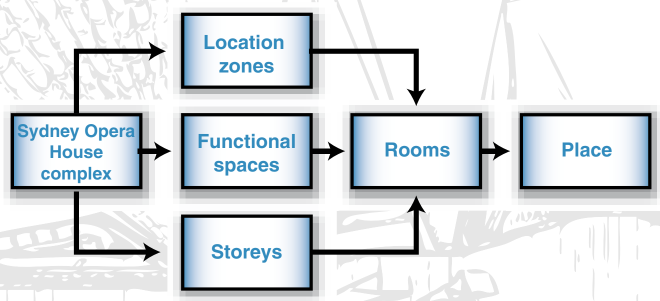



**Figure 4** Spatial hierarchy, showing the relationships between the entities

This hierarchy flows down to "places", where *places* are subdivisions of a room, i.e. the "child" of a room (see above). A place, within a room, is identified by adding a suffix to the room ID (e.g. for room G539A, *G539A/1* is the first place within the room). All places in Sydney Opera House will be defined as an entity *ifcSpace* and linked to their owning room by an *ifcZone*.

## *The site model and GIS*

The Sydney Opera House main complex is located on a site overlaid by a complex network of historical development, archaeological artefacts, current and disused utilities, and underwater and underground features. Information about this is sourced from many private and state utilities and government agencies, and in many different but principally GIS formats. The objective of the master model is to integrate this data, such as Cadastre, Land Use, Terrain, Utilities and Asset Register, in IFC format.

## *The architectural model*

**Building elements**
Building elements (the term used in the IFC specification to describe the main building parts) are the most numerous in the model. Where possible, the following information will be recorded:

| Property | |
|---|---|
| *Material* (and layers) — in accordance with Australian Building Glossary or other definitive industry reference | *FireRating* — in accordance with BCA* |
| *AcousticRating* — in accordance with BCA | *Combustible* |
| *SurfaceSpreadOfFlame* | *ThermalTransmittance* |
| *LoadBearing* | *Compartmentation* |

*Building Code of Australia

This data will be applied to the relevant property set (PSET), e.g. for walls *PSET_WallCommon*, or, if no such standard PSET exists, then a custom PSET.

Slab, beam, column, wall, window, door, ramp, and stair and railing elements as architectural elements, are a designated discipline, and along with other disciplines such as structural engineering, mechanical services, electrical and digital communications, CAVS (stage and audiovisual equipment), security, hydraulic services, transportation, and equipment, conform to Sydney Opera House sub-models when exchanging data.

Fire zones correspond to the location zones, with smoke compartmentation, a subdivision of the location zones in accordance with the BCA and relevant authorities.

**Asset maintenance and presentation**
Where model entities are part of Sydney Opera House asset maintenance or presentation, data is attached to the entity in the form of a custom PSET, named "Sydney Opera House Asset Maintenance" and "Sydney Opera House Building Condition Index" respectively, and conforms to the following:

**Maintenance**
IFC PSET "Sydney Opera House Maintenance"

| Property | Setting |
|---|---|
| Name | *Plant reference* as defined by Sydney Opera House e.g. "BG1147". |
| Description | *Plant description* as defined above (complementing the matching asset item *Name* e.g. "Lift No. 06"). |
| Element | Sydney Opera House Asset element classification e.g. *"*Transportation*".* |
| ItemLocation | Sydney Opera House *Room number*. |
| Functional space | Refer Figure 4: Spatial hierarchy |
| Parent | Owning *Plant reference* e.g. "BG1141 Lifts". |
| Name | *Plant reference* as defined by Sydney Opera House e.g. "BG1147". |
| Maintenance task schedule | The Sydney Opera House maintenance *Task allocation* code. |

**Building Condition Index**
The Building Condition Index (BCI), a combination of a Building Fabric Index (BFI) and a Building Presentation Index (BPI), is a method Sydney Opera House has adapted to measure general appearance, tidiness and cleanliness of functional spaces of the building.

The BPI data is described in a custom IFC PSET "Sydney Opera House Building Condition Index"

| IFC property | Setting |
|---|---|
| Name | *Asset element* or *place* as defined above |
| Description | *Asset name* as defined above (complementing the asset name) |
| BFI Date | *dd/mm/yyyy* date the *Fabric index* was measured |
| BFI Rating | % *rating* |
| BFI Target | % rating to be achieved |
| BFI Benchmark | Reference rating |
| BFI Note | Comments made at the measurement inspection |
| BFI Inspection name | Reference for inspection |
| BPI Date | *dd/mm/yyyy* date the *Presentation index* was measured |
| BPI Impression | % *rating* |
| BPI Cleanliness | % *rating* |
| BPI Tidiness | % *rating* |
| BPI Target | % *rating* to be achieved |
| BPI Benchmark | Reference rating |
| BPI Note | Comments made at the measurement inspection |
| BPI Inspection name | Reference for inspection |

### *Model auditing*

Model data submitted for update of the Sydney Opera House master model is audited[3] before submission, with several levels of auditing applied:

- Sydney Opera House BIMSS compliance (BIMSS — Building Information Model Open Standard Specification)
- IFC project data for controlled collaboration
- model entity geometry and properties
- model veracity.

The IFC file data must comply with all of the specification's requirements, such as set-up of the model, the naming of storeys, buildings, rooms and so forth. The IFC specification supports many geometry representations. All geometry is properly constructed so that abutting or related elements are represented faithfully. Attribute data (mandatory properties required by the IFC specification) and PSETs must meet Sydney Opera House information and material standards.

# Showcase: IFC BIM supporting AM/FM for Sydney Opera House

### *Introduction*

Several high-level processes have been identified that could benefit from standardised BIM:

- maintenance processes using engineering data
- business processes using scheduling, venue access, and security data
- benchmarking processes using building performance data.

Linking this data together can support these processes even further. For example, to:

- quickly find the responsible person/contract when an element fails
- retrieve all objects (walls, doors etc.) scoring on the BPI (number or level) which have had a major maintenance
- retrieve all history of cleaning scores of objects before and after a new cleaning contract for comparison
- list the location of assets and their performances including maintenance history
- query vacated spaces and their BFI scores
- simulate and visualise the effect of taking a service out of commission.

The integration of disparate information sources supports the alignment of different processes. For example space planning and maintenance operations can benefit from integrated planning.

[3] Note: Several commercial tools are available for this purpose, e.g. *Solibri Model Checker*, Finland, *NavisWorks Jetstream*, UK and *DesignCheck*, CRC for *Construction Innovation*, Australia. IFC model servers such as *EDM Model Server* (EPM Norway) and *Eurostep Model Server* (Eurostep) also perform many customisable and sophisticated model auditing functions.

## *An overview of an integrated FM system for Sydney Opera House*

Figure 5 represents an overview of a framework for an integrated FM system for Sydney Opera House.

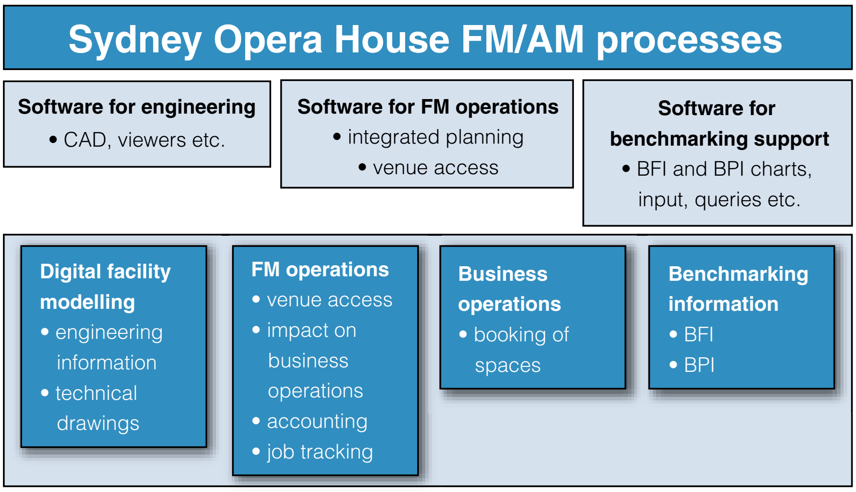



**Figure 5** Digital facility modelling supporting Sydney Opera House's FM processes

The information environment can be extended by many other sources of information such as data on occupational health and safety. The input of OHS data would assist the system to become the usable body of knowledge for Sydney Opera House to store OHS best practices and implement rules on its information environment to reduce risks and mistakes. For example, the system could flag when certain spaces are performing under a certain threshold or make suggestions regarding maintenance planning.

The showcase demonstrates and tests the potential of digital models for the FM industry.

## *Sydney Opera House specific information*

The integrated FM system needs to deal with Sydney Opera House specific information such as Sydney Opera House building decomposition and specific information such as BFI and BPI. Figure 6 demonstrates the usage of a BIM which incorporates a part of the Sydney Opera House decomposition. In addition, the objects in the BIM have properties such as BFI and BPI.

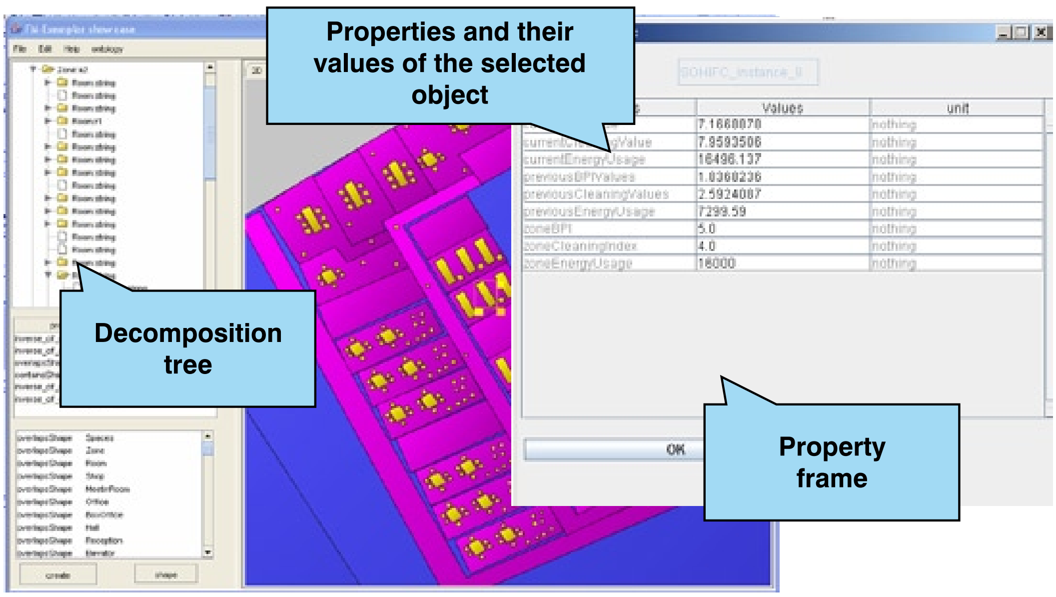



**Figure 6** Objects such as building, storey, zone, room, chair are organised in a tree similarly as Sydney Opera House building organisation structure. All objects have properties containing specific information such as BPI and BFI values. The objects, properties and their relation form the framework for the building model.

## Visual reporting

The results of queries with colour coding techniques can be used to present the information using the building geometry. For example, results of queries such as retrieving all objects with a certain performance index can be visualised (Figure 7).

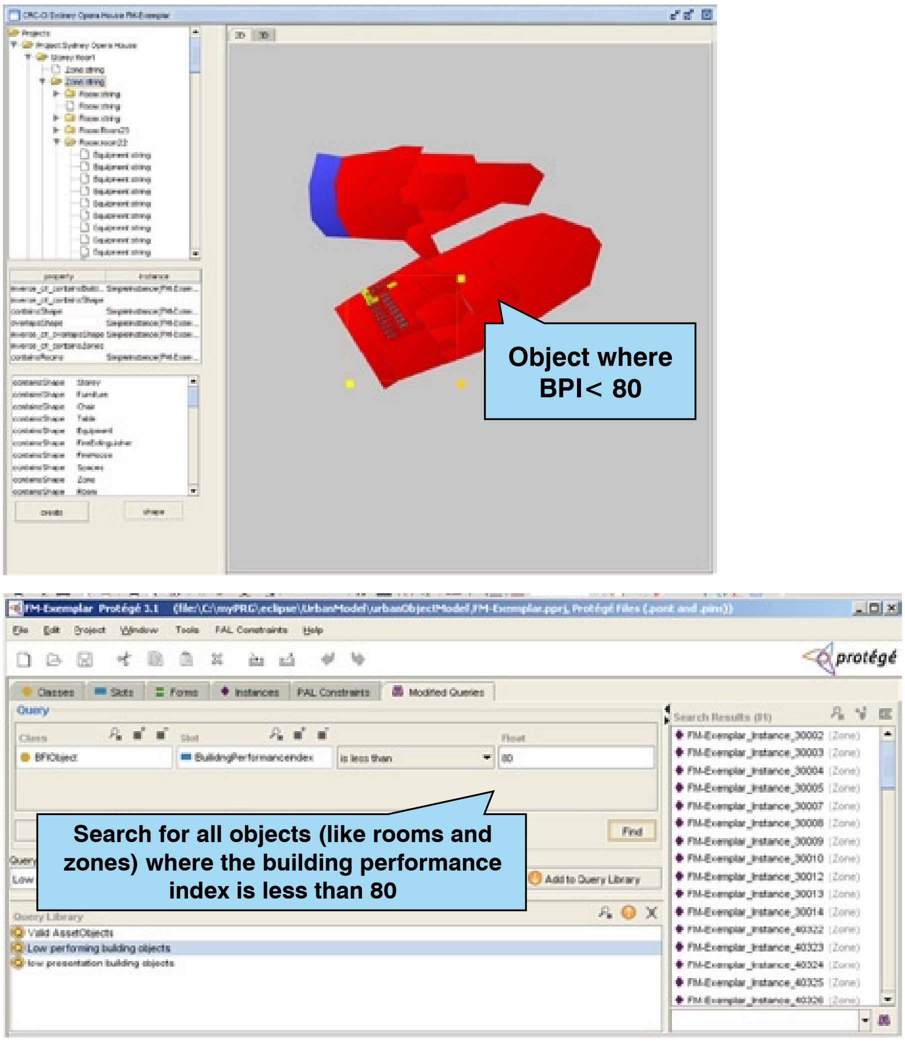



**Figure 7** Visualising results of queries

Figure 8 shows an example in which all the zone scores have been colour coded.

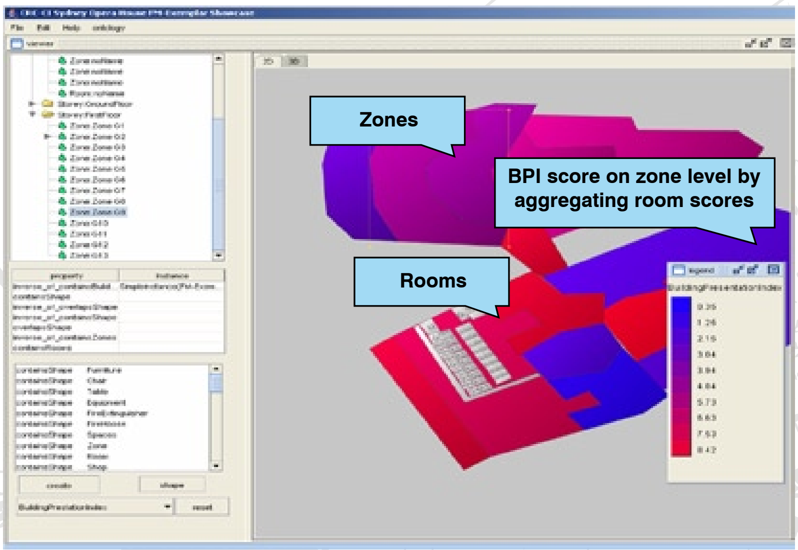



**Figure 8** An example of how to present BPI and BFI more graphically by color coded indices

### Adding intelligence

Rules can be created working as an added layer of business intelligence using the raw, yet comprehensive, data of the integrated database. For example, BPI and BFI scores can be calculated automatically for zones. This can be done by aggregating the scores of objects “in” the zone. Other types of rules can help assess what will happen when, for example, a certain service is failing. Figure 9 shows what happens when power is cut in one of the rooms. The system automatically shows the rooms affected by this action.

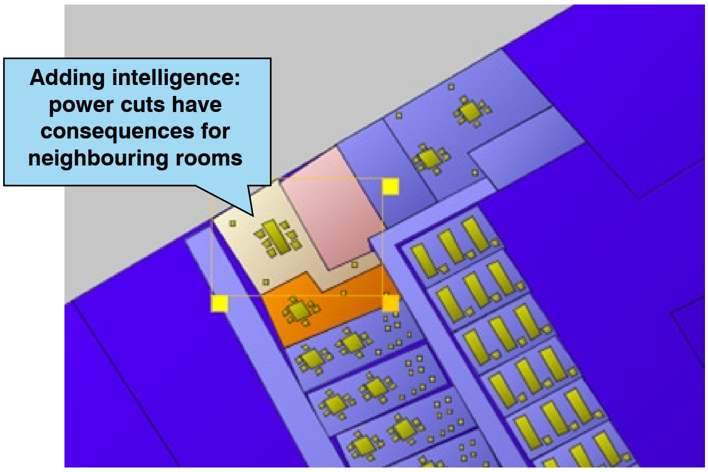



**Figure 9** Computing and visualising the impact of taking a service out of commission

## *Interoperability using the IFC*

### CAD interoperability

The use of IFC has been proposed to gradually develop a digital facility model. To demonstrate the feasibility of IFC-based data, Arup’s structural model has been exported from Bentley’s Microstation in IFC format. This file has been imported in ArchiCAD without loss of data and then extended with rooms. From ArchiCAD a new expanded export in IFC format has been used in the showcase software used by CSIRO.

This modest, but informative, test has confirmed that a partial model of Sydney Opera House could be created. Where possible, this test model adopted the standards proposed in the draft BIM Standard Specification for Sydney Opera House. Structural, architectural and analysis applications were able to share and collaborate with the same model data.

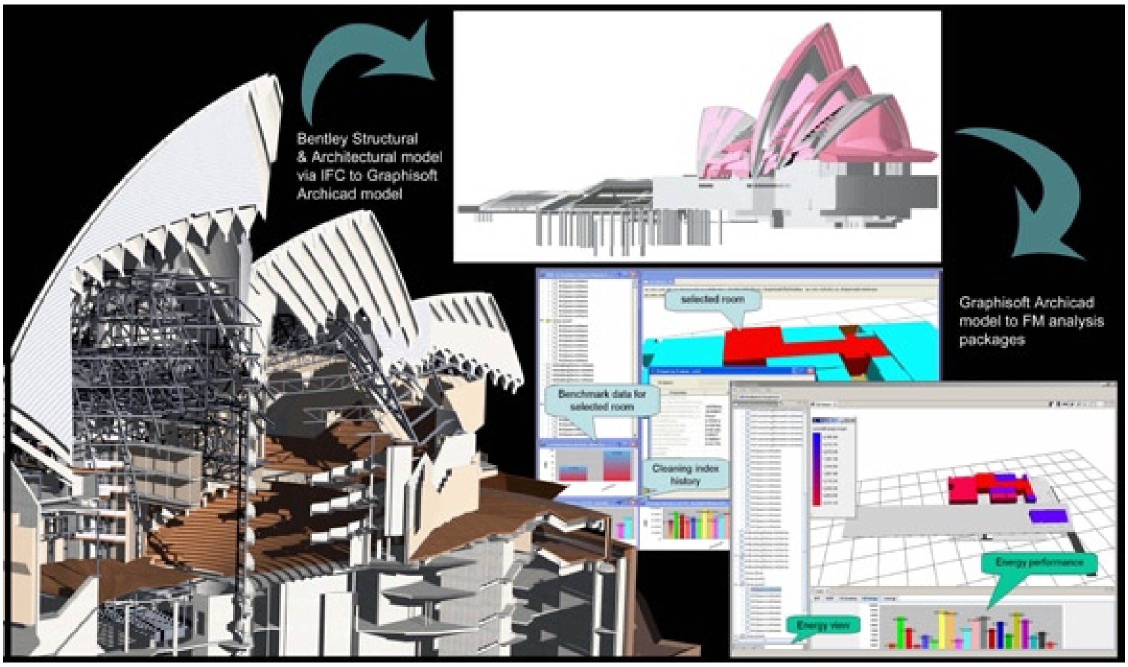



**Figure 10** IFC interoperability between different software systems

## Extending the model with benchmarking

Figure 11 is a simplified data model for storing and retrieving benchmarking data. The data model defines zones having several functional spaces. The functional spaces contain elements such as doors and walls. Several elements are already available in the digital facility model, such as the elements, doors and walls, and such a schema can easily be implemented in a relational database such as an SQL database.

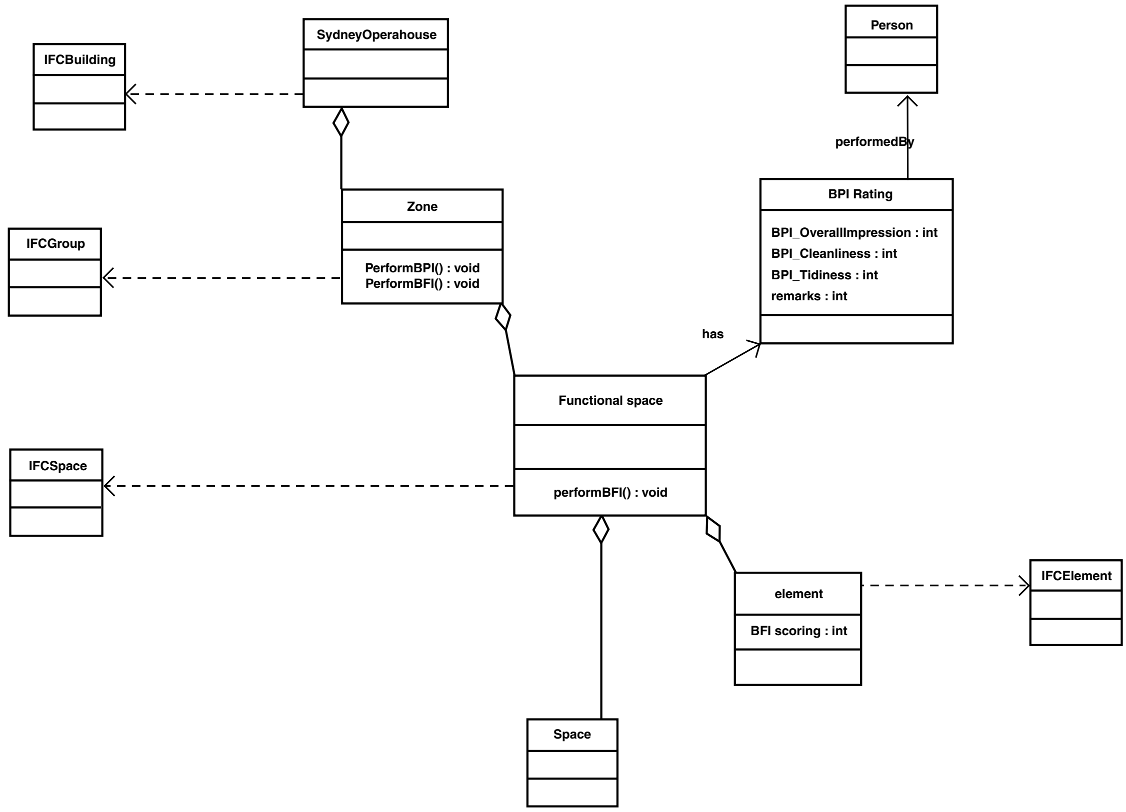



**Figure 11** Simplified data model for supporting benchmarking including relations to the IFC

This specific Sydney Opera House data model can be linked with a standardised building information model such as the IFC. For example, functional spaces can be linked with the IFC space (Figure 12).

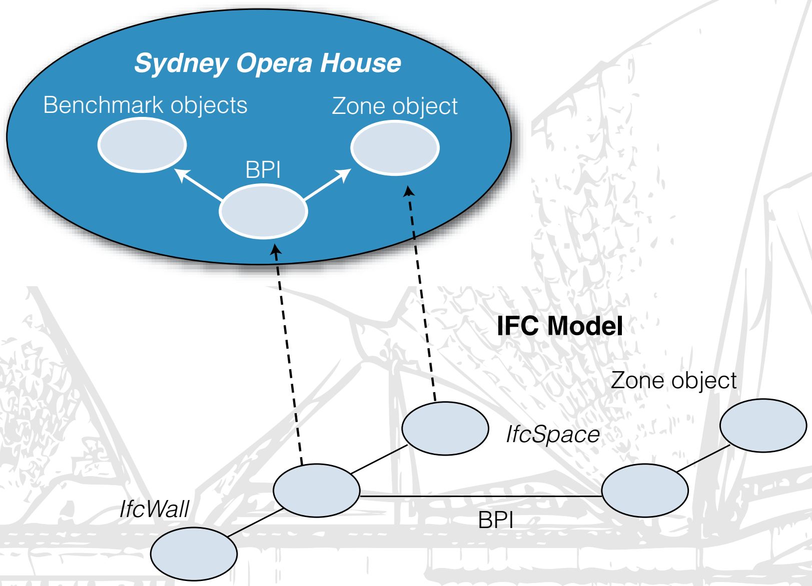



**Figure 12** Adding company-specific information

The result is an integrated model combining the IFC with a benchmarking data model. This approach has been implemented resulting in a system re-using IFC data extended with Sydney Opera House specific functionality such as BPI history data etc. (Figure 13).

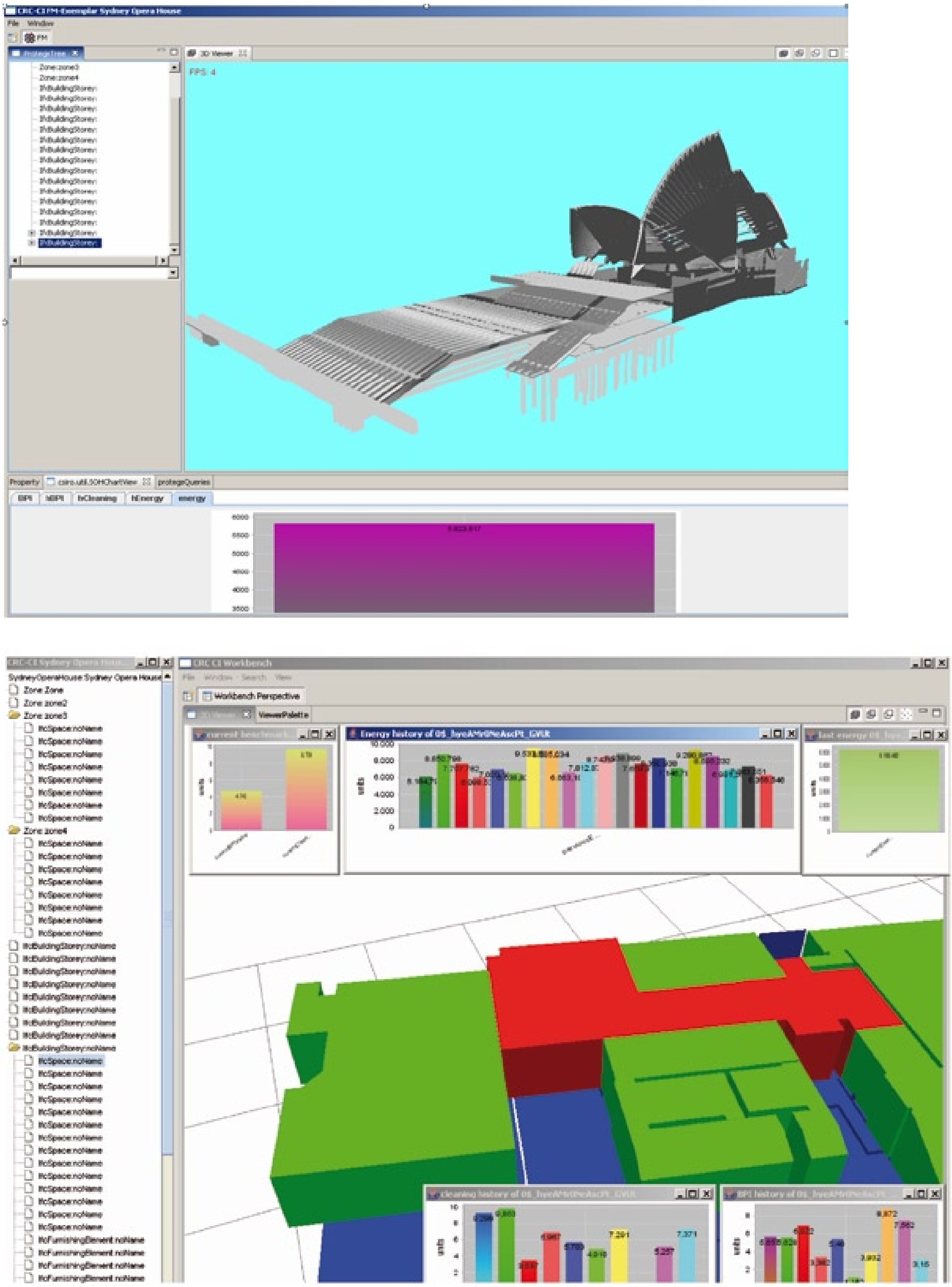



**Figure 13** IFC-based showcase extended by Sydney Opera House benchmark model

This showcase demonstrates the re-use of the IFC model for FM purposes and demonstrates the potential of extending the IFC with more organisation-specific information.

## *Technical recommendations*

### Centralised approach

Temporarily setting aside existing tools and infrastructure, an ideal situation would have an integrated data model containing all relevant information for Sydney Opera House for different departments (Figure 14). Such a data model would have a benchmarking module containing the necessary benchmarking data. All other necessary data would be re-used. The data would be reasonably maintainable. However, the applications need to be compliant with this data model. It seems that extending the IFC data model could potentially result in such a data model. In addition a heterogenous solution containing, for example, an SQL database and links to the IFC model is also feasible.

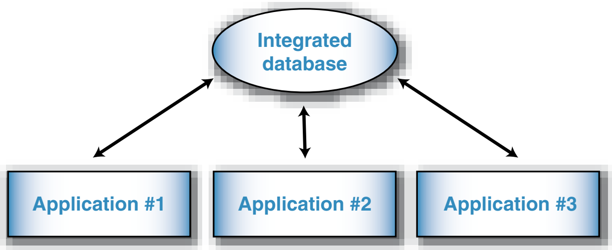



**Figure 14** Integrated data model

### Decentralised approach

Several systems are already installed, such as Mainpac and space planning software. These software systems have their own database or data storing mechanism. Overlap of information can be present. This means that similar information resides in different databases resulting in redundancy. In order to keep all systems up to date, changes in the data must be communicated to several other databases. Integration of these databases means that these relationships have to be determined and implemented (Figure 15). When many applications are available, the amount of relationships can increase rapidly.

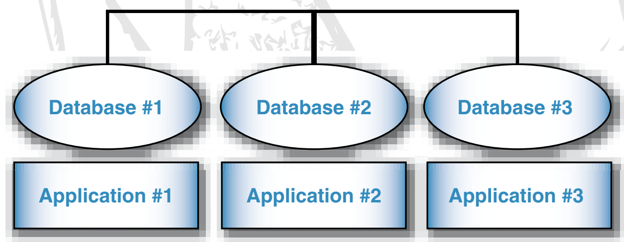



**Figure 15** Decentralised approach

The decentralised approach is also a feasible approach. Nowadays standardised communication languages are available. Querying different systems and combining their information is possible. A simple interface could be based around the unique ID of each element. For example, a room planning calendar service could provide booking information based on a room ID and a date. The maintenance calendar could do the same thing for maintenance operations. A location service could provide the location of an element by submitting its ID. Software applications can use these services to provide users with more information (Figure 16).

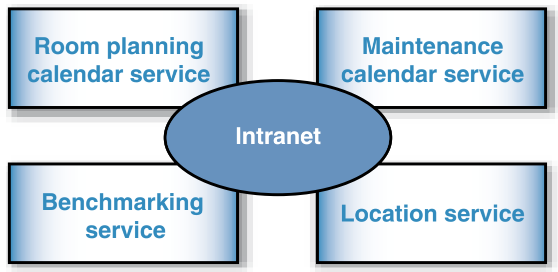



**Figure 16** Potential web services for Sydney Opera House

An advantage of the web services approach is that the systems are loosely coupled. Updating a system or completely replacing one can be done without problems if the service outcomes expected from the system remain the same. In addition new services can join the intranet in order to deal with future extensions.

# Key findings and recommendations

## *Findings*

Apart from the benefits noted earlier in this publication, the project has established several process and procedural milestones, and these are detailed below.

Sydney Opera House current building standards have been successfully drafted for a BIM environment and are confidently expected to be fully developed when BIM is adopted operationally by Sydney Opera House.

There have been remarkably few technical difficulties in converting the House's existing conventions and standards to the new model-based environment. This demonstrates that the IFC model represents world practice for building data representation and management.

Sydney Opera House has already implemented data quality checks to improve reliability and synchronisation of data, and this is a good platform for further development

Availability of FM applications based on BIM is in its infancy but focussed systems are already in operation internationally and show excellent prospects for implementation at Sydney Opera House.

Processes can now be carried out faster and more effectively because information is more easily shared, and can be value-added and reused.

The IFC specification allows for any number of user or project-specific properties according to a common format. (This is one area where proprietary solutions may constrain users. In some proprietary systems it is very difficult for an ordinary user to add additional properties.)

- *Controlled whole-life costs and environmental data* — Environmental performance, maintenance and investment is predictable, and lifecycle costs can be analysed and understood.
- *Better customer service* — Information can be accessed in multiple formats appropriate to each user, e.g. seating plans are understood through accurate visualisation.
- *Common operational picture for current and strategic planning* — As model data is interrelated, developing scenarios and their impacts (such as budgeting for major maintenance, assessing security or understanding dislocation during construction activity) can be understood more easily leading to better decision-making.
- *Visual decision-making* allows executives, management and lay users (particularly) to understand the nature and relationships of the facility, e.g. building services failures through graphic 3D or abstract views generated from the model.
- *Total ownership cost model* — All aspects of the facility including building usage and operations are in a single integrated repository.

Tests with partial BIM data — provided by several of Sydney Opera House's current consultants — show that the creation of a Sydney Opera House complete model is realistic, but subject to resolution of compliance and detailed functional support by participating software applications.

The showcase has demonstrated successfully that IFC-based exchange is possible with several common BIM-based applications through the creation of a new partial model of the building. Data exchanged has been geometrically accurate (the Sydney Opera House building structure represents some of the most complex building elements) and supports rich information describing the types of objects, with their properties and relationships.

A benchmarking system, already in use for a BPI for example, can be derived from the BIM model. Whilst there are several options in detail, an ideal situation would be to have an integrated data model containing all relevant information for Sydney Opera House for various departments. Such a data model would have a benchmarking module containing the necessary benchmarking data. All other necessary data would be re-used. The data would be reasonably maintainable. However, software applications need to be compliant with this data model.

## *Recommendations for Sydney Opera House*

In summary, this study has identified a technology solution that can be implemented at Sydney Opera House. An immediate benefit would be a description of information flows in the process and provide options for organisational and technical solutions to improve process efficiency. It would form an important road map to identify a technical and organisational framework for improvement.

It is recommended that:

1. Sydney Opera House should adopt standardised BIM for the support of AM and FM functions and proceed with the development of an implementation plan.
2. Sydney Opera House should present these findings to government agencies, and seek evaluation of this report with a view to its adoption in NSW as the standard for the exchange of information in the built environment.

There are many factors about which this study team has neither knowledge nor a brief to consider. They include, in particular, funding, current asset and facility planning and operations, capital improvements, and committed work.

The key steps needed for Sydney Opera House to proceed to implement BIM are:

- Form a BIM implementation committee, directed by Sydney Opera House, with representatives from all relevant internal and external parties, to manage the process.
- Develop a budget for a staged implementation of the model.
- Collaborate with interested parties — reporting agencies, consultants, suppliers, users and the Sydney Opera House FM technical team, to determine the availability and acquisition of operational BIM software to support model creation and management. This will include:
  - evaluating CAD tools that can edit model data and possibly host integrated data
  - reviewing model server options
  - evaluating hardware needs for the above.
- Work with appropriate stakeholders to pilot BIM modelling and IFC exchange to ensure that they support, comply and can collaborate according to the new Sydney Opera House standards and procurement procedures.
  - Ratify the draft BIM standards, in particular with the key disciplines of architecture, structure and building services.
- Commence implementation in a sequence, for example as follows:
  - Implement small discipline Sydney Opera House partial sub-models.
  - Audit the existing Opera Hall sub-model to see how it complies with the Sydney Opera House BIMSS.
  - Develop a plan to upgrade it, extend all the relevant discipline data and create a preliminary Sydney Opera House partial master model.
  - Review technology capabilities (servers etc.) to suit the project master model.
  - Develop a plan for the completion of the master models.
- Liaise with NSW Government and industry, and regularly report to them on the BIM implementation as a model of future information management, collaborative processes and potential for innovation.

In parallel:

- Develop an FM implementation plan to convert to the new BIM environment.
  - Specify and procure an application.
  - Audit the current systems and develop a staged conversion.
  - Implementation of a conversion trail of benchmarking data.
- Work with external suppliers and contractors to develop procurement systems based on the Sydney Opera House BIM model.

## *Recommendations for the FM Industry*

Standardised BIM as an integrated information source for FM processes including business processes is feasible.

- IFC offers interoperability between CAD systems enabling re-use of building information.
- The IFC model is standardised, making the data more future-proof.
- Commercial FM software systems are already available using IFC data.
- Other related software such as energy prediction models and on-site monitoring are available using IFC data.

- The IFC model is extensible and can incorporate organisation-specific requirements.

It is recommended that:

- the FM industry should adopt IFC for the sharing of AM and FM information
- the FM Action Agenda Implementation Board review the findings of the *Digital modelling* report with a view to promoting the adoption of IFC as a national standard for the exchange of information for the management of the built environment.

# Reference material/ Useful links

**ARCHIBUS,**
www.archibus.com

**BLIS project,**
www.blis-project.org

**Facility Management Association of Australia,**
www.fma.com.au

**FIS Facility Information Systems,**
www.fisinc.com

**IAI International Alliance for Interoperability,**
www.iai-international.org

**Industry Foundation Classes specifications,**
www.iai-international.org/Model/IFC(ifcXML)Specs.html

**Rambyg,**
www.rambyg.dk (Danish language only)

**RYHTI,**
http://www.granlund.fi/granlund_eng/ohjelmistomyynti/ryhti/ryhti_main.htm

**VIZELIA,**
www.vizelia.com

# *Adopting BIM for facilities management*

Sydney Opera House is recognised throughout the world as a building icon of 20th century architecture. The Cooperative Research Centre (CRC) for *Construction Innovation* and the Australian Government's FM Action Agenda chose this iconic symbol as the focus of its Facilities Management (FM) Exemplar Project and partnered with industry, government and research to develop innovative strategies across three research themes — digital modelling, services procurement and performance benchmarking.

Since Sydney Opera House did not have digital models of its structure, there was an opportunity to investigate the application of digital modelling using standardised Building Information Models (BIM) to support FM.

*Adopting BIM for facilities management* (an abridged version of the *Digital modelling* research report) demonstrates that BIM is an appropriate beneficial technology enabling storage and retrieval of integrated building, maintenance and management data for Sydney Opera House.

This publication forms part of a series produced out of the FM Exemplar Project. *FM as a business enabler* is the major publication and it summarises the collective findings from the project's research reports.


Refer to the *Construction Innovation* website to obtain these publications at www.construction-innovation.info

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