CRC Construction Innovation

BUILDING OUR FUTURE

Final Report
Collaboration Platform

Research Project No: 2007-003-EP

The research described in this report was carried out by

Project Leader   Claudelle Taylor

Research Leader   Ning Gu

Team Members   Kerry London
                        Vishal Singh
                        Jerry Tsai
                        Ljlijana Brankovic
                        Robin Drogemuller
                        John Mitchell

**Research Program: EP
Extension Program**

**Project 2007-003-EP
Collaboration Platform**

Date: March 2009

Leaders in Construction and Property Research

Distribution List

Cooperative Research Centre for *Construction Innovation*

The Authors, the Cooperative Research Centre for *Construction Innovation*, Icon.Net Pty Ltd, and their respective boards, stakeholders, officers, employees and agents make no representation or warranty concerning the accuracy or completeness of the information in this work. To the extent permissible by law, the aforementioned persons exclude all implied conditions or warranties and disclaim all liability for any loss or damage or other consequences howsoever arising from the use of the information in this report.

Please direct all enquiries to:

Chief Executive Officer
Cooperative Research Centre for Construction Innovation
9th Floor, L Block, QUT, 2 George St
Brisbane Qld 4000
AUSTRALIA
T: 61 7 3138 9291
F: 61 7 3138 9151
E: enquiries@construction-innovation.info
W: www.construction-innovation.info

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Building and construction projects generate large volumes of information throughout each project life cycle. Project participants both contribute data and access parts of the evolving information database.

A "Collaboration Platform" consisting of a computer based building information model (BIM) combined with a computer server system is critical for accessing, storing, integrating, checking and visualizing the entire data emerging throughout the project lifecycle for all participants.

The project began with a review and analysis of current industry needs and found:

- Knowledge, awareness and readiness for BIM and BIM server based collaboration vary across the different disciplines involved in a typical construction project. An analysis of available BIM applications suggests that the BIM server technology is itself not matured. However, even in its present form these technologies are usable and can significantly improve project collaboration.

- At present the industry is caught in a loop. Low usage and lack of experience is inhibiting technology enhancement, and development of appropriate work-processes and work-culture. In turn, technical limitations, lack of appropriate work-processes and work-culture are inhibiting BIM technology usage.

- There is a general agreement across the industry on the need for specific roles related to BIM model management and BIM server management. Besides technical features, training materials and training programs are required to assist BIM adoption, management and implementation.

Next an extensive review and analysis of existing model servers (collaboration platforms) was used to formulate Technical Requirements of Collaboration Platform as follows:

- BIM server based collaboration platform set-up assistance related requirements: The technical requirements within this group are expected to facilitate set-up, implementation and management of the model server at systems level. Some of these technical requirements are operational, while some other technical requirements in this group are support technical requirements.

- BIM Model management related requirements: The technical requirements within this group are related to the usage of the model server. These technical requirements directly affect operations on, and maintenance of the stored data such as model, documents, and related information. Hence, all the technical requirements in this group are operational requirements.

- Distributed/ virtual design review related requirements: The technical requirements in this group are specifically related to design review activities. In general, depending upon project team and the planned design review process, these requirements can either be considered operational or support technical requirements.

- Data Security related requirements: The technical requirements in this group are related to network security and prevention of unauthorized access into the system. These are operational technical requirements.

Further collaborative action is recommended as follows:

Recommendation 1: Longitudinal case studies with direct involvement of industry based tool experts should be conducted in a real world pilot project. Such case studies are likely to explore greater coordination challenges.

Recommendation 2: CRC for *Construction Innovation* should take the findings to model server vendors highlighting the need for improved training materials and regular helpdesk to encourage and support new users.

Recommendation 3: An interactive version of parts of the National BIM Guidelines and IDM should be developed as a plug-in to aid model server and BIM implementation.

Recommendation 4: While IFC standards should be part of long term goals, model servers with flexibility of data formats should be pursued. This is because an entirely IFC based collaboration platform may not be feasible in near future because of errors in interoperability with dominant proprietary tools.

Recommendation 5: Extensive training of BIM managers and experts with technical and organizational knowhow is needed to facilitate customized system configuration and administration.

1. INTRODUCTION

1.1 Project Introduction

Aim: This Project reviews and analyses the current capability of model servers leading to open software technical requirements with special emphasis on the so-called "non-functional" specification for BIM Model Server which will cater for digital models accessible through a web interface. We borrow this terminology from software engineering where, roughly speaking, functional requirements specify the functionality of the system while non functional requirements specify the qualities of the system. It is not always easy to distinguish between functional and non-functional requirements and when sufficient details are provided the latter converts into the former (Kotonya and Sommerville, 1998). More specifically, non-functional requirements only describe *what* qualities the system should have while functional requirements specify *how,* or through which functionality, the qualities are to be achieved. For example, a non-functional requirement that the data be protected against unauthorised disclosure can be converted to a functional requirement to provide encryption and access control. For both functional and non-functional requirements, detailed specification and implementation solutions are not discussed.

Deliverables of the project include:

- Model Server Audit, Training and Testing
- Industry Needs Analysis / Industry Consultation: Industry Consultation Report
- Final report on technical (including non-functional) requirements for BIM Model Server

Significance of the project outcomes to the industry include:

- For potential users (e.g. architects, consultants, contractors, suppliers, client etc)
  - A report on technical capabilities features and limitations of existing model servers.
  - Increase in knowhow about potential benefits and risks in using a model server as a collaboration platform vis-à-vis other web-based collaboration tools such as document management systems (DMS) commercially available and used widely.
- For application developers
  - Recommendations for product enhancement to meet local (Australian) industry collaboration support needs and expectations.

Technical requirements:

1. industry based on their perceptions (Focus Group Interviews, FGIs)
2. a case study for testing an existing model server (Seawater Chamber)
3. a case study of a building project using BIM and IFCs (The Ark Project)
4. other industry use of the BIM approach

1.2 Report Overview

This report is divided into four sections. Sections 1 and 2 give an overview of BIM model server based collaboration platform. This introduction and background to BIM server is built on a discussion on BIM approach, levels of technical capabilities and technology adoption, analysis of available BIM supporting applications and a detailed review of industry needs based on Focus Group Interviews. Preliminary findings (based on literature review, desktop analysis and FGI data) are used to refine the research approach, as discussed towards the end of section 2.

Section 3 is dedicated to the case studies conducted to cover the various aspects of Collaborative BIM approach. Firstly, industry based case studies include a controlled testing as a pilot study and experiences of using a BIM approach in a real world project. Second, a comparative study of different document based collaboration platforms is presented to identify the technical features for a model server.

Section 4 presents the technical features for a BIM server. This section also discusses some of the possible ways in which the technical features may be incorporated and implemented in a BIM model server to be used as a collaboration platform. A discussion on BIM project management requirements and approaches is included as part of the technical requirements.

2. BACKGROUND

2.1 BIM model server and its role in project collaboration

a. BIM is a process of maintaining an integrated repository of all the information relevant to a building or construction project throughout the different phases of the project lifecycle. This repository facilitates storing, integrating, checking and visualizing the entire data emerging throughout the project lifecycle. This information can be used in combination or separately, but not in isolation, in the sense that they will always be subject to some integrity and cross-checking.

    The information maintained and produced in the BIM approach includes both the geometric and non-geometric data. Geometric data comprises 2D and 3D models, as well as dimensional and spatial relationships. Non-geometric data refers to annotations, textual semantic relationships, reports, tables, charts, freehand illustrations, graphs, images, audio-visual data, and any other form of representing some information generated during the project.

b. BIM implementation: The BIM implementation in general involves a client-server model. A BIM Model Server usually does not include any applications apart from the regular database management operations. Each discipline uses its own native applications to work on the data. Any changes or modifications required to be made on the data in the model server is done externally, using the native application. However, many BIM design tools support an internal database and multi-disciplinary capabilities, allowing a BIM like approach with limited applications.

    While this project aims to provide specifications and guidelines for facilitating collaboration in design teams through the use of BIM model servers, a desktop audit of BIM application tools is also important to understand the BIM process and functionalities.

c. BIM Model server: A BIM model server only holds a repository of the information, and allows native applications to import and export files from the database for updating, modifying, viewing and checking the data. In general, the model server by itself has no inbuilt applications. Figure 2.1 shows how a model server is used along with the other BIM applications that form native tools for the collaborating disciplines.

    A BIM model server may also be connected to other tools such as a document management system or web applications and product libraries. Such integration can enhance collaboration capabilities facilitating a unified source of information access and sharing.

Figure 2.1   BIM model server allows import/export of data to and from BIM application tools
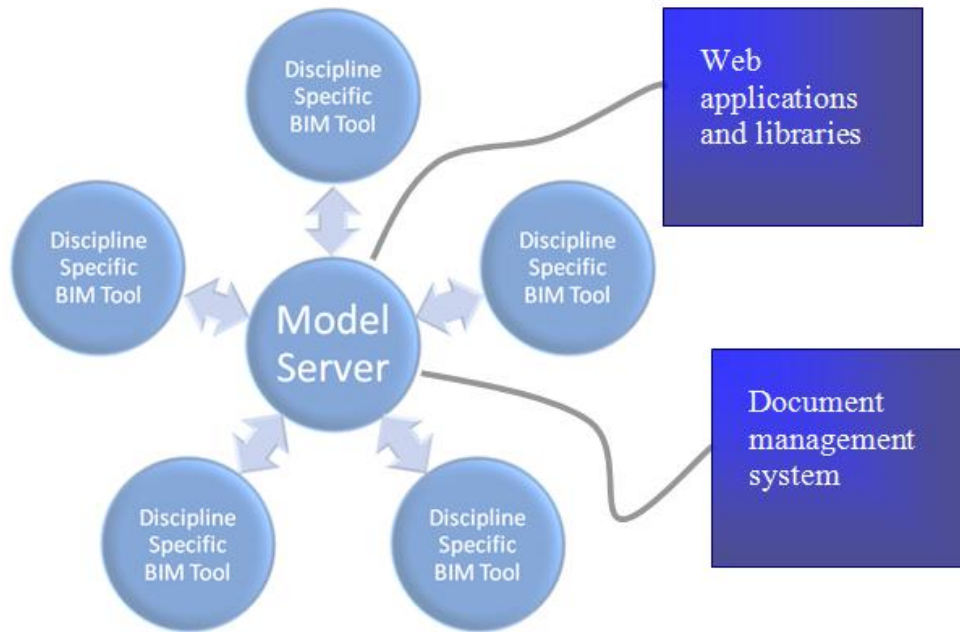
2.1.1   Why BIM?

a. How it is different to a geometric data model? (Khemlani, 2004)

- BIM describes the attributes (geometric and non-geometric) of the entities in the AEC domain as well as how these entities are related to each other.

- BIM enables extraction of the relevant information from the representation that is needed for design, analysis, construction management, operation, and so on.

b. Some of the benefits:

- Allows integration of all the relevant data generated and required by various disciplines involved in a given project.

- Provides instant, controlled and distributed access to data.

- Facilitates easier update, maintenance and retrieval of data, as well as their long-term programming, maintenance and operation.

- Facilitates resource utilization by reducing rework and avoiding duplication.

- Supports automated extraction and processing of data that requires specialized conversion and interpretation like costing, area calculation, conversions, and so on. This can now be done at any stage of the project development.

- Improves visualization and buildability by allowing easier transition between different representations of the same data.

- Facilitates checking and reduction of conflicts and coordination errors.

- Analyses and visualizes product performance over the building life cycle (Mitchell et al. 2007).

- Facilitates and smoothens legal and regulatory processes. e.g. CORENET (Cheng Tai Fatt, 2002)

- Supports content development for electronic building component objects including product data and links to manufacturer Websites

2.1.2   BIM Applications and Products

Since BIM aims to provide an integrated repository of the entire project, the amount of information and the variety therein becomes extremely large. It may not be feasible for a single vendor to be able to develop tools that are capable of supporting the different requirements posed by the collaborating disciplines. A variety of tools and applications are needed, with a range of capabilities to support BIM technology in the AEC industry (Pentilla 2007, Khemlani 2007, Eastman et al. 2004b). The BIM tools are classified here as:

a. Early Design and Briefing Tools

- Preliminary Space Planning Tools- *e.g. Trelligence Affinity*

- Preliminary Massing and Sketching Tools- *e.g. Google SketchUp*

- Preliminary Environmental Analysis Tools- e.g EcoTect, LCAid.

- Preliminary Cost Estimation Tools- e.g. Automated Estimator (CRC-CI)

b. BIM Design Tools- *e.g. ArchiCAD, Revit, Bentley, Vectorworks*

c. Structural Design Tools- *e.g. Revit Structure, Bentley Structure*

d. BIM Construction Tools- *e.g. VICO Constructor*

e. Fabrication Tools- *e.g. Digital Project (Gehry Technologies)*

f. Environmental Analysis Tools- *e.g. Riuska, IES, LBNL*

g. Construction Management Tools- *e.g. JetStream Timeliner*

h. Cost Estimation Tools- *e.g. Calcus, VICO*

i. Specification Tools-

j. Facility Management Tools- *e.g. Active facility*

k. Mechanical Tools- *e.g. DDS mechanical, Bentley Mechanical Systems, Revit*

l. Model Checkers – *e.g. Solibri Model Checker, Navisworks*

m. Product Libraries- *e.g. ADSearch, FormFont*

n. Design Review/ Model Viewers - *e.g. JetStream Roamer, Octaga, Solibri, DDS,*

2.1.3   BIM Model Servers as Collaboration Platforms:

Model servers as a collaboration platform are expected to support Integrated BIM approach adoption in AEC/FM industry. BIM tools have been available for over a decade but the adoption rate has been slow because (1) The industry is not ready, and (2) sufficient engineering tools to complement architectural tools have not been available. Collaboration platforms have been in use for about 10 years particularly for very large projects like the National Museum of Australia in 2001. Generally the tools are used for on-line document management. Examples include Aconex, INCITE, ProjectCentre and Team Binder.

With the increased interest and usage of digital models there is a potential for collaboration platforms to be expanded to include model server capabilities. In this environment a single digital model can be used and accessed by all disciplines through a check-in, check-out process. A future vision would move towards an on-line, real-time simulation where CAD and non-CAD users, client and contractors in building and infrastructure could access data through an nD viewer.

2.1.4   Business Basis:

Virtual models providing performance testing (cost, time, construction, safety etc) with multi-disciplinary input at the early stages of projects will facilitate effective decision-making at a time when the cost impacts are less. Design time will be reduced through a collaboration platform as stakeholders will be able to openly discuss constructability and buildability

(material selection, work method statements) generating creative solutions or efficiencies through a process of visualization and clash detection.

2.1.5 Integrated BIM:

Figure 2.2, generated by AIA shows the various levels of digital technology available for architecture and design practice. This range of technology usage varies from 2D drafting to integrated BIM development, which entails two-way collaboration and a shared model. There are no prior examples of a fully integrated BIM approach in Australia, and even the adoption of a partial level of BIM in practice has been slow with only a handful of examples. The majority of the practices in Australia is still in 2D/3D transition stage. (see Fig. 2.2)

According to the classification in the AIA diagram the BIM server technology falls under the category 3A and 3B. Thus, most of the discussions on BIM adoption refer to the capabilities for 3A and 3B.

However, the decision framework proposed in section 4 is aimed at allowing evaluation of project partner's current capabilities and readiness i.e. which level of adoption they are capable of, and providing the support for a structured and informed transition from one stage to the other.

Figure 2.2   AIA diagram for digital design technology in Architectural practice

TOWARDS INTEGRATION
Taking the Australian Construction Industry forward

TOWARDS INTEGRATION

WHERE WE WERE	WHERE WE ARE	NEXT STEP	WHERE WE ARE GOING

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

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

2 – COLLABORATION
Sharing of object-based models
between two or more disciplines

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

Representation	Prototype	Full Information Capture

ESD   Efficiency   Project Economics   Lifecycle Economics

3D CAD

MODELLING SOFTWARE

SINGLE PLATFORM/IFC

INTEROPERABILITY

BIM

Manual 2D   CAD 2D   3D   Intelligent 3D   One Way   Two Way   Local Server   Web Server

0A   0B   1A   1B   2A   2B   3A   3B

TRUST

Distribute Information

Collect Information
Information Management
Repository
Life of Building

Building Project

BUSINESS MODEL

ISOLATED	COLLABORATIVE	INTEGRATED

Digital communication
Traditional communication

UPTAKE

Version: 4
Date: November 19, 2008

Australian
Institute of
Architects

CRC Construction Innovation

Bentley

Your feedback is welcome – email us at: ipd@raia.com.au

2.2   Literature Review:

2.2.1   Introduction to BIM Servers

Literature and the trend in BIM application development suggests that the prime enablers of the BIM approach are:

- Technology and tools
    - o Distributed access and sharing
    - o Import/ export
    - o Management
    - o Operations
    - o Control and validity
    - o Coordination
- Object-oriented models with data associativity and relationships
- Common platform for data exchange format e.g. IFC (Industry Foundation Classes)
    - o Terminologies (vocabulary) (e.g. IFD-International Framework for Dictionaries)
- Process Definition
    - o Relevance (minimum and sufficient data) (IDM- Information Delivery Manual)
- Customizability and flexibility

Why do we need IFC?

a. Provides open data exchange format required to deal with issues of interoperability

b. Facilitates smooth and efficient workflow across different tools

c. Provides guideline to determine necessary and sufficient information to be given

What is IFC? (Khemlani 2004, IAI website)

- IFC is an object-based building data model. However, it is non-proprietary.

- Being an open data exchange format that captures building information, IFC can be used by the commercial building-model based applications to exchange data.

- IFC model represents not just tangible building components like walls, doors, etc., but also more abstract concepts such as schedules, activities, spaces, organization, construction costs, etc. in the form of entities All entities can have a number of properties such as name, geometry, materials, finishes, relationships, and so on.

Key aspects of the IFC model that enhance its flexibility and extensibility are (IAI website)**:**

- **Property sets:** If an entity has a property that is universal and unambiguous, such as the U-value of a wall or the cross-sectional area of a beam, that property is hard-coded into the model as an *attribute*. On the other hand, if a property can be seen differently by different parties, it is defined in a separate *property set* that can be attached to the model and behaves just like attributes.

- **Proxies:** It is also possible for software implementations working with the IFC model to create altogether new entities that have not been defined in the IFC model. These are referred to as *proxies*, and can be defined with geometry and property sets just like regular IFC entities.

Since an IFC model is not designed to work with one particular application, it is deliberately abstract.

IFC and Data exchange:

- Since the file size of any file format is related to how the data is structured in its data model, the size of an IFC file would generally be larger than a native ArchiCAD or Revit file carrying the same project data.

- Data loss can happen both in importing from and exporting to the IFC format.

Is IFC the only way?

- Apart from IFC there are other methods of data integration that allow individual applications to communicate with each other, such as APIs (Application Programming Interface), other data-oriented export formats such as ODBC, XML for Internet-based applications, and so on. (Khemlani 2007)

- Seamless integration of a suite of commercial applications based on the IFC format has not yet been demonstrated, except for carefully modelled test projects.

However, IFC's integration capabilities and collaborative benefits can go a long way towards eliminating the inefficiencies and waste in the building industry.

IDM (Information Delivery Manual)

The Information Delivery Manual (IDM) provides a state of the art approach to connecting building information modelling methods with business processes. It provides exchange requirement definition that is (Christensen and Gruppen 2005)

- Easy to understand for different groups
  - Managers
  - Project people
  - SW developers
- Useful for
  - Interoperability
  - Software development
  - Contractual interface
  - Knowledge management
  - IFC model extension
  - Process understanding
  - Transaction messaging
  - Model server queries
  - Data quality assurance
- Recursive, enabling re-use and re-combination at many levels

2.2.2 BIM in the Industry

BIM adoption in practice has been slow. There are some examples from larger firms such as ARUP and Gehry Technologies, which have developed their own processes and systems somewhat similar to a BIM approach. However, in general the adoption rate has been lethargic. The primary reasons discussed in literature include: lack of initiative; lack of training; varied market readiness across geographical boundaries; and reluctance to change the existing work practice. In an industry where most projects are handled in multi-organizational teams, the lack of clarity on the responsibilities, roles and benefits in using a BIM approach has been found to be a critical inhibiting factor.

Some of the main characteristics of the AEC industry that may have led to the low adoption of BIM by the AEC industry, as compared to some other industries such as automobile and aircraft industry, where technologies similar to BIM have been in use for more than a decade now are:

- **Fragmented business practice:** The AEC industry is fragmented into very few big players and a large number of small and medium size players that work as collaborative networks. The financial status, technological requirements and capabilities, and work profile of these organizations vary considerably, whereas the automobile sector, for example, has a small number of large firms.

- **Control and benefit:** In the automobile industry, the various phases of the product lifecycle ranging from design to delivery are often managed in-house by the various discipline units. Thus, the benefits of the efforts by any discipline directly apply to the organization. This is very rarely the case in the AEC industry. The fragmented structure and inter-organizational collaboration in the AEC industry means that each organization involved in the project requires greater clarity on the efforts versus benefits for the participating organizations or disciplines (Holzer 2007). At the moment the roles of the various disciplines involved in generating a BIM model is not very clearly defined in practice. The premises on which the technological development has taken place assume that each discipline adds the relevant data to the model which requires additional effort. This may be in conflict with the economic interests of certain disciplines, which may not directly see the benefit of an integrated model proportional to the required effort.

  In addition, in the AEC industry at different phases of the project lifecycle the control of the project data may change hands. For example during the design phase the Architects generally lead, whereas during construction this passes on to the contractor. This may then be transferred to the facility manager for later use. In the automobile industry changing data ownership is not an issue because of an integrated and more or less fixed organizational structure.

- **Change drivers:** In an integrated business organization like in the automobile industry, policy introduction and changes in work practice are often a matter of management decision. It is relatively easier to re-structure the various disciplinary units within a single organization. On the other hand, in case where different organizations are involved the conflicting aspects of independence and interdependence inhibit such changes, until all the involved parties agree to such changes collectively. In such case, the organizations that often hold an upper hand or dictate terms can force in such changes. For the AEC industry such internal drivers could be in form of the large organisations. External drivers can come in form of the regulatory authorities and clients that make specific requirements.

- **Product type and scale of projects:** The product of a single project in an AEC industry is quite often a custom one, unlike the automobile industry, where one model goes for mass production. However, the scale of the projects may still be the same. The realization of an AEC project may still consume high financial, infrastructural and manpower resources. Scale of the project is an important factor determining the economic and functional benefits of putting in the extra effort.

- **Distribution and maintenance:** In the AEC industry facilities management has become a major aspect. With the growing complexity of the buildings the integrated database can support efficient maintenance and operation of the built facility. Facilities management makes one of the most useful and economically viable cases for a BIM approach. It is important to note that this also means that the BIM model has to be updated with the as-built model, which may have some differences with the design model.

- **Modeling requirement:** In the automobile and manufacturing industry the model is directly used to generate the physical prototype. This means the modeling precision

has traditionally been an important criterion. On the other hand, the traditional use of 2D drawings in the AEC industry has meant that 3D models primarily served visualization purposes. Hence, most often models remained incomplete, or lacked precision which was never a critical factor. As the building industry moves towards greater automation in construction and fabrication, including both on-site and prefabricated systems, modeling precision will become important.

Global challenges

Across different regions and boundaries the present status of the AEC and industry and its readiness for BIM adoption varies significantly. Hence different strategies may be required in different places to promote BIM usage.

In some places where the AEC industry is more organized like Singapore, Norway etc, and where the regulatory authorities have taken a lead, BIM adoption is well on track. For example, the CORENET project in Singapore enables electronic submission of models and drawings to the regulatory authorities. This makes the entire process more efficient and faster, besides many other advantages (Cheng Tai Fatt, 2002). What is important here is to realize that for any changes to take place there should be very distinct incentives in place. In practice such incentives should also have a competitive and economic aspect to it.

There are other cases where the regulatory processes have remained unchanged, but some of the large and multi-disciplinary organizations like ARUP have adopted a BIM kind of approach within their own projects, to facilitate their own project management (Bentley News 2006, BE Magazine 2004). Adoption of BIM in such projects has been possible because of the leadership taken by these organizations. Their collaborating partners had to adapt. Often, in such cases the scale of the project forces organizations to adopt new and more efficient approaches to project data handling.

Globally, there are other regions where the design detailing is still in 2D stage. While BIM is far from the scene, even intelligent object-oriented CAD packages have not yet percolated into these markets. In some cases like India, given their leadership in IT sector this may sound contradictory. However, the lack of automation in the construction industry, the low cost of construction labour, and inefficient regulatory authorities have hindered this progress (Khemlani 2004a). On the other hand, even here some pockets of BIM awareness and usage exists in form of outsourced modeling projects. This suggests that economic and business incentives are the main driver to bring in the process change.

Industry survey and top criteria for BIM solutions

From the technical aspects, a recent survey by AEC bytes (Khemlani 2007) gives a good overview of the current status of BIM in the AEC industry. Some of the findings of earlier studies were reinforced in the survey, and the main ones are listed below:

1. Despite each disciplines working in 3D environment, collaboration is still primarily based on exchange of 2D drawings.

2. As modelling packages have become object-oriented there is greater demand for object libraries, and modelling capabilities.

3. Significance of technologies supporting distributed collaborative works has increased.

4. Smaller firms prefer more intuitive design and workspace environments. This is reflected in the popularity of Autodesk Revit and ArchiCAD. Larger firms that are often involved in large scale projects prefer tools with greater flexibility in setting up project environments and tools with strong modelling capabilities. Accordingly, Bentley Systems is more popular with bigger players and is found to be more suitable for such projects.

5. 3D visualization is no more a major concern. The visualization capability of existing tools is already very good, and users want to get more out of the accurate models than just the visualization.

6. The need for better training guides and help on tools has been emphasized.

Support on analysis, performance simulations and interoperability has been discussed, but the survey suggests it is not an important issue.

A review of document based collaboration platforms is provided in Section 3.3

2.3 Desktop Audit of BIM Tools

A desktop audit of the different types of commercial applications that form a part of BIM approach was conducted. This involved live demonstrations and trials; data gathered from product brochures (GehryTechnologies, Navisworks, EPM Technology 2004, etc.); and analysis of tools reported and published by other sources (www.aecbytes.com, CyonResearch 2003, STATSBYGG 2006, etc.). Products evaluated include BIM model servers, discipline specific design tools planning tools, analysis tools, design review and viewing tools, FM tools, product libraries and so on. The desktop audit provided an overview of the technological capabilities and applications, their role in BIM approach, and trends in development of commercial BIM applications.

A wide range of products are available for various applications that form a part of the BIM approach ranging from product suites to very specific products for design, analysis and libraries (Khemlani 2007a). There is a rapid growth in the number of supporting technologies and products. Only few of these are IFC (Industry Foundation Class) (Khemlani 2004) compatible. This means they can only be integrated with specific tools that accept those formats. Tools for early design phase (Pentilla 2007), and integration of conceptualization tools is lacking at the moment. The most popular model authoring tools like ArchiCAD, Revit and Bentley are all weak in supporting conceptual design activities.

Web-based product services are growing, benefiting from the object-based modelling that has gained a widespread acceptance. Object intelligence, which brings associativity and relationships within objects and object properties, enables modelling constraints (Eastman et al 2004). This has allowed emergence of more efficient analysis tools (Mitchell et al 2007) that can automate a lot of processes, which were so far primarily manual and time consuming.

Each tool reviewed is categorized and discussed in terms of:

a. Application - service disciplines, and the purposes and usage of the tool.

b. Main features

   a. Collaboration: Capabilities and features that facilitate co-ordination and information exchange.

   b. Organization

      i. Data management: how the data is handled.

      ii. Version management: how the data integrity is maintained.

   c. Modelling: 3D modelling capabilities.

   d. Viewing: Navigation, graphics and viewing capabilities.

c. Underlying technology

d. Add-ons/ Plug-ins

e. Data exchange

f. Business model: Business approach of the vendor and the target market segment.

g. Shortcomings and limitations

Some tools may have all the categories of features applicable to them, while some may be very specific for which only few of the features can be discussed. A summarized chart of the studied tools is presented in Table 3.1.

Table 2.1   Indicative summary of main BIM tools

Application	Type	Approach	Purposes	Features and strengths	Limitations	Comments
BIM Application Tools (Discipline specific)						
Acrobat 3D	Standalone	Document viewer	Design collaboration tool	Very good viewing capabilities Light files, easy to share	Functions limited to viewing and annotating	Can be used with Adobe reader, hence easy access
ArchiCAD	Suite	Integrated database	BIM design tool Architecture/ construction	Object intelligence Visual compare Hot-linked drawings Trace features	No conceptual design support Lacks modelling constraints	Wide recognition for its BIM approach.
Revit	Suite	Integrated database	BIM design tool Architecture/ Structure/ MEP	Object intelligence Linked models Relationship based workflows Interference check Rich product library and plug-ins	No conceptual design support Allows many illegal operations Not easy to make non-regular geometries	Rapidly growing market share and product capabilities.
Bentley	Suite	Federated database	BIM design tool Architecture/ Structure/ Mechanical/ Electrical	Object intelligence Very useful for large projects Inherits the strengths of Microstation	No conceptual design support Needs greater effort on project organization	Widely used in large engineering in process plant industries

Application	Type	Approach	Purposes	Features and strengths	Limitations	Comments
Navisworks	Suite		Design collaboration, review, and visualization	Clash detection Exploration/design review Conflict resolution Accepts data in most formats Very good integration and visualization capabilities	Not a design tool. Limited to design review and visualization	Very useful for coordination
Model Servers						
ActiveFacility	Standalone Model server	Relational database	Facilities management	Coordination Data management Reference data Share project data No infrastructural requirement (web-based)	Data hosted by a third party	Service provider
EPM		Object oriented database	Design collaboration, BIM integration and visualization tool	Coordination Data management Conflict resolution Model check Reference data Share project data Web-based Range of Products available for licence	Flexibility and customizability is compromised if user does not buy multiple products. Cost of buying all licenses is expensive. User interface is confusing and non intuitive.	Service provider and product supplier

2.3.1   Model Servers

Review of two model servers is provided, based on trials, product demonstrations, white papers and product brochures. Further review of EDMmodelServer™ is provided alongside the case study conducted using EDMmodelServer™.

2.3.1.1   *ActiveFacility*

Overview: A web based model server to support hosting of a unified building model for enhanced and effective facilities management.

Application: Model server for facilities management

Main features: (ActiveFacility 2004)

- No local computational requirement. Everything happens at the server end.

- It uses a natural language interpreter for making queries to the database.

- Site specific glossary can be developed as per the customer requirement.

- Organization:

  o There is a separate website for each customer and each project. Thus, the access is provided through a web application.

  o ActiveFacility team builds the Unified Building Model once the data is provided by the client. The object relationships are identified and references are made.

  o It is essentially a Database management system.

  o The database is hierarchically organized based on the IFC specifications.

  o Object description comes from IFC specifications. This classification is done in the parent model development tool based on object attributes and these cannot be over-written in the model server.

- ActiveFacility is a service provider that manages the project data for the client.

  o Supports import and export of data

  o Supports viewing of data in both graphical and non-graphical form

  o Interface to systems used at client side is possible. This allows automatic update of the data in Active Facility system based on changes made on those systems. In turn changes made to data on Active facility system may trigger changes in another system.

- Viewing:

  o GUI is customized to meet the client requirements.

  o On the client side SVG viewer needs to be loaded for graphic support.

Underlying technology:

- Built around Oracle relational database technology, which

  o Supports XML messaging as native data types within the database.

  o Provides an object layer as part of its relational technology.

  o Provides a spatial module that allows geometry to be stored directly.

- Microsoft.NET architecture allows high level of development and integration possibilities, and acts as the technology interface between the user and the data.

- Uses Microsoft English query, which allows natural language processing.

BIM and Business Approach:

- Web based model server.

- No investment on client side on hardware and infrastructure.

- Business process outsourcing. Helps client organize and manage their building data better.

2.3.1.2   EPM suite

Overview: Offers a wider range of tools to allow a full range of model export/imports, partial or full model exchange, access rights and role definitions, querying, analysis, visualization etc.

Application: Model server with supporting applications and development tools

Underlying technology:

- EPM is based on a native IFC database.

- Model driven architecture. Models are instances of IFC specifications.

Main features: (Bengtsson 2005, EPM Technology 2004)

- The database has a hierarchical structure, where project is at the top, which is the model.

- Supports the IDM - information delivery manual based on definable processes that specify the data (objects & content) necessary to support model collaboration transactions.

- There are two types of associations in the model: (1) data associated and (2) back/ inverse relationships.

- The model server has checks before data can be merged. Synchronization of the models from different disciplines is what is checked.

- Model server has a global administrator.

- Model server has multiple ways of data importing and exporting.

- Check-in and check-out allows for version management.

2.3.1.2.1   EDMServer™

Overview: Enables product data to be effectively managed, exchanged and shared across radically different systems, independent of location, type or network design.

Application: Product Model server, Data management

Main features:

- Modular by design that allows mix and match of the products and desired options. This allows expansion or update of the system as needs change and as the standard continues to evolve.

- Native support for any standard data model like STEP (Standard for The Exchange of Product Model Data) and specifically IFC.

- It allows access to the data throughout the project life cycle.

Underlying technology:

- Unified database system.

- Model driven architecture. These models are created and defined in EXPRESS, the information modelling language specified in STEP.

EPM's BIM and Business Approach:

- A range of products supporting building information integration.

2.3.2   Observations from Desktop Audit

Examples of the use of BIM approach in practice suggest that in the present state there are tools that can significantly improve the work process in the AEC industry. However, lack of tools supporting and integrating different design phases has been a major concern (Khemlani, Holzer). Technical support will improve as more specific BIM applications are developed for specific aspects of design process, and allow integration with each other. Accordingly, as the desktop audit suggests a wide range of applications are being developed to facilitate the BIM approach and different kinds of approaches are being adopted that need to be analyzed. Some of the issues yet to be resolved in BIM implementation include:

- **Design model – construction model:** what is the best approach? Since the kind of detailing and models required for design and construction purposes are significantly different, some believe that developing separate models for each from the scratch might be a better option. Others believe that this leads to redundancy and a single model with efficient versioning can serve the purpose.

  This may be a matter of choice and practice. As the organizations gain experience working with BIM, they would explore the benefits and drawbacks of the two approaches. With time they may be able to decide on the best approach that suits their needs. Similarly, as more experience is gained in using BIM some sort of best practices will evolve over time.

- **Centralized vs distributed database:** Is a distributed database the best approach? What are the co-ordination and maintenance issues with a distributed database? For a discussion on database technologies see You et al. (2004). Bentley has adopted a distributed database approach, which allows sharing the load of data generated in large project. However, this means that there is a greater effort required for ensuring data integrity across these distributed databases, which is easier done in a centralized database as adopted by other vendors like Archicad and Autodesk Revit.

- **Modelling constraints vs flexibility** (Eastman et al. 2004b, Khemlani 2007): How much intelligence is good? The object-oriented modelling using intelligent objects is the core of the BIM approach. This allows associations and relationships that enable writing rules that provide modelling constraints. These constraints make certain modelling actions invalid, if they are in conflict with the rules. However, at times creative design involves overlooking the generic rules and hence it is important not to over-constrain the modelling capabilities. The trade-off between the modelling constraint to ensure model and design integrity, and flexibility to allow creative design is a critical issue.

- **Details and resolutions:** the level of detailing of the model is an important decision making exercise. It is important that the model is detailed enough to ensure that all the relevant data can be generated and checked. At the same time those details that may be redundant in terms of their usability can be avoided.

- Is there a **role change** for the involved professions? (Eastman et al. 2004a): With the changing tool capabilities and the kind of information support provided by the tools, the roles and responsibilities of the involved disciplines may change over time. Architects and designers can get feedback on technical aspects of their design at an early stage using the analysis tools. This gives them greater independence and capability on technical decisions and design.

2.4   Industry Needs Analysis

2.4.1   Data Collection: Industry Focus Group Interviews (FGIs)

Two Focus Group Interviews (FGIs) have been conducted with active participation of representatives from all sectors of the AEC/FM industry including architects, engineers, project managers, contractors, consultants, academics, vendors, and delegates from Australian government agencies. The main goal of the FGI is to uncover and analyse the industry perceptions of collaborative BIM adoption.

Discussions in the FGI and the earlier BIM literature review suggest that the reasons for low adoption of BIM in the industry are not only technological. Other factors that influence BIM adoption include work practice, organizational structure, business interest and user training. It has been recognized that the introduction of BIM would require a different approach to data organization and structuring, including the security of data. Some legal/ contractual measures will also be required to deal with security and work practice related issues.

The FGI were recorded and then the comments segmented. The segmented data and background study were analyzed firstly using an open-ended approach to identify the main themes. Based on these main themes a coding scheme has been developed and applied to the FGI data for detailed analysis. The design of the coding scheme reflects on the importance of various factors affecting collaborative BIM adoption.

The coding scheme has five categories:

- Discipline;
- Type;
- Context;
- Content; and
- Keywords.

Discipline, content and type categories are used to cluster the data such that we can identify the pattern of BIM and collaborative BIM awareness, interest and knowledge across different disciplines. Keywords allow identification of major issues.

Discipline Category

The 'Discipline' category is used to classify the data based on the disciplinary and functional background, or roles in the industry of those interviewed (speakers). Marking of each segment, based on the disciplinary background of the speaker, gives useful information about the importance of the different aspects of collaborative BIM (in terms of the content) within each discipline.

Type Category

The 'Type' category is used to classify the data based on the perceived purpose of the FGI statement. Values for the 'Type' category are:

- Suggestion /idea;

- Concern;

- Opinion/viewpoint;

- Observation/analysis;

- Query;

- Inform (to enlighten other FGI participants);

- Strategy; and

- Wish-list.

Context Category

The 'Context' category is used to mark the circumstances under which a given segment of data has been discussed. Classifications within Context category include:

- Initiated (if the segment of data was for starting a new subject of discussion);

- Reply (if the segment of data was for answering a question);

- Follow up (if the segment of data was continuing an ongoing subject initiated earlier in the discussion); and

- Chair (if the segment of data was a statement to control the flow of discussion, and in general was often given by the moderator).

Content Category

The 'Content' category classifies the segments based on the subject of discussion and identifies the dominant topics. Accordingly, there are eight classifications within the content category:

- Technical;

- Cultural / work practice;,

- Structural / data organization;

- Training, legal / contractual;

- Organizational-team, process / method; and

- Business case.

Keywords

'Keywords' allow identification of major issues across the different categories, and priorities have been set for the keywords by evaluating the frequency of occurrence in the data.

Examples of coded segments are shown below in Table 2.2 to demonstrate the use of the coding scheme:

Table 2.2   Examples of coded FGI data that demonstrates the use of the coding scheme

Comment / Segment	Discipline	Context	Type	Content	Keyword
"Frustrating part is having different (approval) regulations across states" ….	Design Manager	Initiated	Observation	Legal / contractual	Regulations
"How do we get one agreed standard?"	Contractor	Follow-up	Query	Culture / work-practice	Standard
"Force them to do that."	Design Manager	Reply	Opinion / strategy	Culture / work-practice	NA

The design of the coding scheme allows a detailed analysis of FGI data. For example: Discipline versus Content mapping indicates which content has the dominant issues to specific disciplines; Type versus Content mapping indicates awareness, interest and knowledge about the content; and Discipline versus Type mapping indicates awareness, interest and knowledge across specific disciplines. Similarly other correlations can be mapped to plan future research and strategies can be designed for specific disciplines and issues.

2.4.2　　Industry Needs Analysis: Key Issues

The two FGIs have a slightly different composition in terms of the industry representation in that active participation of the disciplines varies between the two FGIs. While overall the discussions have similar patterns and raise the same points, there are some differences. These have been discussed below under the following main headings:

- Participation;
- Discipline versus Content;
- Type versus Content; and
- Discipline versus Type.

Participation

The discussion on participation is provided to inform the readers of the composition of the FGI in terms of the discipline they represented. At the same time representation and participation is differentiated. This allows identification of disciplines that were more active in the discussions. Differences in active involvement of participants from different disciplines could be related to:

1. levels of knowledge and awareness about a collaborative BIM approach;

2. levels of interest in collaborative BIM;

3. the content of discussion

Participation of the disciplines is equated in terms of the frequency of statements and data coming from the representatives of each discipline. Details of participation are summarized in Table 2.3, and Figures 2.3 and 2.4.

In both the FGIs **BIM consultants and application vendors have higher active participation**, mostly providing information. Relatively higher participation of academic research in the second FGI is a result of the observations made from the first FGI and bringing those issues in discussion for the second FGI.

Table 2.3　　Breakup of the number of segments in the two FGIs by discipline

FGI Participation: Sydney	No. of Segments	FGI Participation: Brisbane	No. of Segments
Contractors	72	Contractor	37
Architect / Engineer / Design Manager	58	Engineer / Design Manager	50
Architect / BIM Conversant	51	Government Architect	127
Research / Academic	8	Research / Academic	60
Research / BIM Consultant / Application Vendor	72	Research / BIM Consultant	51
Collaboration Tool Application Vendor	13	Collaboration Tool Application Vendor	84
Facilities Manager	14		

Figure 2.3   Charts showing participation of disciplines at Sydney FGI

Participation (S)

- ■ contractors
- ■ architect/engg/ design manager
- ■ architect/ BIM conversant
- ■ research/ academic
- ■ research/ BIM consultant/ application vendor
- □ collab tool appl vendor
- ■ FM
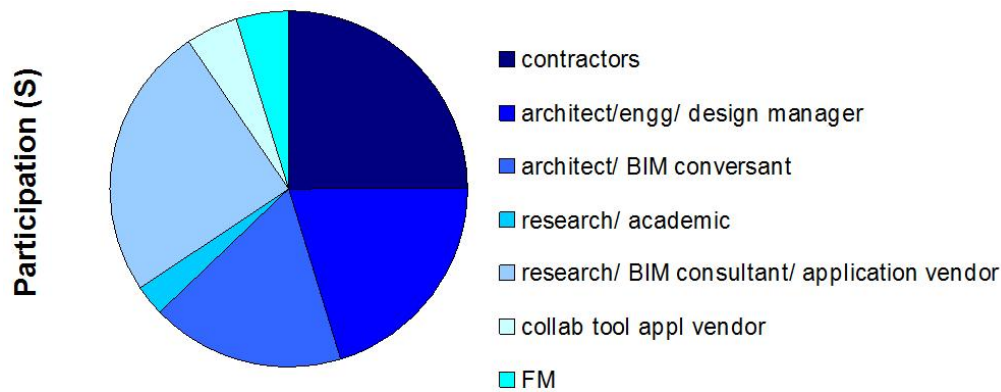
Figure 2.4   Charts showing participation of disciplines at Brisbane FGI
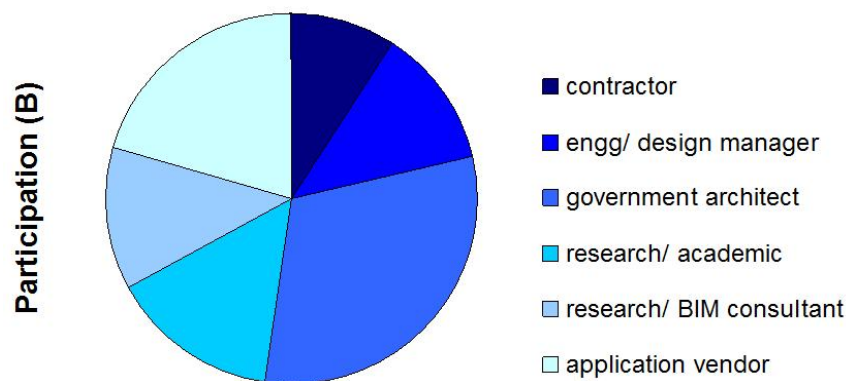
Participation (B)

- ■ contractor
- ■ engg/ design manager
- ■ government architect
- ■ research/ academic
- ■ research/ BIM consultant
- □ application vendor

Discipline versus Content

The distribution of the segments under each of the content categories is mapped according to the discipline of the participant. Discipline versus Content mapping of the FGI data allows:

    a. Identification of issues that specific disciplines actively discuss; and

    b. Identification of disciplines that are interested in specific aspects of collaborative BIM.

In both the FGIs the subject of discussion shows a similar pattern, as summarized in Tables 2.4 and 2.5, and Figures 2.5, and 2.6. The FGI data reflects that

1. **Technical aspects are the dominant subject** in both FGIs with the application vendors primarily providing information to others. Architects and other design consultants focus on technical issues presenting their concerns, queries and suggestions.

2. **Architecture** and **design disciplines talk more about the processes, methods and the work practices** than any other disciplines.

3. There is almost no discussion on legal /contractual aspects related to the collaborative BIM approach in the first FGI, which is different in the second FGI. This can be attributed to two main reasons:

    a. Presence of government architects in the second FGI.

    b. Application vendors in the second FGI are also service providers. Hence, they need greater clarity on legal agreements and contracts, while the application vendors on the first day are product suppliers.

30

4. **Data organization is primarily a concern for the architecture, design disciplines and vendors**.

Table 2.4   Number of segments by content for each discipline (Sydney FGI)

Discipline versus Content: Sydney	Technical	Cultural / Work Practice	Data / Structuring / Organisation	Training	Legal / Contractual	Organizational- Team	Process / Method	Business Case
Discipline	**By Content - Number of Segments**							
Contractor	17	10	4	2	1	6	13	8
Architect /Engineer / Design Manager	25	15	11	2	1	7	30	6
Architect / BIM Conversant	39	4	14	0	0	1	18	2
Research / Academic	4	2	2	0	0	0	3	0
Research / BIM Consultant / Application Vendor	49	9	12	5	0	6	25	2
Collaboration Tool Application Vendor	6	1	5	0	0	1	4	1
Facilities Manager	9	0	2	1	0	3	4	3

Table 2.5   Number of segments by content for each discipline (Brisbane FGI)

Discipline versus Content: Brisbane	Technical	Cultural/ Work Practice	Data / Structuring / Organisation	Training	Legal / Contractual	Organizational- Team	Process / Method	Business Case
Discipline	**By Content - Number of Segments**							
Contractor	13	8	3	2	1	2	14	2
Engineer / Design Manager	12	12	6	0	3	3	11	0
Government Architect	52	30	18	6	9	13	41	10
Research / Academic	19	11	15	5	3	7	12	6
Research / BIM Consultant	26	6	10	1	4	5	20	2
Collaboration Tool Application Vendor	59	2	13	1	4	5	22	5

Figure 2.5   Contents of discussion by specific disciplines (Sydney FGI)
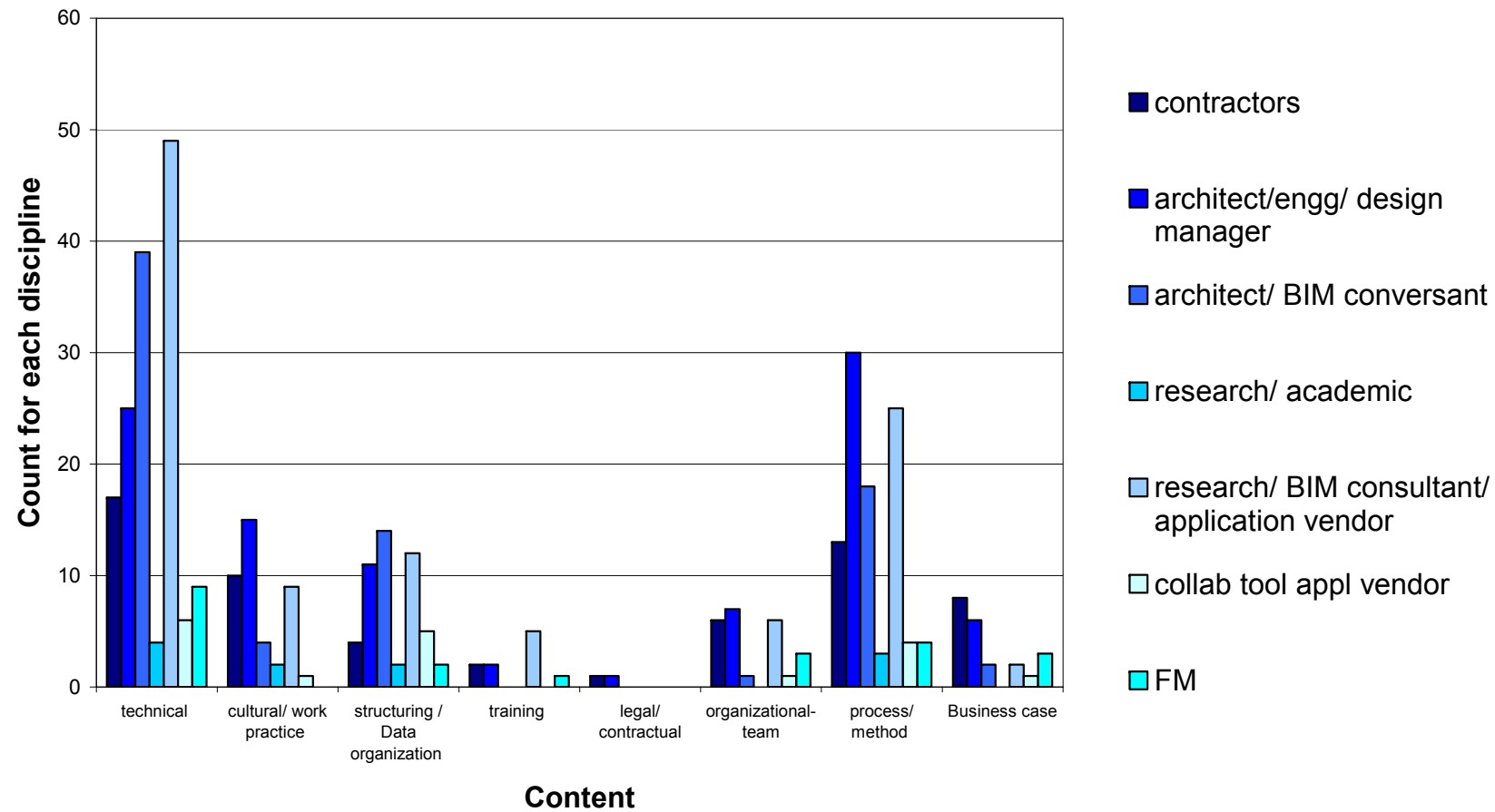
Figure 2.6   Contents of discussion by specific disciplines (Brisbane FGI)
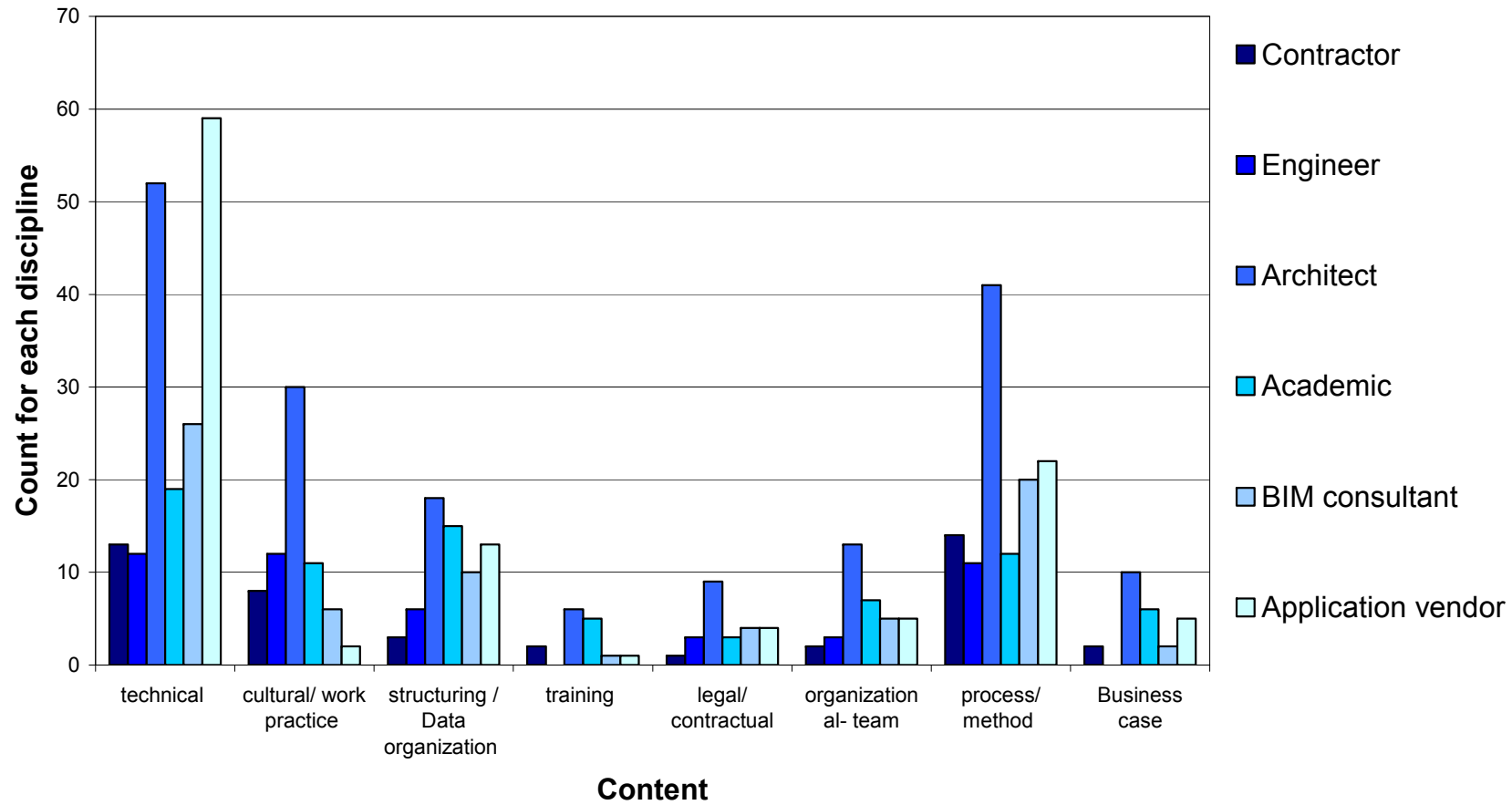
Type versus Content:

The distribution of the segments under each of the content categories is mapped according to the type of the data. Type versus content mapping of the FGI data allows:

a. Identification of aspects of BIM that participants need information about (query / concern) or

b. Observation of participants who have knowledge and experience to share (opinion / observation / inform) or

c. Examination of expressed interest and desire from the participants in features they would like in a collaborative BIM approach (suggestions / wish list).

A summary of the FGI data mapping the frequency of the different types of discussion with respect to content (topic of discussion) is provided in Tables 2.6 and 2.7, and Figures 2.7 and 2.8. The key points identified from the FGI data can be summarised as listed below:

1. In both FGIs a **significant part of the technical discussion is based on providing information**, quite often done so by BIM application vendors.

2. Opinion and views relate to "what could be done" or "what technical features may be useful" in a collaborative BIM application. In both the FGIs, participants share opinions on technical as well as process related issues.

3. Wish lists are features that the participants would like to see and mostly relate to technical aspects. While there are very few wish lists from the first FGI the number of wish lists in the second FGI is considerably high. The greater participation of academic / research discipline in the second FGI could be a reason, as they often initiated such queries.

4. **Concerns are primarily related to technical, cultural / work practice and process / methods**. Technical concerns are greater than the other two, cultural and process.

5. While very few strategies are discussed in the first FGI, there are relatively **more strategies discussed in the second one. The strategies in the second FGI relate to technical aspects, processes and business cases**. Again the active participation of academic research disciplines could be a factor as they posed queries. The difference in the business model of the application vendors in the two FGIs also influenced this variation in amount of strategies discussed. Application vendors in second FGI being service providers see greater potential in new strategies for collaborative BIM adoption. This is because they emphasize customized services to suit client requirements. Being a service provider they are more willing to have a flexible approach.

Table 2.6   Number of segments by type for each content category (Sydney FGI)

Type versus Content: Sydney	Technical	Cultural/ Work Practice	Data / Structuring / Organisation	Training	Legal / Contractual	Organizational-Team	Process / Method	Business Case
Segment Type	**By Content– Number of Segments**							
Suggestion / Idea	16	1	7	1	0	1	10	1
Concern	13	9	3	4	0	2	10	1
Opinion / Viewpoint	50	12	13	5	2	10	29	11
Observation / Analysis	18	14	5	1	0	3	13	4
Query	19	6	10	0	0	2	8	3
Informing	43	7	11	0	0	5	21	5
Strategy	2	1	4	0	0	4	9	0
Wish List	2	1	3	0	0	0	5	2

Table 2.7   Number of segments by content for each discipline (Brisbane FGI)

Type versus Content: Brisbane	Technical	Cultural/ Work Practice	Data / Structuring / Organisation	Training	Legal / Contractual	Organizational-Team	Process / Method	Business Case
Segment Type	**By Content– Number of Segments**							
Suggestion / Idea	21	5	16	3	2	4	16	3
Concern	25	17	6	4	3	7	16	0
Opinion / Viewpoint	37	22	11	3	9	14	44	10
Observation / Analysis	11	19	7	2	1	4	13	1
Query	22	7	10	1	0	3	12	5
Informing	65	9	14	3	9	8	32	4
Strategy	41	13	11	2	4	11	26	16
Wish List	26	0	10	0	0	0	6	2

Figure 2.7   Types of statements on specific content (Sydney FGI)
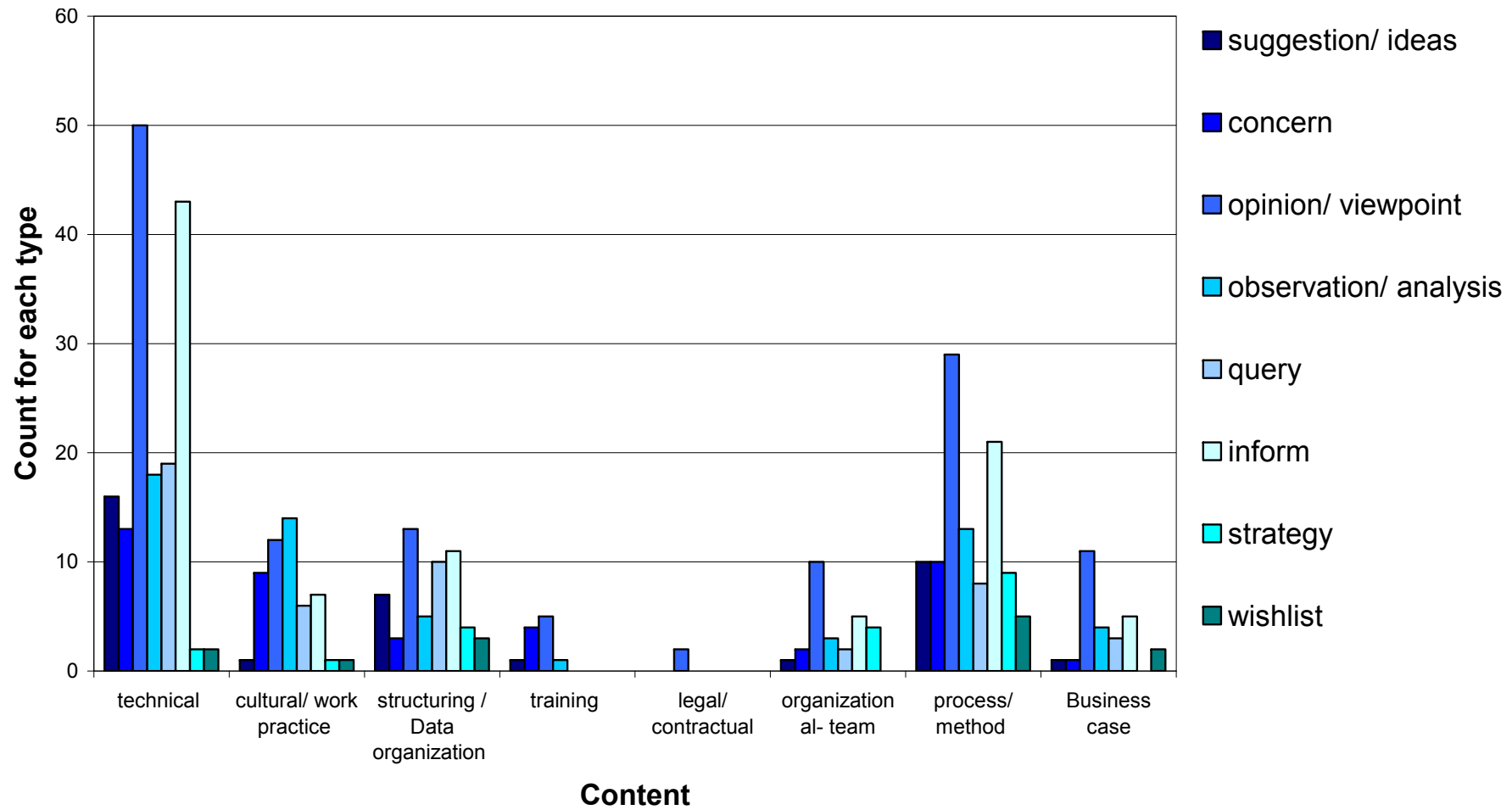
Figure 2.8 Types of statements on specific content (Brisbane FGI)
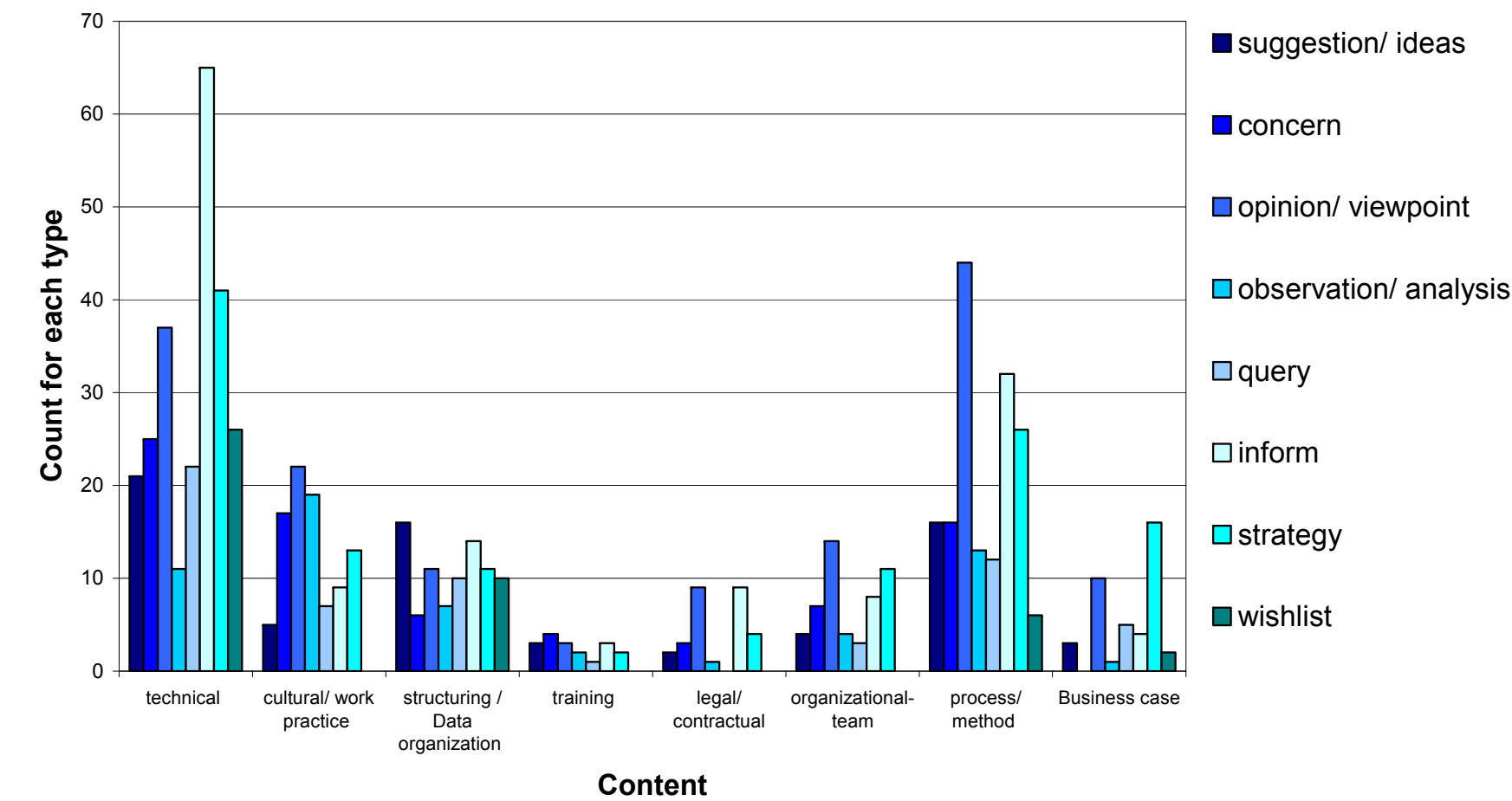
Discipline versus Type

The distribution of the segments under each of the type categories is mapped according to the discipline of the participant. Discipline versus Type mapping of the FGI data allows:

a. Understanding the levels of knowledge, awareness, interest and apprehensions about a collaborative BIM approach across each discipline.

b. Identification of disciplines which are apprehensive of the collaborative BIM approach and those that lack awareness and information on BIM.

A summary of the FGI data mapping the frequency of the different types of discussion corresponding to each discipline is provided in Tables 2.8 and 2.9, and Figures 2.9 and 2.10. The key points identified from the FGI data can be summarised as listed below:

1. **Architects share views and opinions the most, mainly on technical, data organization and process** related topics. Most of the concerns come from the architects, who also discuss strategies in both the FGIs.

2. **Design managers, working for Contractors, primarily provide information on current processes and work practice**.

3. In both FGIs application vendors primarily provide information. While in the first FGI the vendors spend as much time giving opinions in the **second FGI the vendors spend considerable time discussing strategies, primarily arising from collaborative BIM as a service point of view**.

Table 2.8   Number of segments by discipline for each type (Sydney FGI)

Discipline versus Type: Sydney	Suggestion / ideas	Concern	Opinion / Viewpoint	Observation / Analysis	Query	Informing	Strategy	Wish List
Discipline	**By Type – Number of Segments**							
Contractor	1	6	18	2	9	5	1	4
Architect / Engineer / Design Manager	5	9	16	9	1	11	11	8
Architect / BIM Conversant	8	1	16	12	2	15	2	2
Research / Academic	0	1	2	1	2	1	0	0
Research / BIM Consultant / Application Vendor	7	3	26	8	2	26	11	2
Collaborative Tool Application Vendor	1	0	4	0	5	2	1	0
Facility Manager	0	1	3	0	5	2	0	4

Table 2.9   Number of segments by discipline for each type (Brisbane FGI)

Discipline versus Type: Brisbane	Suggestion / ideas	Concern	Opinion / Viewpoint	Observation / Analysis	Query	Informing	Strategy	Wish List
Discipline	**By Type – Number of Segments**							
Contractor	6	4	10	2	5	2	8	6
Engineer / Design Manager	4	5	14	11	3	7	8	1
Government Architect	13	31	50	17	11	8	27	12
Research / Academic	12	11	11	4	18	6	14	6
Research / BIM Consultant	8	3	15	3	1	22	9	1
Collaboration Tool Application Vendor	8	8	8	5	4	60	28	1

Figure 2.9   Types of statements on specific disciplines (Sydney FGI)
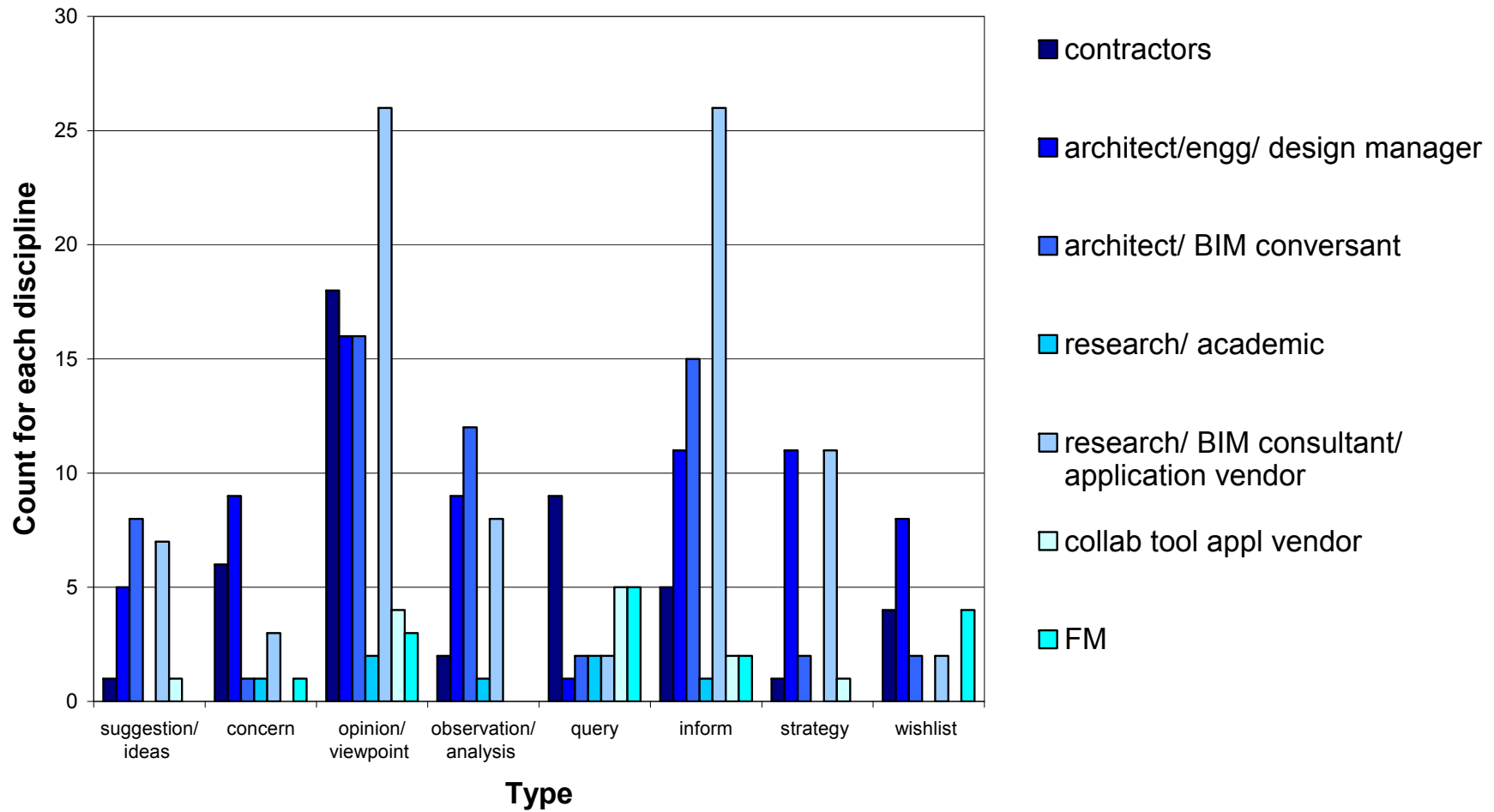
Figure 2.10   Types of statements by specific discipline (Brisbane FGI)
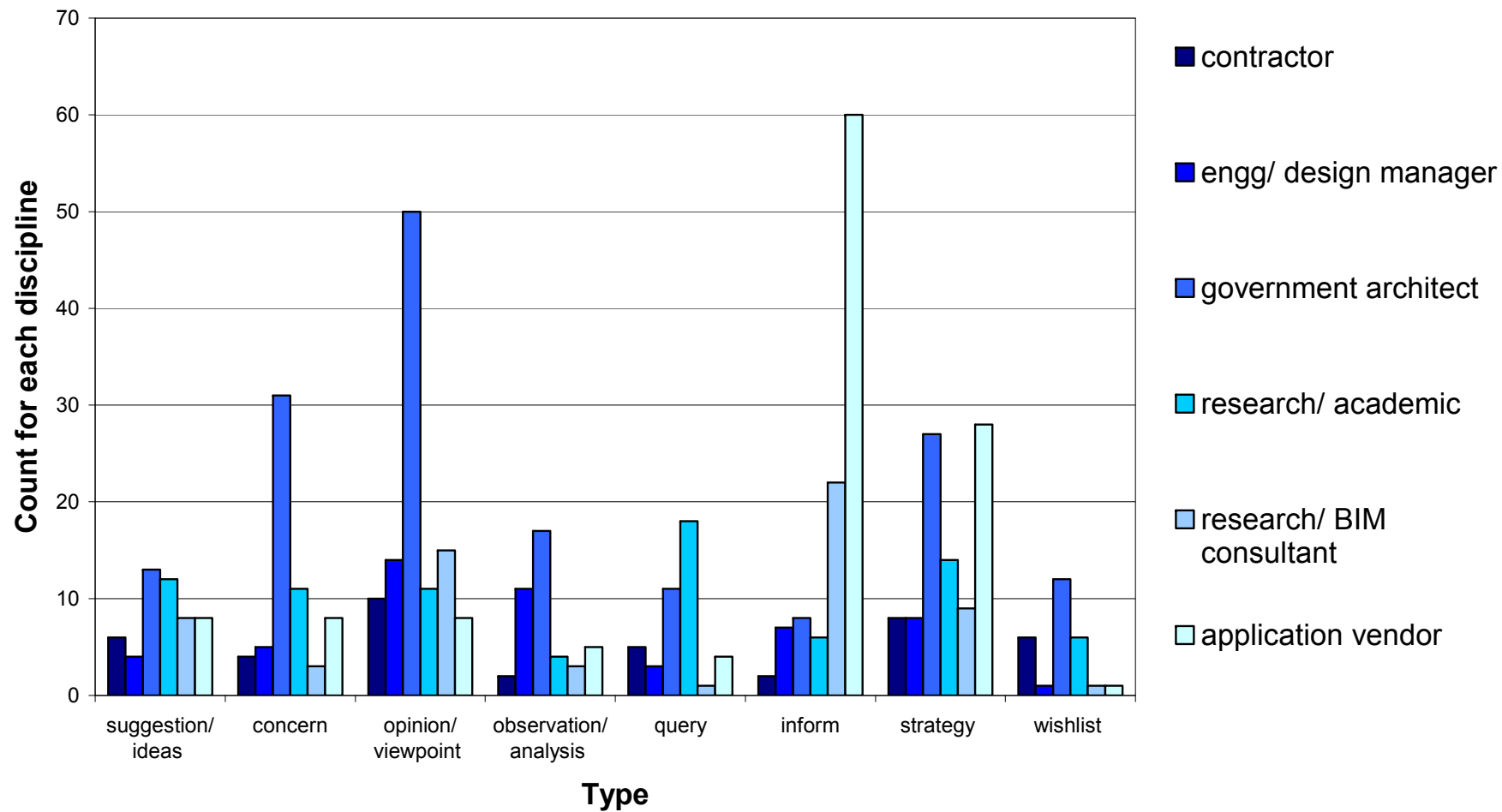
2.4.3   Industry Needs Analysis: Key Issues

BIM technologies and processes are the most prominent points of discussion in the FGI. While some issues discussed are similar to those found in the literature review, the FGI discussions and the data analysis give greater insight into the issues, as well as their causes and possible solutions. Some of the key issues to emerge from the FGI are:

- Model Validation
- Standards for Data Exchange
- Version Control
- Data Management and Organisation
- Communication Registers and Information Exchange
- Training
- Change Enablers
- New Project Roles and Shifting Team Dynamics
- Model As Built Data
- Collaborative BIM for Civil Projects
- Model Security

Validation using 3D Models

Over the years, even though 2D drawings are increasingly being generated out of 3D CAD packages, the **lack of trust on completeness and accuracy of models** has remained a major concern for the practitioners involved. This is the case despite the fact that within the AEC/FM industry some disciplines like steel structures, in some cases rely completely on model accuracy as their outputs are Computer Numerical Control (CNC) fabricated. The development of intelligent model checkers has done little to alleviate the concern. Some work practice-oriented measures like standard evaluation and validation procedures need to be put in place to generate confidence amongst the users. As Bernstein and Pittman (2004) suggest, it is important to create awareness amongst the practitioners about the greater computability of the digital designs created by the available applications.

As the building industry moves towards greater use of pre-fabricated building components and advanced on-site fabrication technologies that can directly take computer-generated data, the accuracy and completeness of models will become a critical issue. In such scenario, automated checking of the model, and agreed processes and protocols for 3D validation will be required for design approval.

Standards for Data Exchange

Though the AECbytes survey (Khemlani 2007b) suggests that interoperability is not critical, the participants in the FGI spent a considerable amount of time discussing the need for standards across proprietary tools. Accordingly, Industry Foundation Class (IFC), International Alliance for Interoperability (IAI) and Geographic Information Systems (GIS) has been frequently discussed.

Interoperability issues, due to the availability of different commercial software that may not have a common format, remain a dominant topic during the FGI. At present, the IAI's certification of IFC compatible applications is not stringent. Hence, for practical purposes there are many limitations with IFC data conversion and exchange. This is a serious concern for managing an integrated database at the model server using IFC standards. Most product libraries and specific BIM applications that are commercially available, target specific commercial applications with a wide market base, for example, Autodesk Revit. This means that such libraries cannot be shared or used by other packages. Besides a standard format for data exchange, there is a greater need for standard vocabulary for the consistency of data when exporting from one package to another.

Version Control

This is another important issue discussed during the FGIs, for the following reasons:

- When application vendors develop a new version of the application sometimes there are significant differences from the previous versions. This brings in problems such as data loss and compatibility issues if different versions of the same software are used by different team members.
- The version of project data, if collaborative BIM is to be adopted using an integral database where each discipline maintains, modifies and updates the data, then technical measures, work procedures and methods need to be put in place to ensure data integrity, allowing different versions of the project to be managed throughout the project life-cycle.
- The version of IFC. At present the IFC standards are still evolving, and the format has changed significantly in the last few years. Service providers who maintain IFC data for the clients may have to update the stored data's format for the clients accordingly. Such updates may not be easy if the changes are significant.

Data Management and Organization

Concerns have been raised by the FGI participants that as more and more building data are managed and stored electronically, standard practices and procedures need to be put in place to deal with data organization, storage and security. Ability to manage different **subsets** of the project, which relate to compatible sets of data for different purposes at different stages of the project, will be useful. For example, subsets can be based on entities such as "all wooden doors in the building" or "all single-storey buildings in the campus". Similarly, subsets can be based on activity or work-set such as "all buildings in the campus done in phase one" or "all building zones that have been surveyed" and so on. Some subsets are possible to generate on runtime, provided the criteria for categorization is part of IFC or object property that can be extracted from the model and matched. However, other sub-sets need to be registered either in anticipation of requirement or as-and-when those are identified and generated, such that they can directly be accessed at a later date, if required.

While the ability to constantly update the data gives unprecedented flexibility it also adds to the complexities related to version management, **data explosion** and **usability**. Some of these issues may have been addressed in Database Management Systems (DBMS), but from a technological perspective, and not from an organizational perspective for the AEC/FM domain. This poses a new challenge involving strategic decision making which need to be taken up early in the project planning stage.

Digital data management provides new alternatives different from the traditional paper-based file management system, but at the same time losing stored data can be a click away. A new set of CAD drawings can easily **overwrite** the earlier versions. **History** of the actions taken and the digital data itself should be maintained. Clients and users will need to decide which stage(s) of the data need a backup.

The idea of **public space and private space** within the collaborative model was a key issue for the FGI participants. Individual disciplines generally work on local machines. At some stage of the project, when they deem appropriate they share the data with the rest of the project team at large. The model server should not prevent individual disciplines from storing their own data on the model server that are not shared in the project team. A mechanism is needed to support both private and public spaces within the model server. Private spaces can be at individual level, sub-team level or discipline level. For instance, if a group of people need to interact on a daily basis for the project, but this group is not ready to share the data with the rest of the team, then such private spaces for sub-teams should be possible on the model server.

Communication Registers and Information Exchange

Information exchanged between the BIM users through different media are currently not captured in a BIM server. Participants suggest that BIM servers should allow message flagging and notifications between team members and the other project members who may not be directly using the BIM servers. Though not explicitly discussed, some of the ideas discussed are similar to the concepts of Enterprise Wiki (Kalny 2007).

Training in Design Schools

CAD courses taught at design schools currently do not complement the present industry needs. In most architecture schools CAD courses are separated from the design studio, and the design methodology taught in schools often fails to **integrate CAD in the design phase**. Although some alternative approaches such as parametric design have been introduced as digital means to conceptual design, such cases are still limited. The FGI analysis also indicates the lack of teaching staff with knowledge and experience of modern CAD packages and the reluctance of adopting new technologies and their use in the design curriculum.

Students also need to be trained in applying **computer-supported collaborative tools** in team projects to appreciate the collaborative processes as well as understand and experience the potential benefits. In practice, architects work in a team and often coordinate team activities. In architecture schools although students also involve in team projects, the coordination of team projects is normally manual, face-to-face and within the single design discipline. Students need to be trained to explore state-of-art computer-supported collaborative tools and to collaborate across disciplines.

Industry based training: An integrated model development needs greater collaboration and communication. A different approach to model development is needed in a collaborative setting where multiple parties contribute to a single shared model (Lee et al 2006). Standard processes and agreed protocols are required to assign responsibilities and conduct design reviews and validation. In addition, users developing an object oriented model (which is a pre-requisite for the BIM approach) need to be trained in actual build and construct process. The BIM approach can facilitate involvement of contractors and construction mangers in early design stages. This will allow modellers to get a feedback on their model development, aligning it to the actual construction process. At present, the importance of setting-up the model has often not been realized, leading to inaccuracies and conflicts in later stage. Users need to be aware of the potential pitfalls and risks involved in using traditional practices with new tools. In the training modules it will be useful to discuss the common mistakes made in intelligent model development.

Key Drivers: Leadership which can enable Change

The FGI analysis and successful examples of BIM implementations in practice suggest that there has to be a **strong driving force** to bring about the change. In most cases BIM usage has been enforced by the **dominant partners** in the project. In general, in a collaboration project there is variable power status, and often, the more prominent players determine and control the work practice. For example if a leading engineering firm decides to change their work practice then they are in a better position to convince other smaller partners to change. Bigger organizations have greater incentives to put new systems in place. In general, for them the large scale of the project requires more efficient approaches to project data handling. These organizations are more willing to invest in measures with long-term benefits.

Government and regulatory authorities can play an important role in BIM adoption. Changes made in regulations and processes at the government end can guide the entire industry to adopt the new systems. Government and regulatory authorities can set the benchmark for technological capabilities and competencies of the parties working on government projects. Government organizations are also in the position to make the mandatory and regulatory processes smoother, which can provide greater incentives in the forms of reduced project approval time, simpler submission processes, reduced paperwork, etc. CORENET in Singapore (Cheng Tai Fatt, 2002) is one such example that allows electronic submission of approval drawings.

New Project Roles and Shifting Team Dynamics

As new technologies are being adopted in the industry, new roles and relationships are emerging. 3D modelling has already become common practice, and since 2D drawings can be generated out of 3D models, the modellers have increasingly taken the place of

draftsmen. What used to be **"architects and draftsman"** is changing to **"architects and modellers"**.

Dedicated roles like BIM managers will be useful for improved project collaboration and coordination, particularly in large-scale projects. At present with collaboration tools in place a lot of coordination activities are still manual, and hence a dedicated person with relevant experience and training will be required. In some of the ongoing large-scale projects the roles of BIM managers have been created and appointed, as discussed in the The Ark Project case study (Section 3.2).

Importance of As-Built Data

Ability to support **facility management** is considered as an important value-added feature for the collaborative BIM approach, making a strong business case. The information stored and maintained during the project is useful for later access and retrieval. This database is useful in updating and identifying the information needed for maintaining the building facility. However, in most construction projects changes are made during the construction phase. Hence, the final output may have some variations from the initial design, represented in the form of the BIM model. At present there is no process in place of updating the designed model to incorporate the changes made during construction. This is particularly important because it is the actual as-built data which is required for facility management.

As-built drawings may become important for **regulatory** purposes like sustainability assessment and other performance measures. Once the BIM model is updated with the as-built data, it can be used for comparison of projected building performance against actual performance to **evaluate design quality**. These types of comparisons will allow more accurate analysis tools by providing more effective and detailed evidence. Quality of as-built data is important. When the surveyors provide data for the built facility, the BIM managers need to register the quality of the surveyed data. Measures like grouping sets of data as sub-models for different parts of the model, based on the quality of the survey can be adopted. These measures are closely related to version and data management.

Collaborative BIM for Civil Projects

A number of large projects have involved significant overlaps of both civil and architectural works. For effective collaboration support this will require **the BIM applications to be compatible with GIS**. At present they are not compatible and in the FGI it is reported that Open GIS Consortium and buildingSMART are working together to resolve this issue. Another area for more development is the expansion of the IFC protocols and civil applications to include civil specific coding.

Data Security

Apprehensions exist about data security of model servers. These include concerns about **Intellectual Property (IP)** and protections of copyrights. Some concerns relating to **network security** may have technical solutions, but other concerns on design protections and access may be alleviated by greater awareness and legal measures. For instance, the access to data on model servers can be controlled through **secured log-in**. Data **check-in and check-out can be registered** for each interaction. On the other hand, service providers may also manage the data under a **contractual agreement** with the data owner, and the terms and conditions of data management and operation can be laid in advance.

Apart from the key issues discussed by the FGI participants, the analysis of the data revealed the following points regarding the use of a collaborative BIM environment:

- Discussions in the FGI suggest that users are hesitant discussing new concepts with technical jargon. While they emphasize the significance of interoperable standards such as IFC, all they expect is a **simple and intuitive interface**. These discussions echo the findings reported in literature (Aranda-Mena and Wakefield 2006, Howard and Bjork 2008). With the increasing number of applications supporting BIM, standard data formats will become inevitable for compatibility across the different tools.

- Object model development requires a different approach than using traditional CAD packages. The **importance of the initial set-up phase** of the model is often not realized, leading to inaccuracies, conflicts, frustrations and disappointments in latter stages.

- Though there is a general agreement on the potential benefits of BIM for all disciplines, the actual benefits and usability of the approach is not clear. There is lack of clarity on how BIM can be **integrated with the work practices** on projects.

- There is a common misconception that the entire work-practice has to be changed for the BIM approach to be adopted. This is primarily because the users fail to realize that the BIM approach can be used for only parts of the project lifecycle. Although the ideal is full implementation the most important aspect is that in the initial stages a clear statement of the purpose and scope of the BIM model is required. That is, users do not realize the **flexible scope of BIM** in an AEC project.

- Different **business models** will be required to suit varied industry needs (Wakefield et al 2007). BIM model can be maintained in-house or outsourced to service providers. In the latter case additional legal measures and agreements will be required to ensure data security and user confidence.

- **Knowledge and awareness about BIM** is low across most disciplines. Discussions reveal little distinction in participants' know-how between current capabilities of BIM applications and wish lists. Disciplinary backgrounds also skew the expectations from BIM (Figure 2.11).

Figure 2.11   Skewed expectation of BIM across disciplinary backgrounds
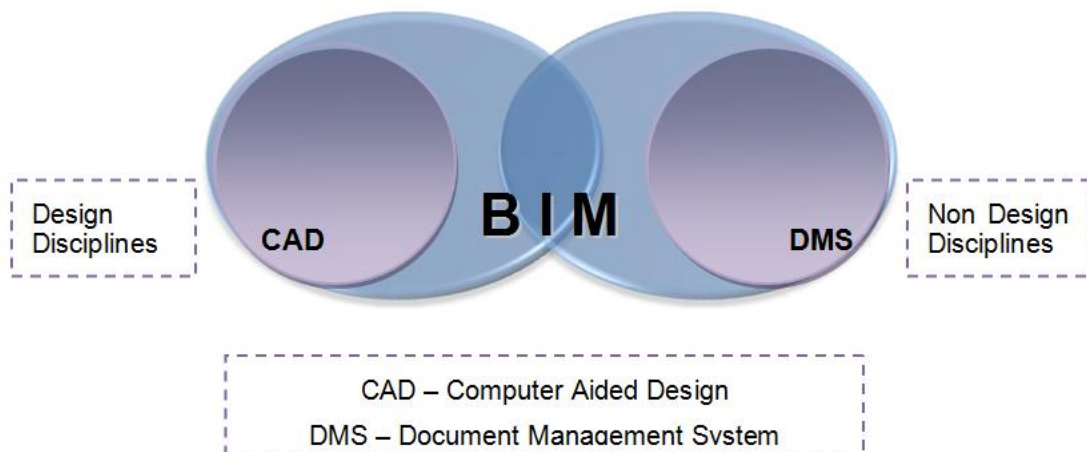
Architects and designers with CAD backgrounds see BIM as advancement from earlier CAD technology to current CAD tools such as ArchiCAD, Revit and Bentley. They expect BIM to primarily support extraction of information and drawings from the model they develop (as already supported by these applications).

Contractors and other participants from non-design backgrounds expect BIM to improve the document management capabilities. In this respect they expect BIM to be an extension of current collaborative document management systems (DMS). They expect BIM to be an enhanced DMS, where all the relevant information is appended and linked to the models. Thus their expectations from BIM go beyond the embedded information of object oriented models as in ArchiCAD or Revit.

Hence, for a widespread adoption of collaborative BIM the scope of BIM approach should be considered to include not only models with embedded information, but also appended and linked information. Thus technologies supporting BIM, and in particular collaboration platforms such as BIM model servers must facilitate the integration of

the models and all related information generated either internally or externally of the models.

- Discussions in the FGI suggest that the industry is stuck in a **status-quo loop** (Figure 2.12). The lack of knowledge and awareness about BIM has resulted in lack of confidence and willingness to adopt BIM. And as a result of the inhibition to adopt and use BIM the level of knowledge about BIM remains low. This is particularly critical to the rate of development of BIM technologies. Some of the BIM applications have not yet matured, which may lead to dissatisfaction among some of the potential early adopters. However, these tools can only improve with experience and feedback for which early trials and adoption are essential. Thus, for the BIM technology to mature and industry to adopt these technologies the status-quo loop needs to be reversed into a recursive development cycle (Figure 2.13). This development cycle reflects the discussions in literature that suggests that Introduction of new work practices and introducing new ICTs must go hand-in-hand (Schaffers et al 2006).

Figure 2.12   Industry status-quo loop inhibit technology adoption and slowing technology maturity

Little or no experience, hence little knowledge of tool capabilities

Little knowledge of tool capabilities hence does not venture to experience

Figure 2.13   Development cycle promoting technology adoption and facilitating technology maturity

Understand tool capability - Reflect on its usability in practice

Identify missing links in tool capability and suggest improvements in tool capability
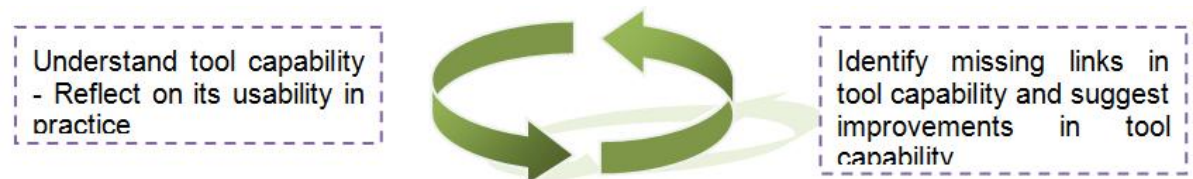
The implications of BIM adoption require changes to four key domains including:

- Work processes;
- Resourcing;
- Scope / project initiation; and
- Project life cycle and tool mapping.

For example in relation to existing work practices data and document version management, workflow, decision points and design and document review methods are all matters which take BIM from an idea to a reality. Resourcing is critical as it not only relates to design consultants being able to develop the models, but the level of interaction that they have and shared understanding of building models. The capability assessment does not rest with the design team as specialist subcontractors will also contribute to the building of models. Ideally product suppliers and all other subcontractors will contribute to BIM. However in many cases it is more than likely that many firms involved in BIM projects will tend to use models rather than contribute to building models in the first instance. Underpinning BIM implementation needs to consider the scope and purpose of the model and to embed roles and responsibilities within procurement strategy and contractual relationships.

New roles and responsibilities such as the BIM manager are emerging and an examination of current workflow and resourcing capabilities would begin to highlight whether this would be an internal or externally resourced role. There was much diversity in the first two FGIs and it was agreed that the scale and business models of the different players in the industry mean that organizations need to develop strategies that suit their requirements and practices, contingent upon the capabilities of their current firms that they work with.

Industry participants suggested that they did not have a structured approach to evaluating their project requirements, particularly in terms of tools, tool usage pattern, capabilities and compatibility across their project partners.

Hence, a Collaborative BIM Project Life Cycle Decision Framework is proposed to allow organizations assess their internal practice, their relationship to the clusters of firms that they typically work with, and then evaluate collaborative BIM applicability to their organization. In summary four key elements underpin the development of the Collaborative BIM Project Life Cycle Decision Framework:

a) Work process roadmaps
b) Tools and applications
c) Scope, roles and relationships
d) Resource capabilities.

The proposed framework is expected to facilitate the reversal of the status-quo loop into a recursive development cycle through:

a) Structured analysis of a firms BIM readiness and know-how;
b) Informed selection of BIM applications through understanding of the underlying capabilities, conflicts and limitations of the selected tools; and
c) Ability of a firm to define the purpose and scope of BIM contingent upon the available resources and project requirements.

In the future scenario, which is expected to revolve around activity-based collaboration environment (Schaffers et al, 2006) such a decision support framework will allow managers to adopt BIM collaboration strategies to best adapt to the project requirement.

2.5 Research Approaches

The industry needs analysis revealed that the industry's lack of experience in the use of Model Servers has lead to the limited feedback on technical requirements and industry needs. Therefore the project scope was expanded to proprietary software and not only IFC compliant software in order to relate to their familiar experience on existing collaboration tools. Use of non-IFC based tools is common and particularly relevant to civil works.

Hence, the following two approaches to elicitation of technical requirements have been adopted.

2.5.1 Approach One: Case Studies - Controlled Testing and Industry Use

A case study based approach is adopted, where a leading BIM model server is tested on a real world project with the following research objectives:

- To test the current functionalities, usability and capability of the existing BIM model server

- To identify the technical limitations of the BIM model server in a collaborative setting while working with other BIM applications such as CAD packages, analysis tools and so on.

- To identify the gaps and missing technical functions of the model server.

- To compare the changes in the design and collaboration practice when using a BIM model server as against the use of other collaboration platforms such as a document management system that support traditional work processes and practices.

To complement the controlled testing, selected industry use of the BIM approach is then presented and discussed.

2.5.2 Approach Two: Collaborative BIM Project Life Cycle Decision Framework

At present there is limited use and hence limited knowledge of BIM applications and integrated BIM development in the industry. The lack of awareness means that a direct feedback on technical requirements cannot be obtained from industry use. This lack of feedback is hindering the growth rate of the BIM related technologies that are yet to mature. Hence a Collaborative BIM Project Life Cycle Decision Framework is proposed as one of the research approaches with the following interrelated objectives:

- To provide a structured approach for potential and willing BIM users to understand their work practice, current tool capabilities and assess their BIM readiness.

- To allow potential users to identify the likely conflicts that would have arisen if they or their project partners had chosen incompatible tools in a given project.

- To create awareness about BIM applications and their usability in different project activities and phases.

- To generate a reflective practice among industry users such that the awareness and knowledge of available BIM applications allows them to give a feedback on what is missing in current applications and what they believe can be improved.

- To facilitate the rate of maturity of BIM applications through industry feedback. This in turn should facilitate greater adoption of BIM in practice.

- To provide a computational framework that can be developed and implemented as an interactive computational BIM collaboration management tool to assist BIM managers and similar roles.

3. COLLABORATIVE BIM MODEL SERVERS CASE STUDIES

This section presents case studies of both BIM based and document based collaboration platforms. BIM based collaboration platform includes Seawater Chamber – a controlled test case study conducted within the research team, in which EDMmodelServer™ is used, and the Ark Building Project – an industry case study in which NavisWorks is used to merge different discipline models. Document based collaboration platform case studies include examination of existing online collaboration applications, such as INCITE, Aconex, Team Binder and Project Centre, along with inquiries and interviews at INCITE, Thiess, EDMmodelServer™, Woods Bagot and Sydney Opera House. ActiveFacility, another BIM based collaboration platform was also reviewed from an application features perspective.

The intention was to review the existing processes for implementing and utilising document based collaboration platforms and investigating how they applied when employing BIM based collaboration platforms.

All the case studies were measured against the "AIA diagram for digital design technology in Architectural practice" in order to apply a common grading system throughout. Please refer to the following table:

Table 3.1   Summary of Case Studies: Integration, Software and Purpose

Towards developing BIM Model Technical Requirements			
Case Study	Level of Integration (AIA Grade)	Software	Comments
Seawater Chamber	Level 3 – Integration 3B:webserver	EDM Model Server ArchiCAD Octaga Modeller DDS- CAD Solibri Model Viewer	Experimental case study to test existing model server capabilities towards developing technical requirements
The Ark	Level 2 – Collaboration 2A:1 way 2B: Documents only – no modelling	NavisWorks INCITE ArchiCAD Revit	1. Marketing 2. Presentations 3. Development of O&M Manual to client 4. Not as a collaboration tool during project delivery.
Towards developing an Implementation of a BIM Model Decision Framework			
Case Study	Level of Integration (AIA Grade)	Software	Comments
INCITE	Level 3 – 3B:webserver [potential for BIM model server integration]	INCITE	INCITE web based server from a document management system approach

EDM Model server	Level 3 – 3B:webserver	EDM	Web based server from a CAD approach Little support for project delivery communication and information flow and current work practices
Active Facility	Level 3 – 3B:webserver	ActiveFacility	Web based server from a CAD approach. Designed to provide client/owner with BIM model for facility management Little support for project delivery communication and information flow and current work practices
Woods Bagot	Level 1 – 1A: Modelling Elements of 2A Collaboration	Aconex/FTP Server/Archicad	Potential for Level 3 Integration
Thiess	No levels	Not applicable. In house organisation online guides	Design and construction project delivery Online Best practice project management Guide Potential to integrate work processes to build BIM models and support BIM Model Server Level 3 Integration
Sydney Opera House	Level 1 – 1A: 3D Modelling	Aconex/TRIM [inhouse document management system]	In house local server with BIM model development from a CAD approach. Does not support document management system. Build individual discipline models for facility management Single point of control by building owner which has not moved towards Collaborative nor Integration level

The experiences and findings from case studies will be then used for the development of technical requirements of a BIM model server.

3.1   Seawater Chamber – a Controlled Test Case Study

3.1.1   Case Study Overview

A seawater chamber in an Australian landmark building is used for the case study of BIM based collaboration platform. Different from BIM applications and BIM model server tested in the HITOS study (Eberg et al. 2006) in Tromso University College Norway, which is a new

building project, BIM applications and BIM model server applied to the Seawater Chamber case study is a project of space renovation and re-functioning in an existing building. Therefore, the existing building information, such as the original design drawings, the existing infrastructures in the Seawater Chamber and its spatial relationships with other surrounding spaces become very important and increase the complexity of the project. These complex factors were considered and respected when constructing each individual discipline-specific models and merging the models into an integrated BIM model using EDMmodelServer™.

The two main tasks of this Seawater Chamber case study are (1) the construction of the discipline-specific models and (2) the integration of the models as an integrated BIM model using EDMmodelServer™. Different disciplines involved in the Seawater Chamber case study are architecture, hydraulics, and lighting. Applications applied for constructing these discipline-specific models include ArchiCAD for the architectural model and DDS-CAD for the hydraulic and lighting models. In addition, there are also some applications used for various processes within the case study including Solibri Model Checker, Solibri Model Viewer, DDS-CAD Viewer and Octaga Modeller (a plug-in of EDMmodelServer™ for 3D model viewing).

Figure 3.1 shows the original design drawing of the Seawater Chamber provided by the client. The construction of each discipline-specific model and the development of the integrated BIM model, firstly, were based on the original design drawings to produce the architectural model. The architectural model of the Seawater Chamber was then converted into IFC format, which was subsequently uploaded into EDMmodelServer™. Further the other project partners downloaded the architectural IFC file from the EDMmodelServer™. Based on this architectural model and the original design drawings, they constructed the hydraulic and lighting models respectively and then converted these models into IFC files and checked-in the data in the BIM model server and merged together with the architectural model to produce the integrated BIM model.

Figure 3.1   Design drawing of the seawater chamber provided by the client
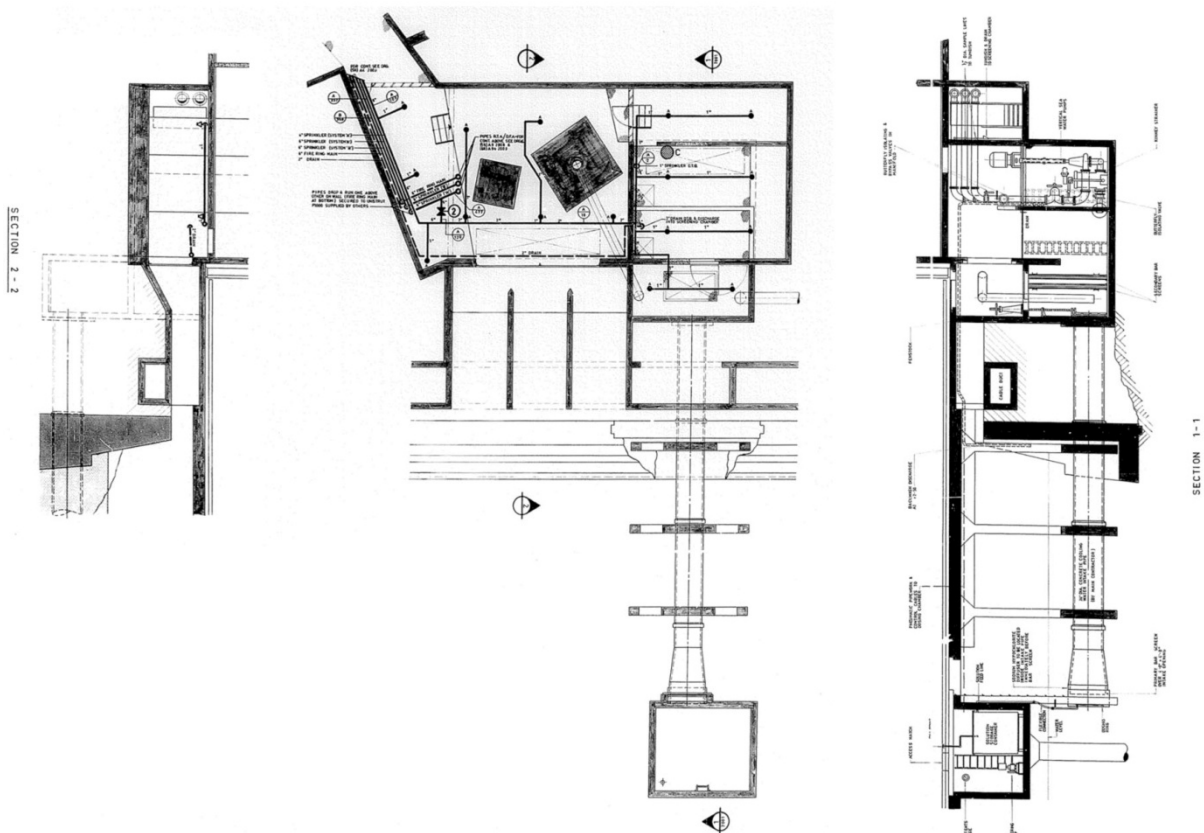
The implementation of the case study focuses on testing the issues of building data visualization, analysis and collaboration. A model consists of numbers of objects which contain different information which can be presented in different forms, such as graphical

representations, schedules and spreadsheets. They comprise the visualization of the model. The integral part of visualization is the ability to access the right information in correct format (Kymmell 2008). Better access to information can improve project understanding, management and control.

Object properties includes component information, parametric information, linked information and external information (Kymmell 2008). Component information is primary visual information which resides in the nature of the model, such as material information or quantitative information including dimension, area and volume. Parametric information is embedded and editable information of the object. It refers to the information that distinguishes one particular component from another similar one. Linked information refers to the information which is not a part of the model but connected to the model through links. For instance, a database of cost information is linked to a model. External information refers to information that is generated and separated from the BIM, such as a construction schedule.

Model analysis based on different features of information is characterized into qualitative analysis, quantitative analysis and sequential analysis (Kymmell 2008). Qualitative analyses include analyses of communication, constructability and system coordination. Constructability refers to a visualization of the methods necessary to construct a project. Quantitative analysis includes analysis of material, energy consumption, construction cost estimation, cash flow and life cycle cost. Sequential analysis includes analysis of assembly and installation sequence and construction schedule and sequence.

A successful collaboration needs practice, discipline and strategic planning (Kymmell 2008). Visualization of a model supports project communication and contributes to project collaboration. Model analysis assists in project evaluation and can potentially reduce construction conflicts, construction waste and project risks and lead to the enhancement of project collaboration.

The testing of the building data visualization, analysis and collaboration for the Seawater Chamber case study includes:

- Object properties, including component information, parametric information, linked information and external information, in discipline-specific models.

- Information links within a discipline-specific model and between different models in an integrated BIM model.

- Visualization, including model representation and data access.

- Analysis, focusing on qualitative analyses and model evaluation that will contribute to design coordination and collaboration.

- Collaboration, for better project communication to reduce construction conflicts and project risks to improve efficiency and accuracy of a BIM Model Sever as a collaboration platform.

3.1.2   Discipline-specific Models

Discipline-specific model constructions in the Seawater Chamber case study include architectural, hydraulic and lighting models. After the architectural model was constructed, converted and uploaded to EDMmodelServer™ in the repository, the architectural model was made available for download and was used as a reference model for constructing the hydraulic model and the lighting model. Different applications are used to construct these discipline-specific models, i.e. ArchiCAD for constructing the architectural model and DDS-CAD for constructing the hydraulic and lighting models. After the hydraulic and lighting models were completed, they were checked-in to EDMmodelServer™ and merged with the architectural model to develop the integrated BIM model. The building information of each discipline-specific model became sharable with other discipline-specific models for project collaboration. Design review of the construction for different discipline-specific models provides data verification to ensure the accuracy of the BIM model. Figure 3.2 illustrates the above model integration process.

Figure 3.2   Discipline-specific model integration
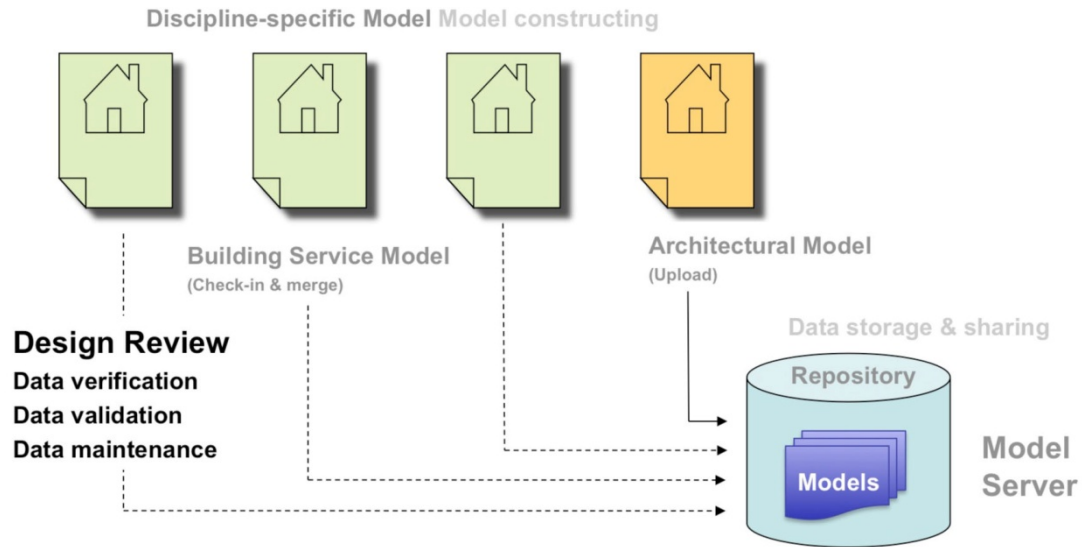
Architectural Model

a. Model construction

Based on the original design drawings, and a partial 3D model provided by the client as shown in shown in Figure 3.3, the architectural model (Figure 3.4) for the case study was constructed using ArchiCAD. The architectural model captured more precise building information for the Seawater Chamber and included surrounding spaces to illustrate spatial relationships. This model was then converted into IFC format and uploaded into EDMmodelServer™, as shown in Figure 3.5.

Figure 3.3   The partial 3D model provided by the client
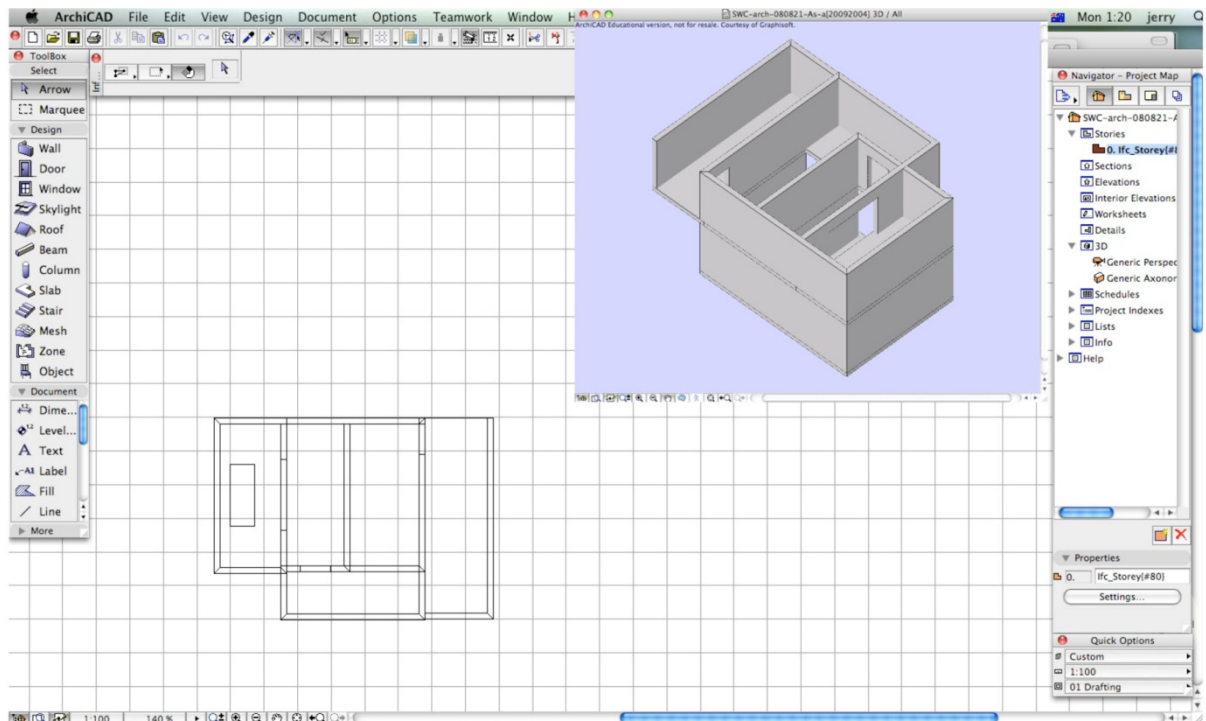
Figure 3.4   Developed architectural model for the Seawater Chamber case study modelled in ArchiCAD
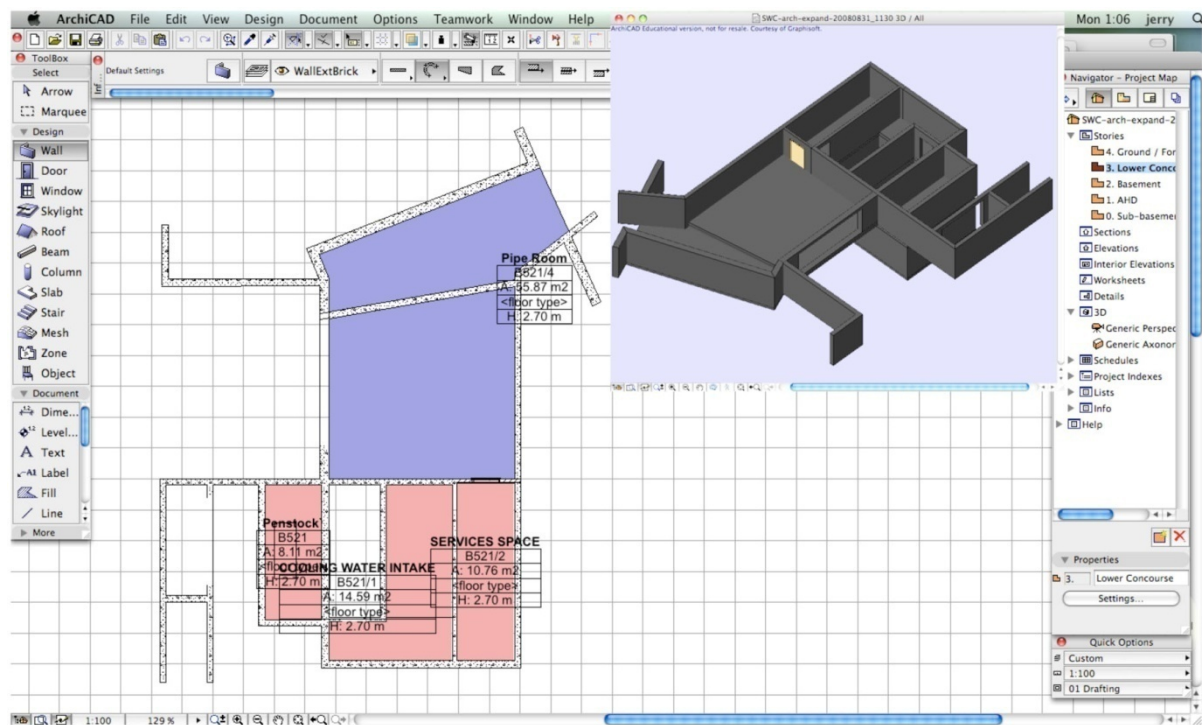
Figure 3.5   The architectural model of the Seawater Chamber uploaded in EDMmodelServer™
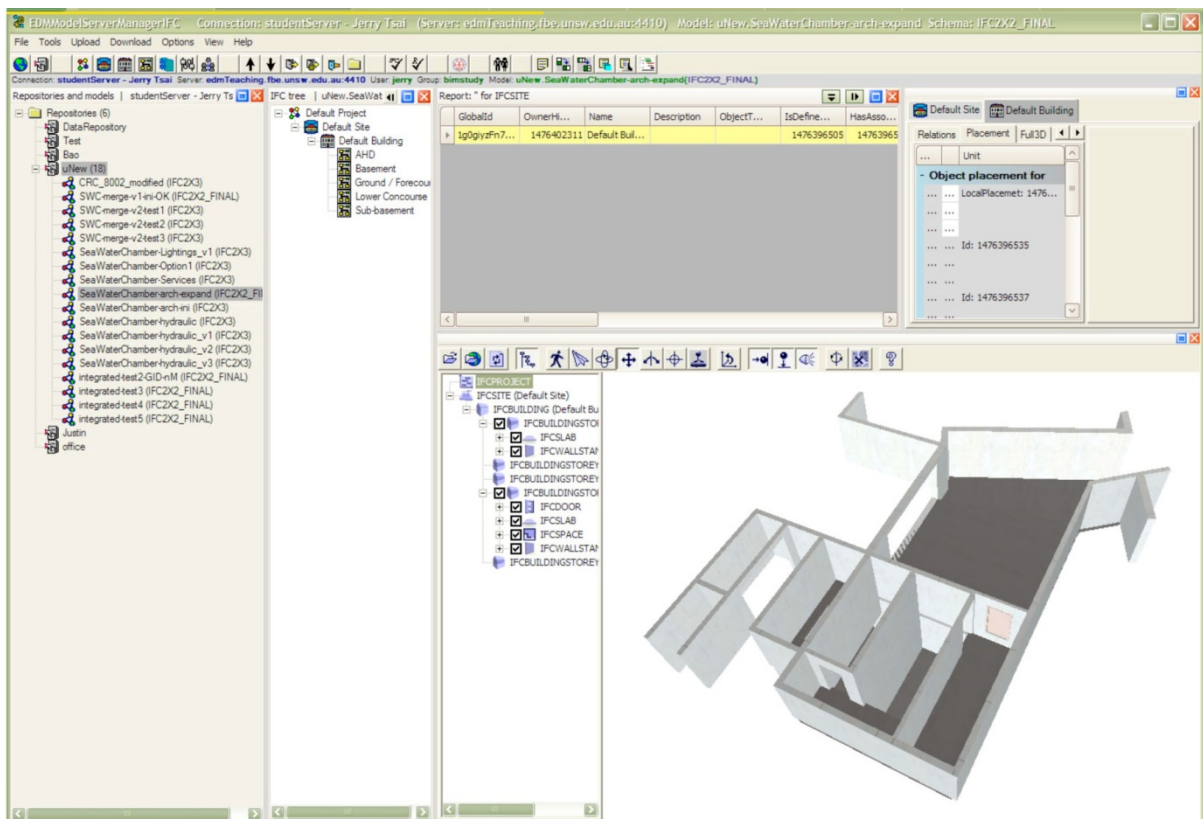
b. Object properties

ArchiCAD is an object-orientated 3D modelling application which provides different functions for defining object properties. The examples of these properties are shown in Figures 3.6 and 3.7 for a slab object, a wall object and a door object respectively. In these two figures,

through Listing and Labelling, various calculations of building information can be performed, for instance,

- ID can be used to track elements for quantity calculations.
- Link Properties enable the use of different criteria for calculations.
- By Criteria assigns variables to special conditions, e.g. element type.
- Matching Priorities displays the property items whose criteria match the current attribute set.

The information in Listing and Labelling can also be used to relate to the linked and external information for further cost estimation and facility management

Figure 3.6   Object properties for (a) a slab object and (b) a wall object
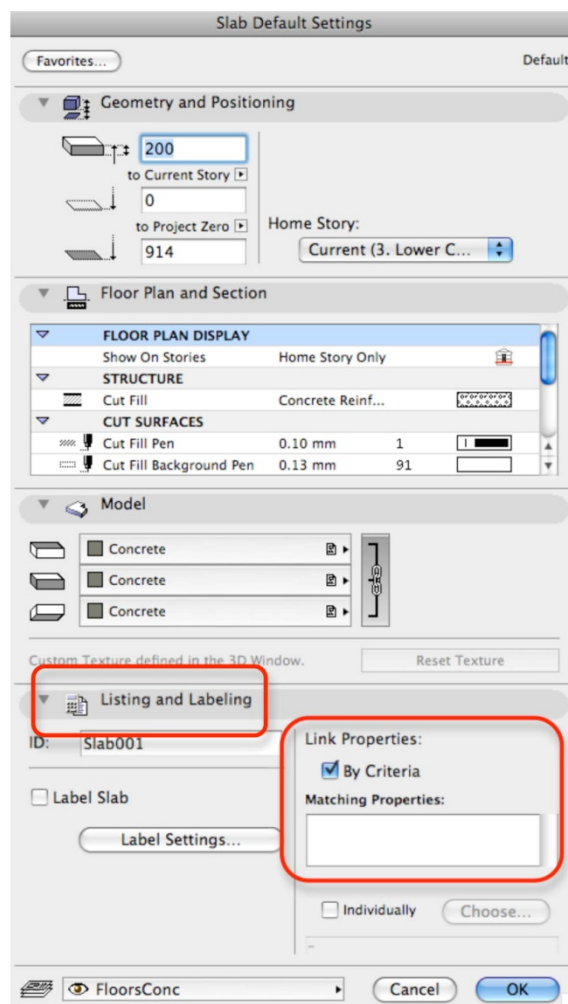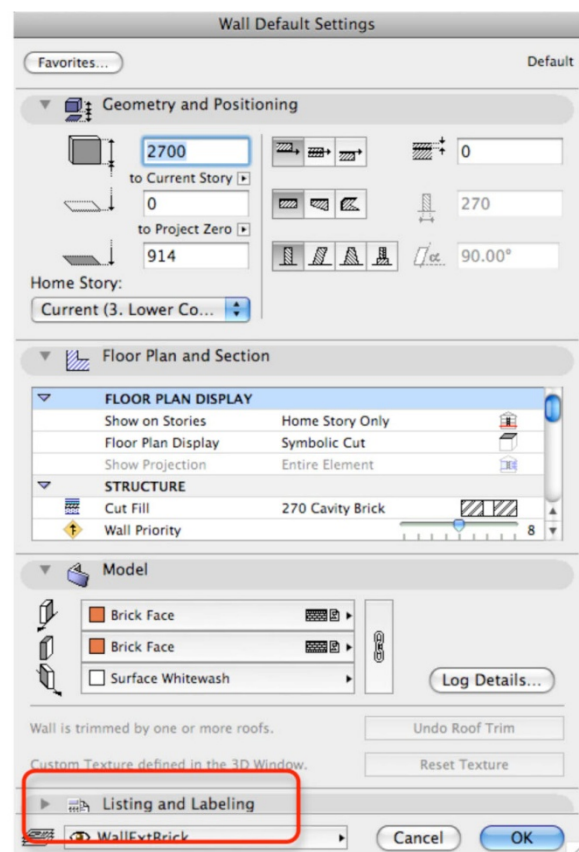
(a)   (b)

Figure 3.7   Object properties for a door object
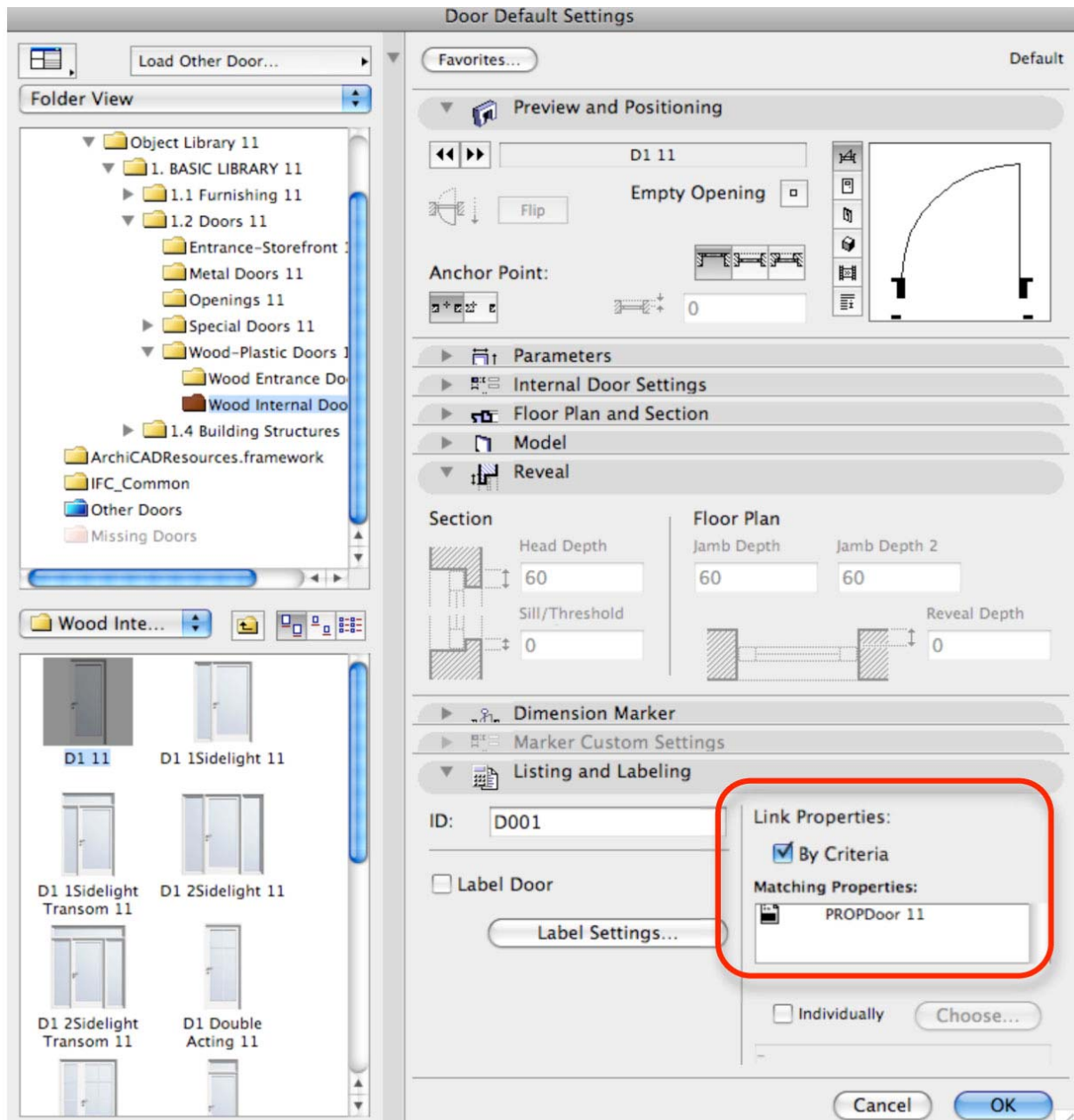
The Seawater Chamber architectural model can be converted directly into IFC format. Figure 3.8 shows the building object hierarchy of the architectural model produced for the case study. The Model Tree on the top left-hand-side of the figure shows different object categories of the model. The bottom left-hand-side of the figure shows detailed information of the object if it is selected. The 3D view of the architectural model is shown on the right-hand-side of the figure.

Figure 3.8   The Seawater Chamber architectural model in Solibri Model Viewer
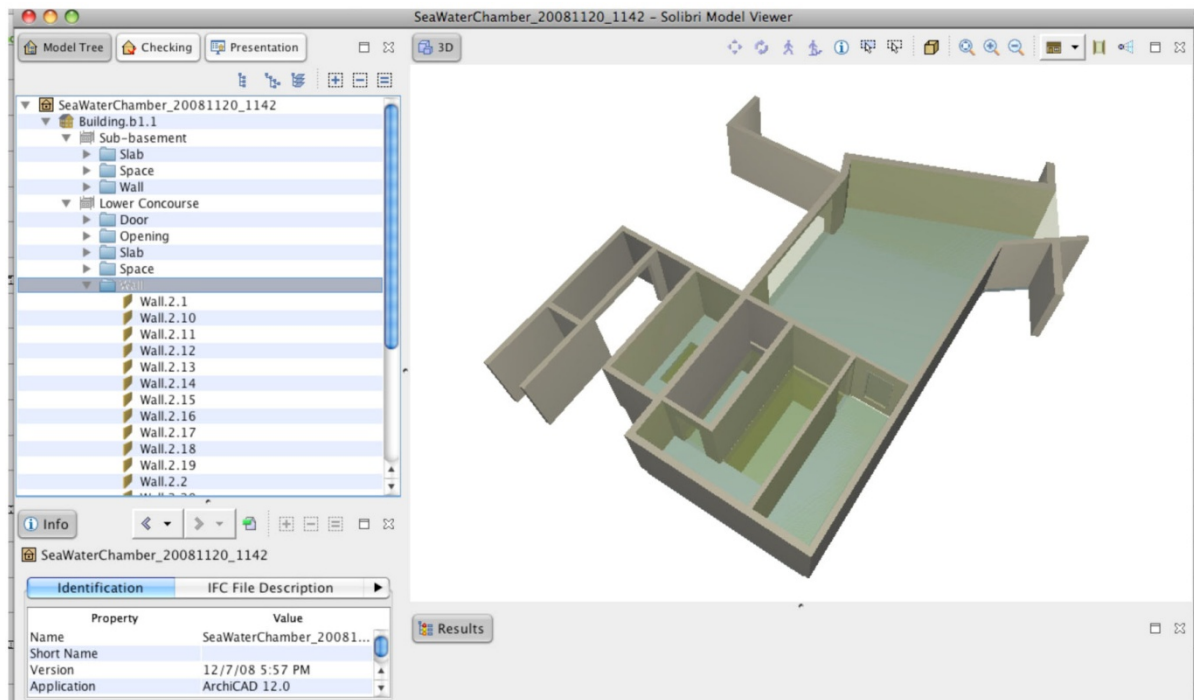
Hydraulic model

a. Model construction

The Seawater Chamber hydraulic model was developed based on the original design drawings as shown in Figures 3.1 and 3.9. The architectural model downloaded from EDMmodelServer™ was used a reference model. The model was constructed using Data Design System (DDS-CAD). DDS-CAD is a CAD solution in the construction industry for the design and documentation of electrical, HVAC and plumbing systems. It is capable of object-based modelling of facilities. With support for DXF/DWG export and IFC integration, DDS-CAD provides the basis for integrated multi-disciplinary planning and design. Figure 3.10 shows the developed Seawater Chamber hydraulic model uploaded in EDMmodelServer™.

Figure 3.9   Design drawing of the hydraulic system and chemical dosing equipment of the Seawater Chamber, provided by the client
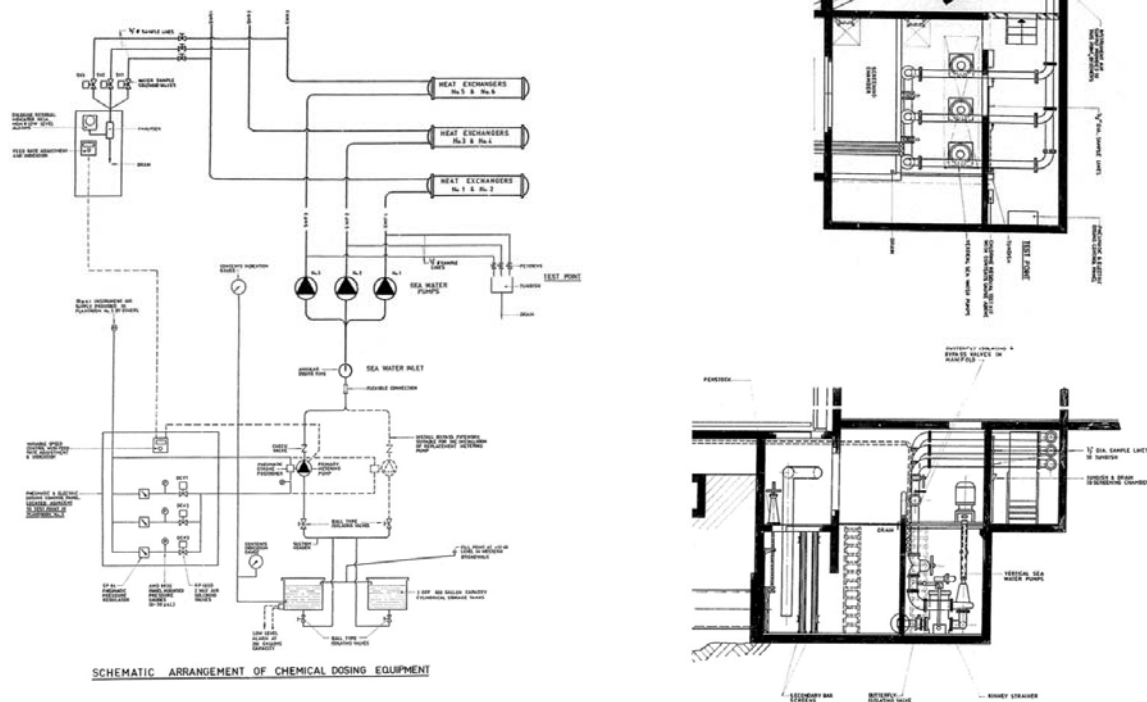
Figure 3.10   The hydraulic model of the Seawater Chamber uploaded in EDMmodelServer™
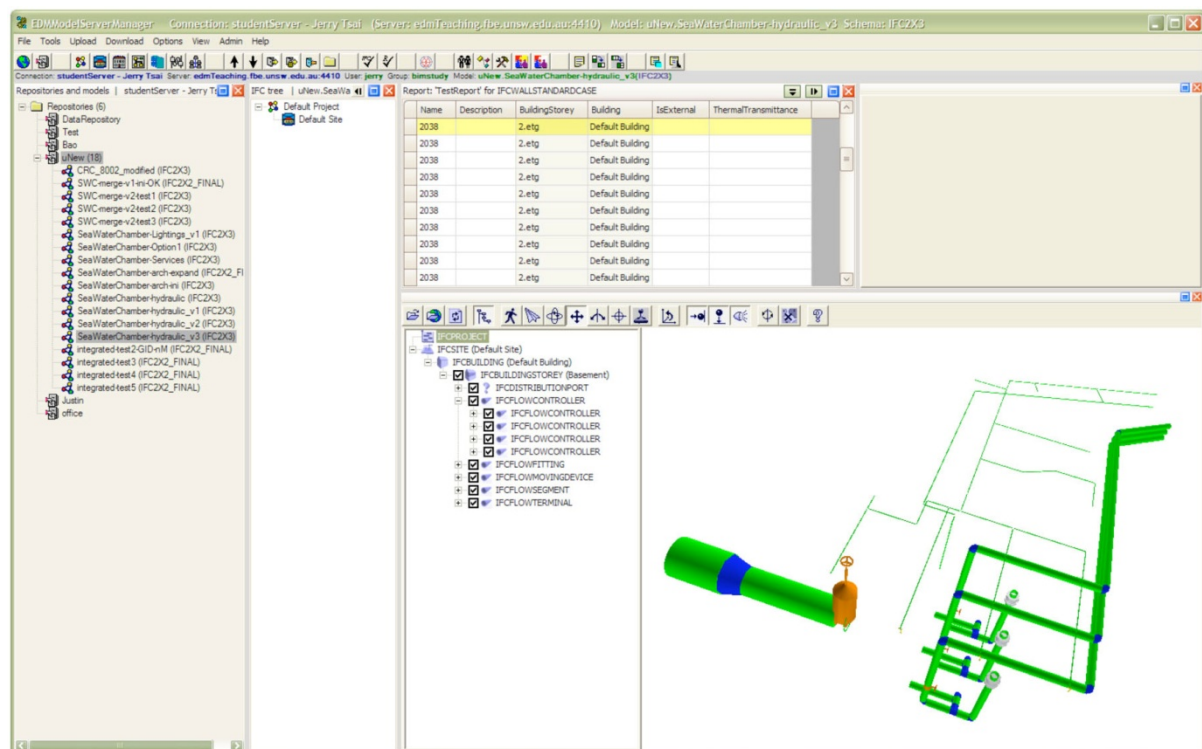
b. Object properties

The hydraulic model of Seawater Chamber is constructed using DDS-CAD. DDS-CAD for hydraulic and HVAC provides functions for creating and modifying different object properties. Figure 3.11 shows an example of the settings of an air handler unit (AHU) in a HVAC system.

Figure 3.11   Property settings of an air handler unit (AHU) in DDS-CAD (image taken from DDS HVAC
　　　　　　　 Partner Training Guide)
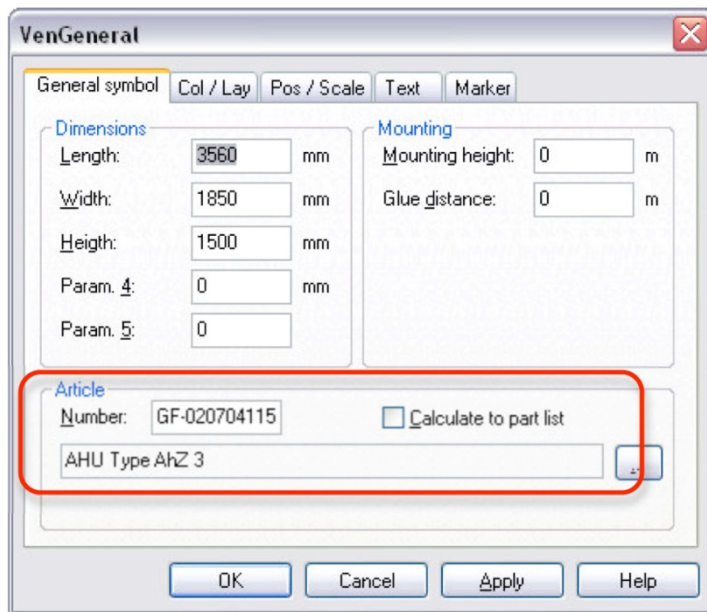
Figure 3.11 Property settings of an air handler unit (AHU) in DDS-CAD (image taken from DDS HVAC Partner Training Guide)

Figure 3.12 shows different object categories of the Seawater Chamber hydraulic model including flow terminal, pipe, pipe fitting, pump and valve (top left-hand-side of the figure), and their 3D view (right-hand-side of the figure).

Figure 3.12   Seawater Chamber hydraulic model in Solibri Model Viewer
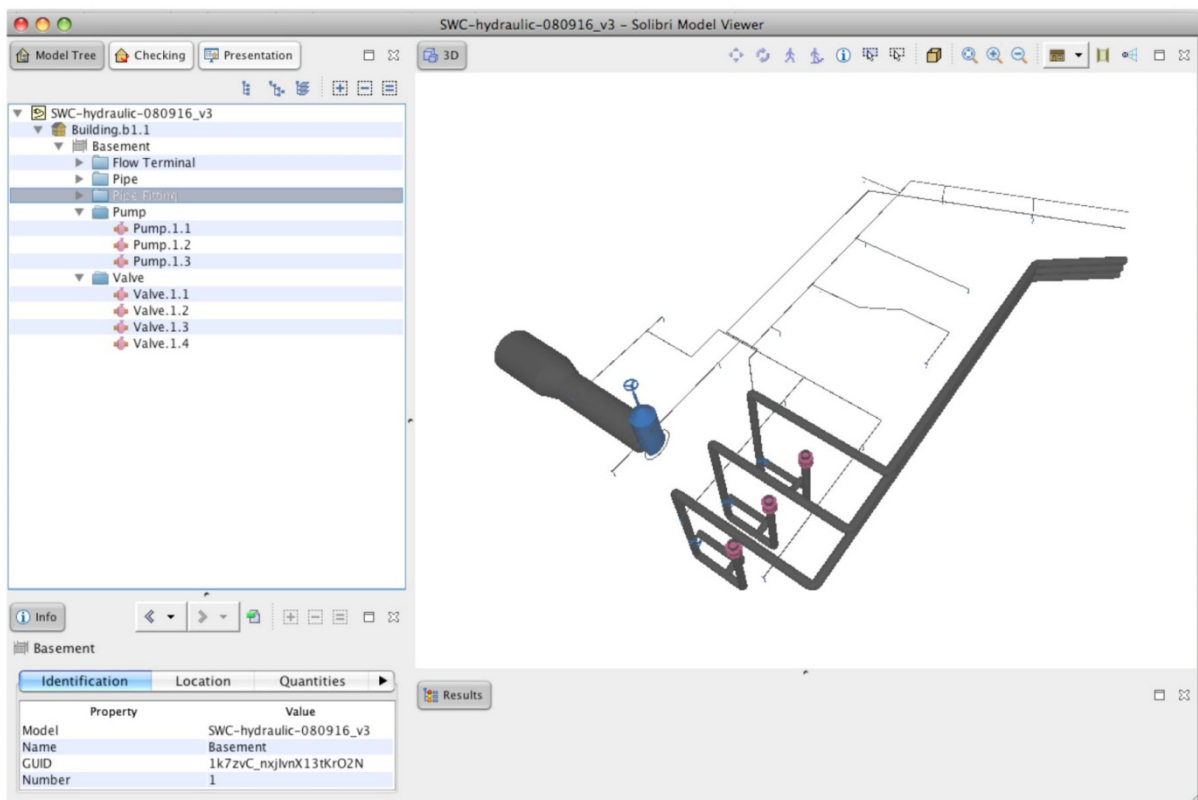
DDS has both modelling and calculation tools. By providing parameter values of objects, the model can be applied for hydraulic energy simulation. However, the hydraulic model should be a closed system which means that every object within the model needs to be connected with other objects.

Lighting model

a. Model construction

The development of the Seawater Chamber lighting model was based on the architectural model as the reference, downloaded from EDMmodelServer™. Due to a lack of detailed information of the lighting system, this model was only a simplified model. Nevertheless it captures key elements of a lighting model and is suitable for demonstration purposes in the case study. The model is developed using Data Design System (DDS-CAD Electrical). Figure 3.13 shows the developed Seawater Chamber lighting model as uploaded in EDMmodelServer™.

Figure 3.13 The lighting model of Seawater Chamber uploaded in EDMmodelServer™

b. Object properties

Similar to DDS-CAD for hydraulic and HVAC, DDS-CAD Electrical also provides functions for creating and modifying different object properties. Figure 3.14 is an example for inserting a light object into the lighting model.

Figure 3.14   Property settings of light fittings to be inserted into DDS-CAD

Figure 3.15 shows different object categories of the Seawater Chamber lighting model including cable carrier, cable carrier fitting, duct fitting, light fitting, lighting fixture and switching device (top left-hand-side of the figure). Their 3D view is shown on the right-hand-side of the figure.

Figure 3.15   The seawater Chamber lighting model in Solibri Model Viewer
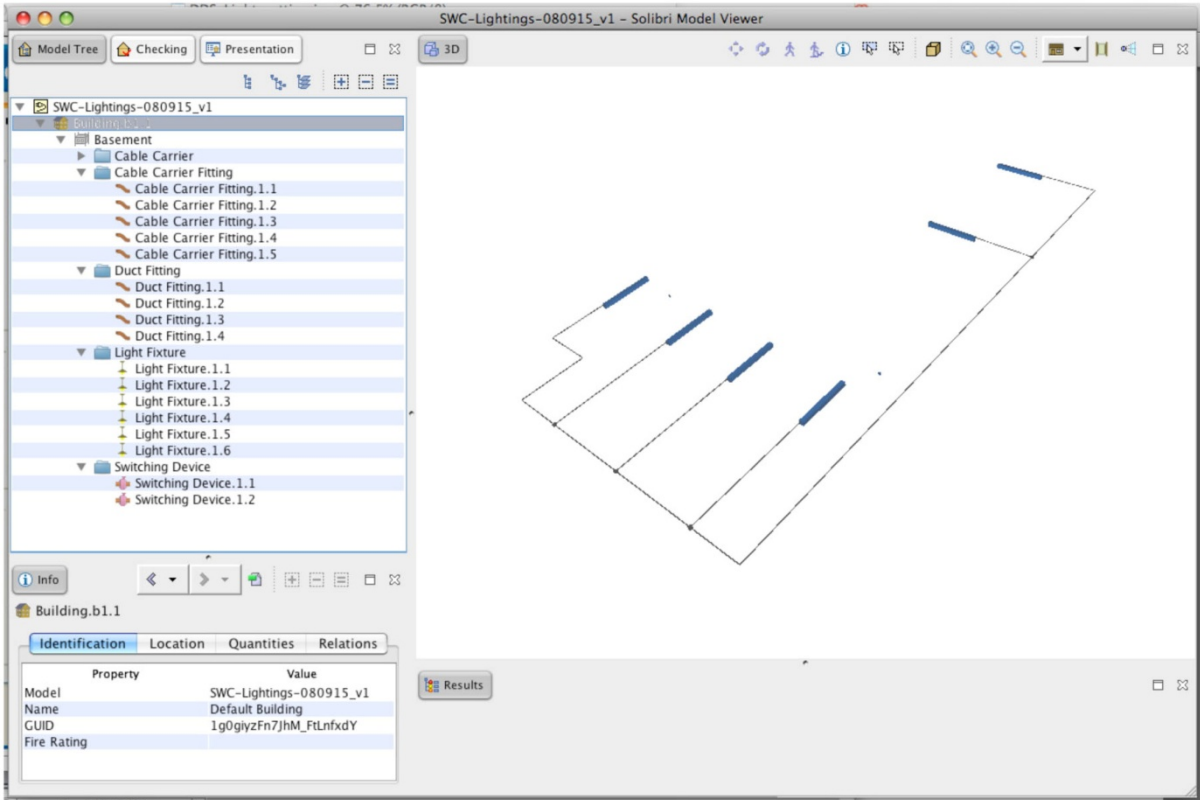
In addition, DDS Electrical provides a built-in light calculation function based on the simple lumen method of calculation. For light calculation, different information and parameters are needed including room data, article data and placing of articles (Figure 3.16).

Figure 3.16   Different parameter values needed for light calculation, as supported in DDS-CAD

3.1.3   Integrated Model in EDMmodelServer™

The BIM model server platform used in the case study was EDMmodelServer™, which supports functions of user control and access, model and data management. Octaga Modeller is used in conjunction with EDMmodelServer™ for 3D model viewing. Solibri Model Viewer and DDS-CAD Viewer were also used in conjunction for viewing specific models and checking object information and relationships in the model. Solibri Model Checker is used in model checking for data verification. Design review of the construction for different discipline-specific models provides data verification to ensure the accuracy of the BIM model. Figure 3.17 shows the integrated BIM model in EDMmodelServer™ that enable building information integration and sharing across disciplines.

Figure 3.17   The integrated BIM model
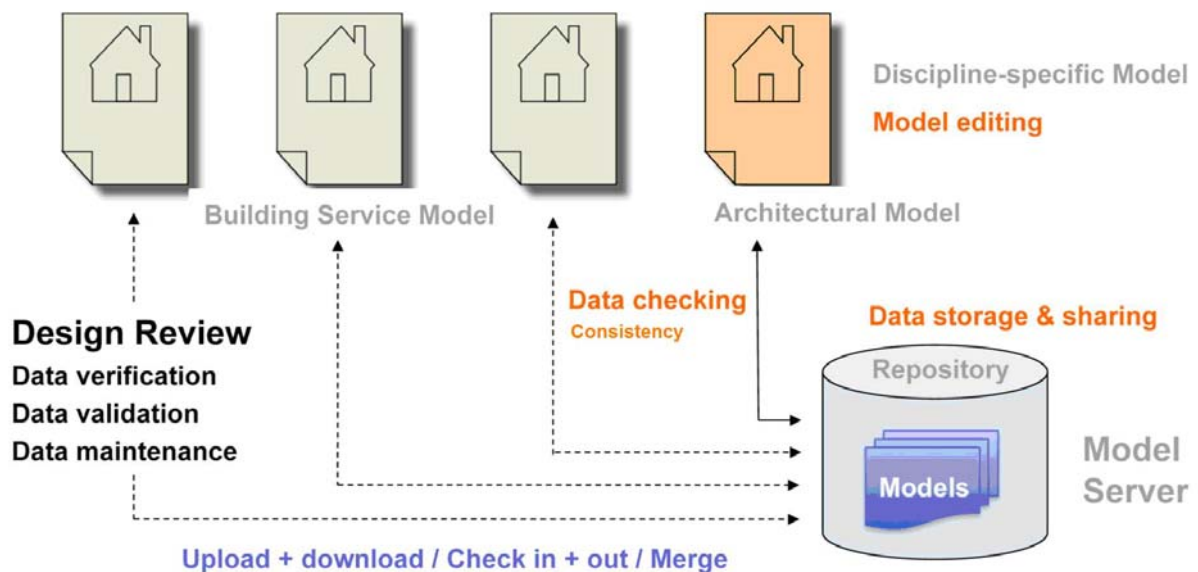
EDMmodelServer™ as a Collaboration Platform

Issues regarding the integration of IFC files of different discipline-specific models into an integrated BIM model in EDMmodelServer™ include:

- IFC name settings

- Security management (e.g. user control and authority settings)

- Model management

- User interface

- Data management (e.g. object properties and IDM - Information Delivery Management)

Spatial Containment Identity: The spatial containment model of IFC is a hierarchy: project, site, building and building storey(s). For successful model synchronisation the GUID (....) must match. For example when the hydraulic sub-model from DDS-CAD was uploaded to the model server, in order to merge it with the architectural model, the GUID of each spatial entity must match.

IFC name settings: Before merging different IFC files, it is very important to confirm the consistency of IFC names in each discipline-specific models. Normally, IFC names are set in the modelling applications for each discipline. They can also be modified by editing the IFC files. The following IFC name settings were used for the Seawater Chamber case study:

ifcProject : CRC Project 1

ifcSite : CRC

ifcBuilding : CRC Building

ifcBuildingStorey : Basement

Security management functions control the access settings of repositories, users and groups. Figure 3.18 shows user, group and access maintenance controls in EDMmodelServer™. Different access rights to the building information can be set including the rights to create, delete, execute, private, write, read and none.

Figure 3.18   User, group and access maintenance controls in EDMmodelServer™ as applied in the Seawater Chamber case study
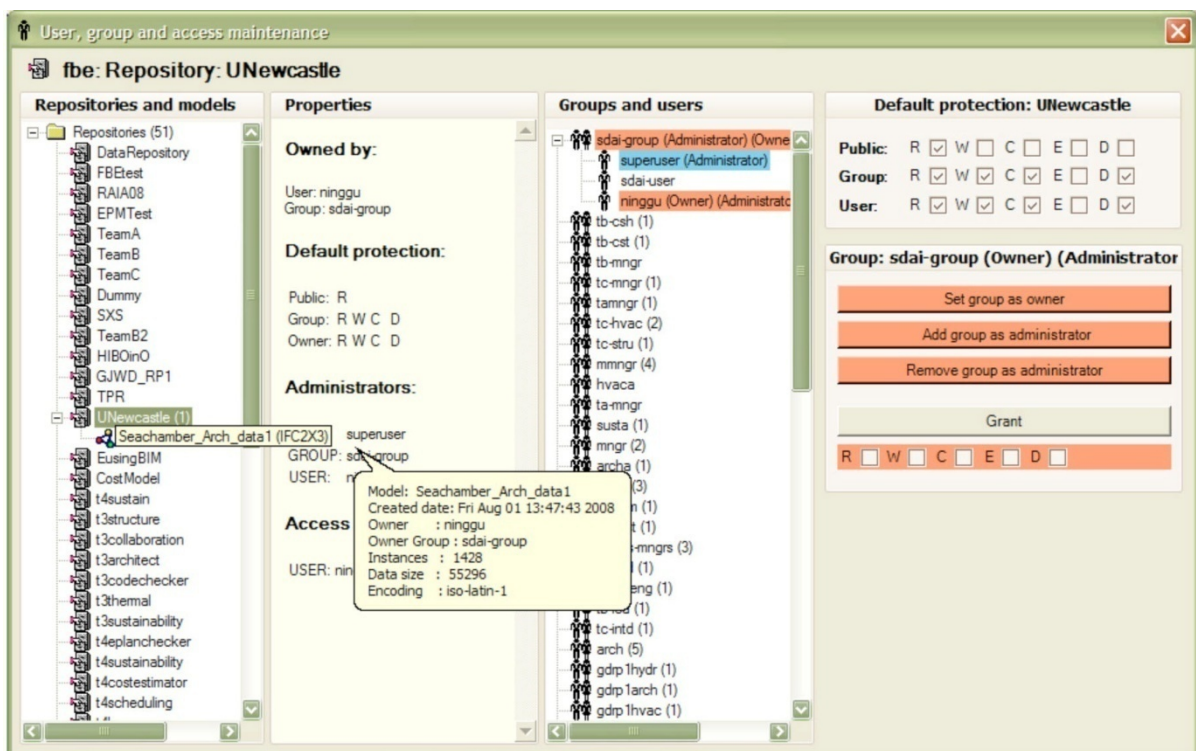
To login to EDMmodelServer™, users must provide information such as user name, user group, password and settings of Host and Port (Figure 3.19), which provides controlled access to the database.

Figure 3.19   Login control of EDM Model Server
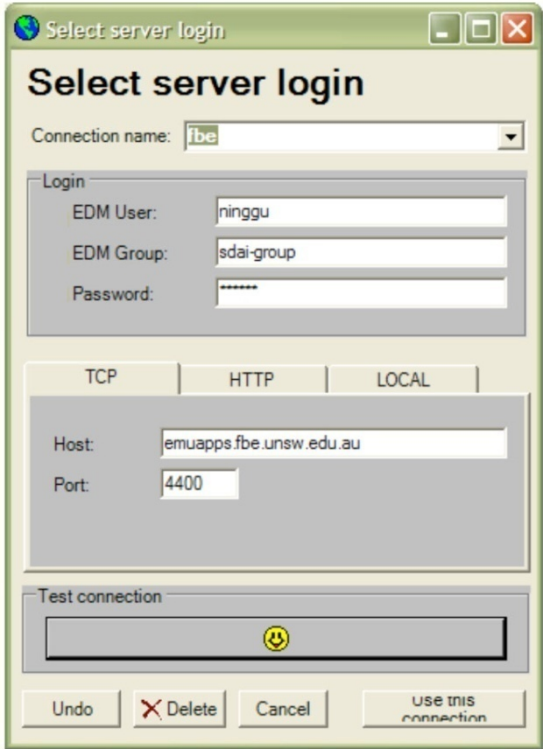
Model management supports different means for managing the BIM model and data sets. The main features in this category are listed in Figure 3.20.

Figure 3.20   Managing models in EDMmodelServer™ (image taken from EDM Model Server User Guide)

Function	Menu item	Button	Drag & Drop
upload file	**Upload>Upload IFC file** populate a model with a new IFC file or make a new version of same model	↑	yes
download file	**Download>Download whole model** download the complete model	↓	yes check-out the model from the selected node
check-out	**Download>Check-out whole model** checkout the complete model		yes checkout (full or) partial model, optionally with locking
check-in	**Upload>Check-in IFC file** merge a modified or new partial model		yes, with **Options>Do immediate check-in/ merge on file-drop** set.

User interface of EDMmodelServer™ consists of two main parts, including text-based information windows and a 3D model viewer (Figure 3.21). Octaga Modeller is the plug-in software that enables viewing of the 3D model. Text-based information windows present information for:

- Repositories with different models.

- IFC Tree with different hierarchies, such as Project, Site, Building and Story.

- Report for Project, Site, Building and Story.

- Detail object information.

65

- IFC Browser

Figure 3.21   User interface of EDMmodelServer™
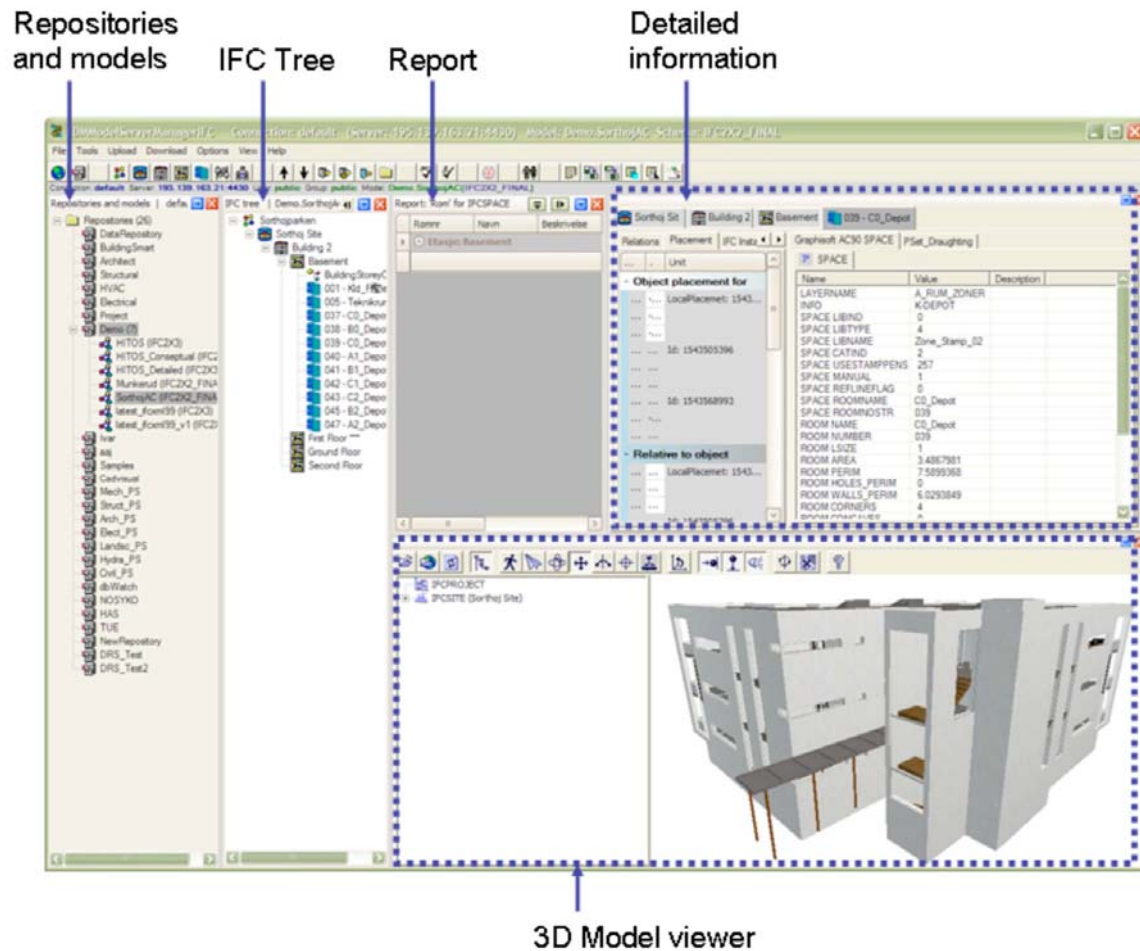
Data management of EDMmodelServer™ include features for managing object properties and information delivery management (IDM). These details can be applied for further applications, for instance, cost estimation and construction management.

Figure 3.22   Presentation of building information in different views for data management
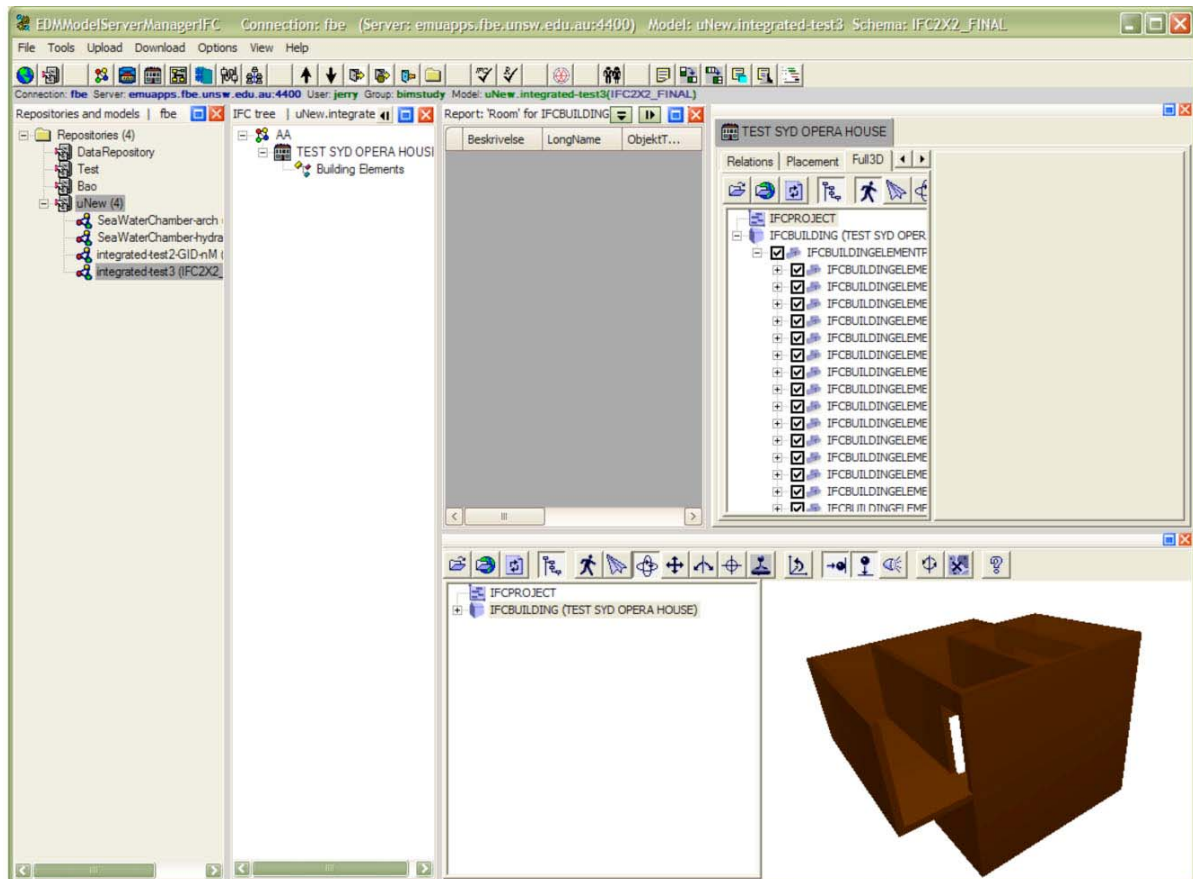
Information delivery management (IDM) defines processes and user specifications to audit model data and server transactions. IDM in EDMmodelServer™ is defined by a script and stored in the Admin Menu of EDMmodelServer™. Figure 3.23(a) shows three IDMs of EDMmodelServer™. Exchange requirement definitions and individual clusters of IDM are written in ExpressX and are editable. An IDM is associated with an import or export in the dialogue to act as a filter on the exchange (Figure 3.23(b)).

Figure 3.23   (a) IDM defined in EDM Model Server and (b) IDM being a filter for data exchange in EDMmodelServer™
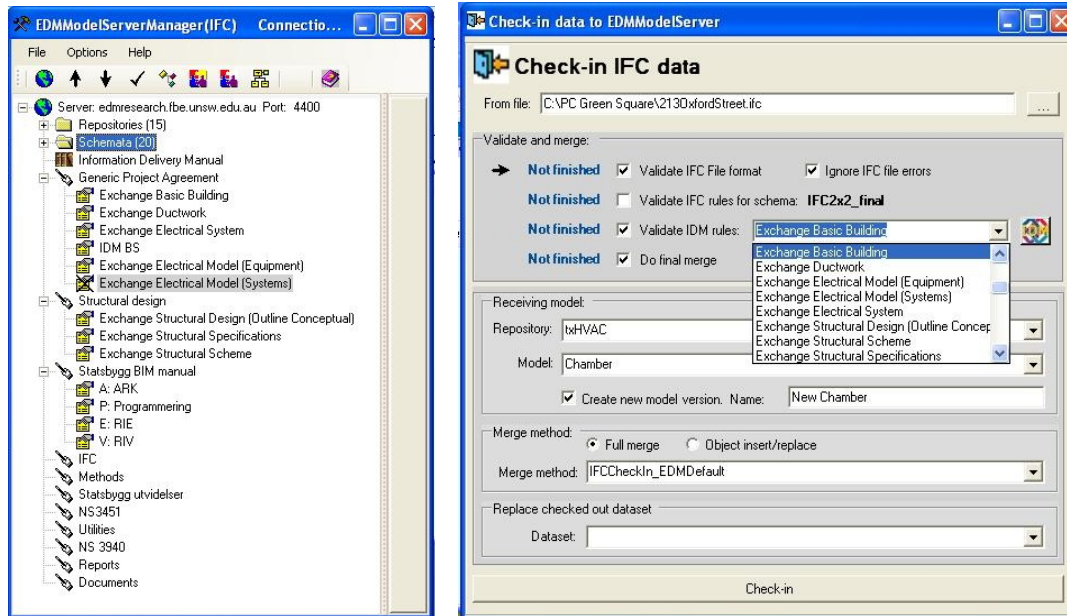
Figure 3.23 (a) above shows several generic collaboration processes: for example *Exchange Basic Building* - an Architect sharing with engineering consultants, *Exchange Structural Design (Outline Conceptual)* - a structural Engineer collaboration with an Architect and, several other options. While many of these may be generic, it is likley there will be national and project specific versions required.

Figure 3.23 (b) shows an import of a complete building model to be checked by the *Exchange Basic Building* IDM, ensuring that all information sought is provided in the IFC data.

Seawater Chamber Integrated Model in EDMmodelServer™

As discussed earlier, the Seawater Chamber case study consists of the three disciplines, architecture, hydraulics and lighting. By using different modelling applications, three discipline-specific models were constructed and then converted into IFC files. To merge IFC files of these models in EDMmodelServer™, firstly, the architectural model is uploaded into EDMmodelServer™ in a model named UNew that stands for the University of NEwcastle. In the UNew directory of repositories, the hydraulic and lighting discipline-specific models are then checked-in to UNew model and merged with the architectural model to form the Seawater Chamber integrated BIM model, as shown in Figure 3.24.

Figure 3.24   The Seawater Chamber integrated BIM model in EDMmodelServer™
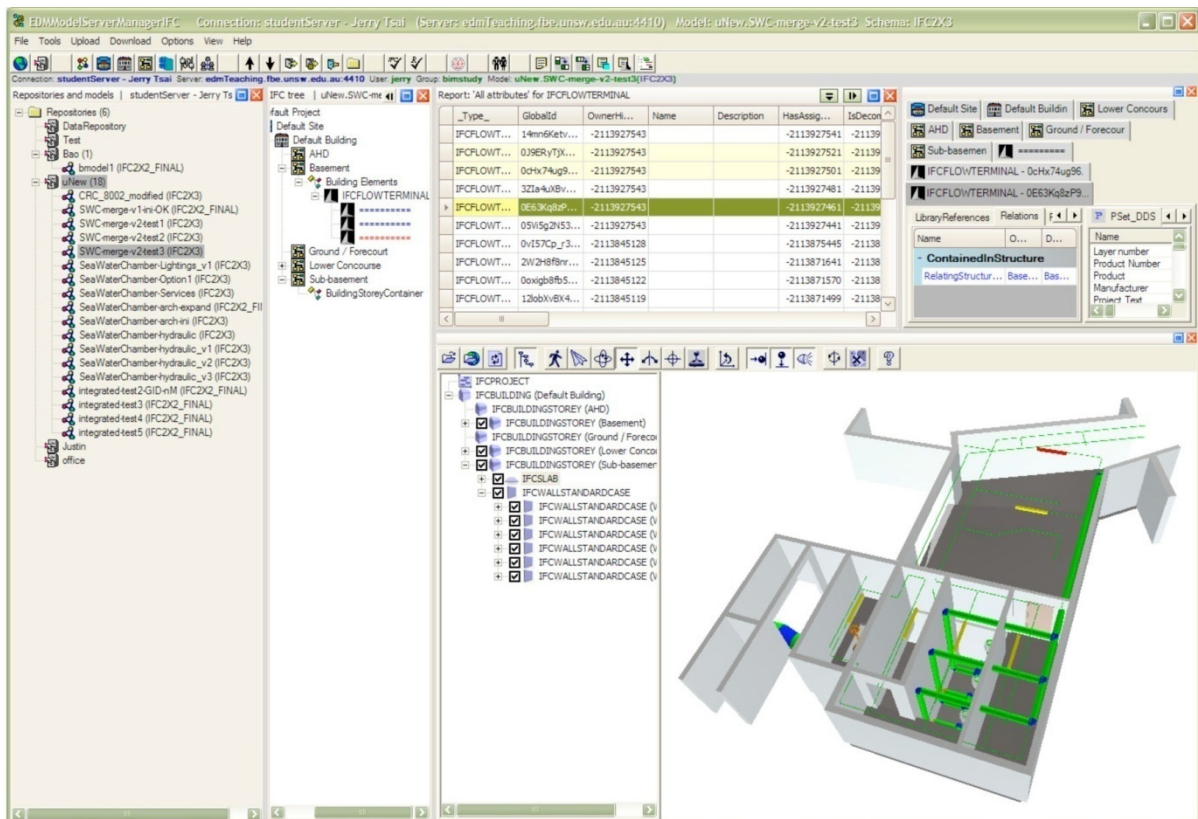
In developing the Seawater Chamber integrated model, some problems were encountered. They are discussed in the following section, which become a part of the base for developing the technical requirements to be presented in the end of the report.

3.1.4   Discussion

The problems encountered in developing the Seawater Chamber integrated BIM model are discussed in the following categories.

- Setting up a BIM model servers using EDMmodelServer™.

- Help function and tutorial.

- User interface control.

- Data management (including object duplication, conflict control, data back-up and system upgrade).

- Extended functions (such as communication supports and other plug-ins).

Setting up BIM model servers using EDMmodelServer™

EDMmodelServer™ is a database that enables building information to be integrated and shared using IFC controls (Mitchell and Jorgensen 2007). Key aspects of the model server include"

- Discipline (partial models/views), and ad hoc queries

- Merge function

- Concurrent usage

- Team members' rights / security

- Speed / performance / integrity

- Version control

- Transaction processing

- Audit (user's roles, decisions, and issue tracking)

- Data protection (mirroring/ back-up)

- Storage

To set up a BIM model server in EDMmodelServer™ and maintain the server, a vast range of knowledge including the concept of BIM, EDMmodelServer™ installation, EDM database creation, user control, IFC entities and so on are required. The knowledge will also need to be combined with specific domain knowledge of the disciplines. Therefore, the tasks are challenging for industry practitioners who often work within their own disciplines.

Help function and tutorial

Jotne EPM Technology provides a help function in EDMmodelServer™ and a helpdesk available through email and telephone. However, problems are often encountered only when wrong and/or incomplete data are entered into EDMmodelServer™. More help functions for integrating the use of discipline-specific applications with EDMmodelServer™ should be provided.

User interface control

User interface in EDMmodelServer™ is very complex which can cause novel user difficulties in understanding and applying EDMmodelServer™. In addition, different users e.g. contractors, facility managers and designers may have different expectations about the application which will require different standard interface profiles for different disciplines. Currently, different data and information are shown and limited in one single window. A more flexible and user-friendly interface is provided is needed.

Data management

Issues under data management include object duplication, conflict control, data back-up and system upgrade.

In EDMmodelServer™, objects are generally well defined and operated in each model. However, during model integration, object duplication or model conflict may occur especially when the same object is created in parallel in different discipline-specific models. Data back-up is very important, especially when the Model Server crashes. Database should be backed up online at regular intervals. The upgrades of EDMmodelServer™ are organized in downloadable modules. If a new version is available, a message from the application provider will notify the users when they login to the application.

Extended functions

Other extended functions such as communication supports need to be considered to support the seamless collaboration of the project. This wish list of extended functions is provided in the end of the report as a part of the technical requirements.

3.2 The Ark Building Project – Industry Case Study

3.2.1 Case Study Overview

The Ark Project is a 21-level office tower and will be located at Mount Street, North Sydney, NSW. It will have large cantilevered floors at the upper levels and a stepped façade integrating external terraces. In this project, a 3D Building Information Model (BIM) is being developed, which will combine all the design and as built information about the architecture, services and fit outs in the building. The Ark Project will be among the first buildings to be delivered using the BIM system incorporating IFC models.

The following image details the project's intended BIM use.

Figure 3.25   BIM usage in the ARK project
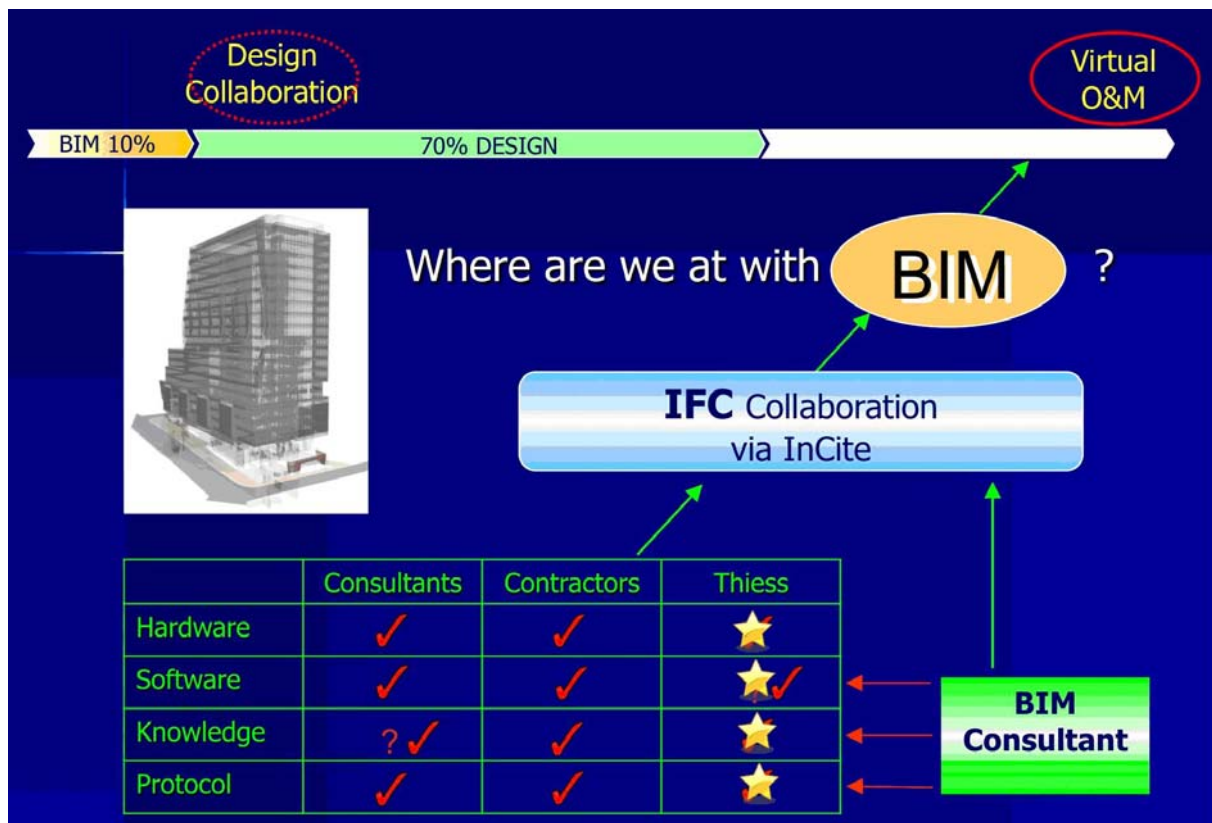
The project has employed a BIM Consultant to ensure the design consultants, contractors and Theiss have the hardware, software, knowledge and protocols in place to create a collaborative BIM platform for use during the design and operations and maintenance phases. The design consultants are to issue their IFC files via a document based collaboration platform, INCITE. Once the IFC files are available on INCITE, Thiess' BIM manager downloads them into the Navisworks server located in the Thiess project office. Changes to the IFC files are communicated via INCITE and the design consultants amend and reissue their files via INCITE. In this instance INCITE is tracking the versions of the IFC files.

3.2.2 Discipline specific Models

Thiess' Model Collaboration Guide, prepared by the BIM Consultant CQR, outlines the requirements for design consultants to create and distribute IFC models:

This Guide sets out a method for multi-disciplinary BIM collaboration on the ARK project using open standard IFC format models. The objective is to develop an integrated Model environment that allows each participant in the project to reference all the other project models, and to export their discipline model. Collaboration models are created in IFC format to allow all participants working on the project to share the model in a common

71

neutral data exchange protocol.

The reasons for using a collaborative BIM platform for the Ark are to:

- Enable direct coordination between all the design consultants and service contractors;

- establish a 4D model for construction schedule review and optimisation; and

- virtually eliminate clashes between the building elements and services.

The discipline-specific model constructions in the Ark Project include architectural, structure, mechanical, electrical, fire services and hydraulic models. The design consultants are:

- Rice Daubney – Architecture

- TTW - Structure

- Hastie - Mechanical Services

- Heyday - Electrical Services

- Axis - Hydraulic Services

- Wormald - Fire Services

These organisations are using either ArchiCAD or Revit-MEP to create their IFC files. The remaining organization, Thiess, who will use the model for construction scheduling and Investa, the client, who will uitilise the model for asset management purposes.

The Guide outlines the steps involved to create the architectural or Master Model in ArchiCAD and how to export in IFC format. The collaboration sub-models for each of the specific design disciplines, are also to convert their ArchiCAD files to IFC and then hotlink it to the master model. The building services, HVAC, electrical, hydraulics and fire models are prepared in Revit-MEP. The services models are classified as collaboration sub-models and need to be hot linked back to the master model after converting to IFC format.

3.2.3   Integrated Model using NavisWorks and INCITE

Once the files are in IFC format, each design consultant must submit them to Thiess via a document collaboration platform, INCITE. The model manager for Thiess collects the models and merges them into Navisworks.

NavisWorks is used as a collaboration platform. It can read different file types from various sources, import and handle large files, combine different file types into the same file together successfully, and facilitate graphical communications across the entire project team. The primary function of NavisWorks is to provide 3D model interoperability for the building design and construction field.

Figure 3.26   Sub-models merged in NavisWorks
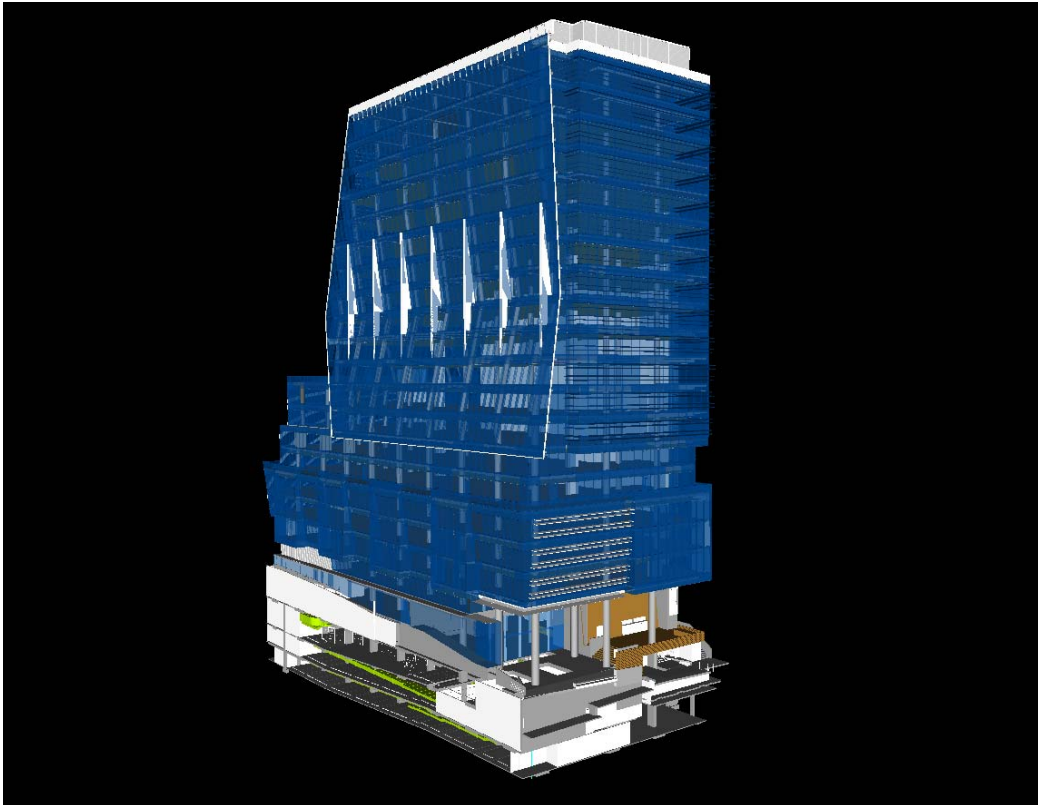
Figure 3.27   B2 Sprinkler Tank Room
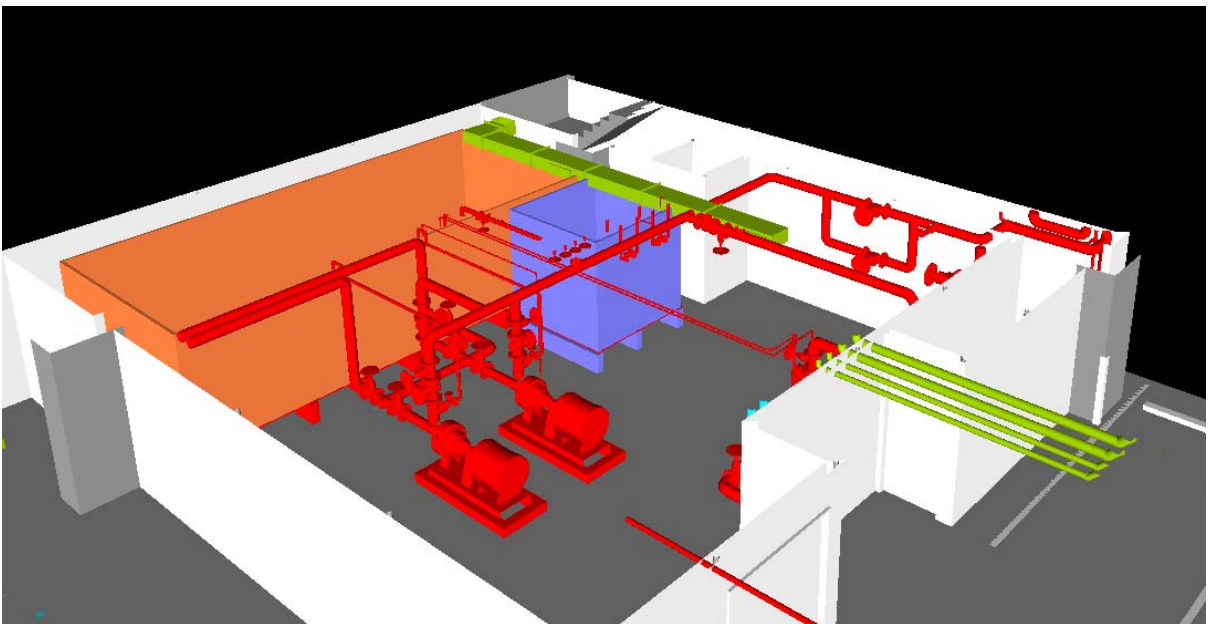
Figure 3.28   B3 Platform
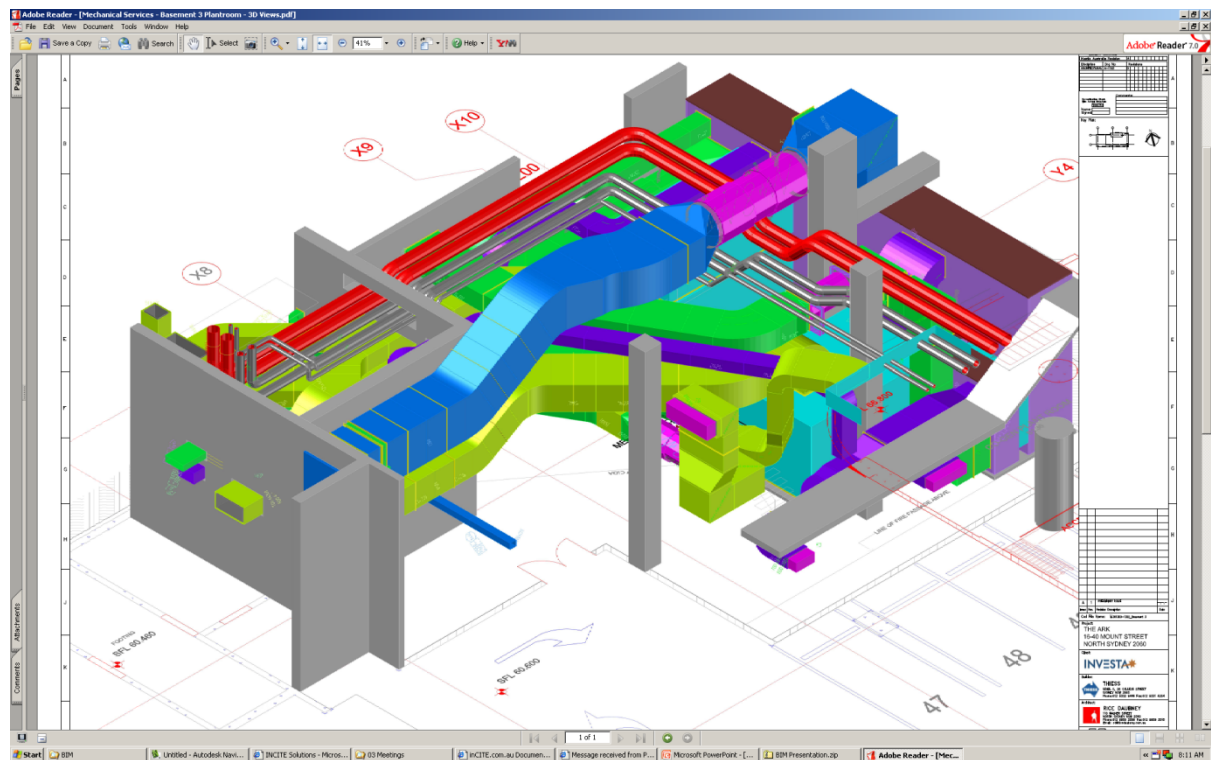
Figure 3.29   Level 9 Ductwork
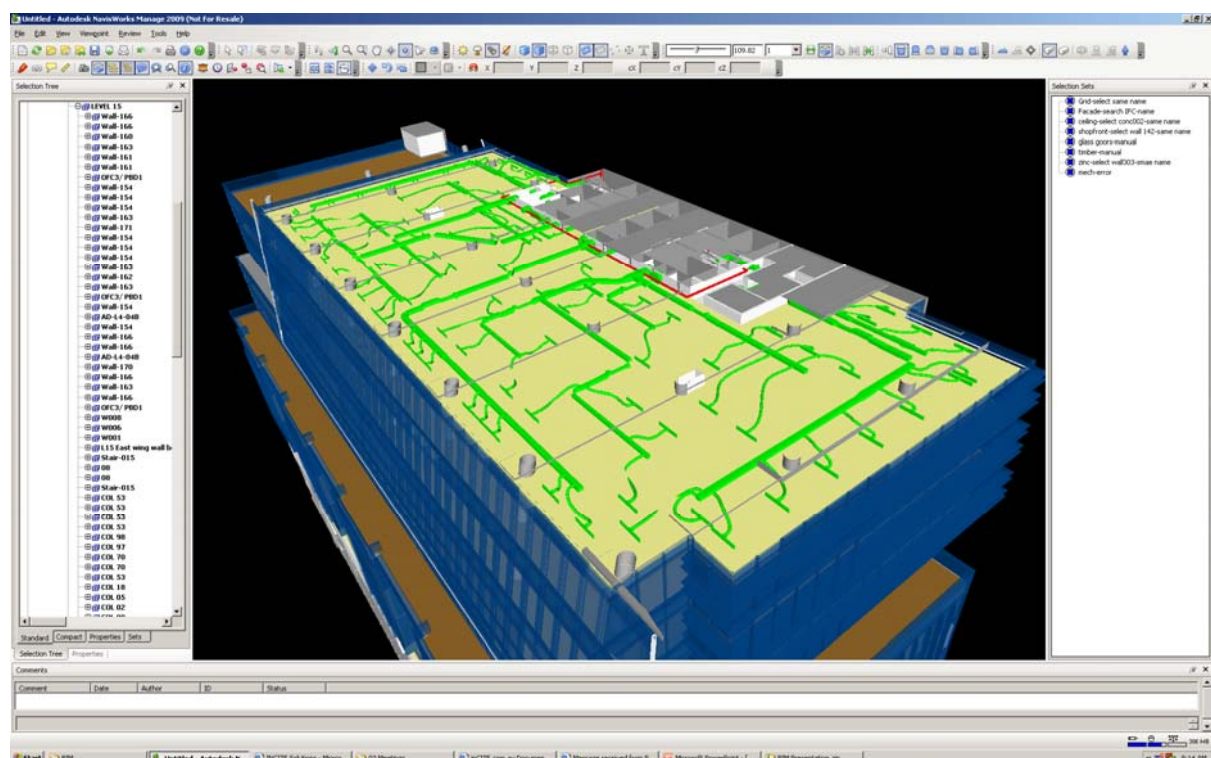
3.2.4   Key Findings on the Use of Collaborative BIM

The Design Manager for Thiess explained that originally the BIM was used for marketing and presentation purposes. Recently, it has been used for coordination / collaboration between the architectural, structural and services models. The client wants the model at the end of the project to represent what they would normally receive as an O&M Manual. Parts of the model

will be linked to other 2D data for information. For example, the client would click on the water tank and a specification (in pdf format) would appear.

INCITE is the repository for the IFC files. The BIM Manager then downloads the IFC files from INCITE and puts it into NavisWorks which they use for their collaborative BIM platform.

The experience of the Design Manager and the BIM Manager has led them to agree that commercially IFC models are not that well thought out. The consultants are having compatibility problems because IFC is not a mature technology. Therefore the Ark project is using the model to review what they have already done, rather than how they are doing to design and build the job.

The major drawback for the BIM Manager is that he requires a server for his PC. As the files are so big and take so long to load, he cannot turn the computer off otherwise it would take half an hour to start it up again. It also takes time to move around the model and move between sub models. A suggestion to get around this is to reduce the file sizes by not storing all the attributes in the model but rather link the model to attributes in another file store.

Other issues they have faced are around model ownership. An example of this is that the architect will not touch the structural model, even to make a small change. It takes a lot of coordination effort for the BIM Manager, because although the architect could change something quickly, they do not want to take the responsibility for the change. Therefore the BIM Manager has to go to the structural engineers and have them make the change, merge it with the architectural model and hope no further changes are required. Doing this process on 2D drawings is much simpler and quicker. Another issue they have faced is legal, in that, what are the procedures for reviewing the model. The Design Manager asserts he would not approve the model during the design phase, and that he would only approve design once the project was built.

The Design Manager concluded if they were to do a model again, they would do it in-house and manage BIM rather than invest the time and money to collaborate with the design disciplines. Both the BIM Manager and Design Manager believe the main consideration in making collaborative BIM successful is to ensure the estimators budget for BIM in the tender so the project has sufficient funds use BIM properly. It costs a lot to engage professionals to get the consultants on board, train them, and ensure the right hardware, software and relevant protocols are established.

3.3   Document Based Collaborative Platforms – Industry Case Studies

Document based collaboration platforms have been included as case studies to understand the implementation and ongoing processes for using a web based collaboration platform. These document collaboration processes are already existing and working within the Industry and therefore may act as a gauge for using collaborative BIM platforms.

3.3.1   INCITE project set-up process

"*INCITE Project Collaboration is an innovative online project communication and information management platform. Flexible and easy to use, it combines communication and workflow processes with document management and is designed to handle all the key project processes that include: Design Management, Document Control, Project Correspondence, Approvals & Variations, Requests, Instructions & Notifications, and Scheduled & Ad Hoc Project Reporting.*"(INCITE website)

INCITE is currently used in over 1000 projects worldwide across projects of varying complexity. Like any other document management system such as Aconex, ProjectCenter, and Team Binder, INCITE at present does not support intelligent 3D object-oriented models. However, the experience that INCITE has in handling the project collaboration requirements using documents and various linked and related project data for their clients is valuable to this research.

A detailed study of the INCITE project set-up process reveals that setting up a project collaboration platform is an intensive and time consuming process. Requirements vary from project to project and often experience with the INCITE platform varies across project partners. The initial platform set-up involves a structured approach for identification of project information flow requirements, clarity on roles and responsibilities and adherence to contract agreements. Before the collaboration platform is functional the information dependencies and project specific document management protocols must be clarified and tested. Figure 3.30 shows the typical steps involved in setting up the INCITE collaboration platform.

Figure 3.30   INCITE project management process

INCITE Project Implementation Process

Project Summary

Prepare Executive Overview

Prepare Setup Workshop

Present Executive Overview

Run Setup Workshop

Able to run functional workshops? → no → Prepare Functional Workshops

yes

Run Functional Workshops

Provide Progress Report

Complete Project Build

Test/Validate Project

Are modifications required? → yes → Make Modifications

no

Project Sign Off

Conduct Training

Allocate User Names

Go Live

Key

	Nexus Point Solutions (NPS)
	NPS and Client
	Client
	NPS Build Point

77

INCITE has structured workshops agendas, templates, questions and standard collaboration processes that can be modified for setting up the project collaboration environment for specific projects.

Before the INCITE collaboration platform is fully operational in a project some of the typical information that must be clarified includes:

- Incoming and Outgoing Correspondence Process:
    - Mode of correspondence such as emails, SMS and fax
    - Type of correspondence such as confidential or general to include memos, letters and meeting minutes
- Record Management Plan
    - Project filing and file structure
    - Identify reporting requirements
    - Period of retention
    - Back up and disaster management
- Project document management contractual agreements and variations
- Roles, responsibilities and access rights
- Workflows, review and approval process
- Documentation conventions

The INCITE experience suggests that the initial collaboration platform set-up process is a complex process. Various dependencies within the process, activities and people needs to be identified before the collaboration platform are operational in a project. The complexity in setting up a collaboration platform for integrated BIM development can be expected to be higher as coordinating model based information exchange will require greater coordination than document exchange where file formats and tool capabilities are rarely an issue.

Experience from INCITE suggests that a structured framework to support BIM decision will facilitate collaborative BIM development across project partners. This framework should facilitate identification of dependencies on information flow and should account for model management plan, contractual agreements, roles and responsibilities, review and approval processes and agreed conventions.

3.3.2   ProjectCenter, Aconex and Team Binder – Review of Application

a) Aconex

Aconex is a document management and collaboration system for construction and engineering projects. Aconex has 34 offices worldwide servicing clients in over 50 countries.

Aconex primarily works as an application service provider, which means like other similar service providers all that users need is a web browser and no software needs to be installed in client machines.

The main features of Aconex include:

- Allows complete correspondence management to include project mail and facility to can scan, store and distribute letters, documents or other written correspondences including automatic filing of faxes from lines already registered with the system.
- RFIs, variations, memoranda, architects' advices, transmittals, quotes, site instructions, schedules and reports.
- Allows simultaneous viewing and mark-up with real time instant messaging.

- Aconex Site Cams capture the full history of project. Images are stored every 15 minutes and can be viewed remotely.

- Automated document and correspondence distributions and notifications.

- Additional, integrated modules and services for task management, project and company workflow management, and the time consuming process of issuing and awarding tenders.

Aconex Implementation methodology:

Aconex meet with clients to review the expected communication flow throughout the project life-cycle and to agree on the protocols and processes that the team should adhere to. Depending on the project set-up, support is provided at the local Aconex office or a virtual Aconex team is assembled in the cities and countries where the project participants are based.

A Project Instruction document is developed that mirrors standard industry processes and is customized to specific project needs. The Project Instruction becomes a working guide for the project. This ensures that as the teams change, areas like standard file types, document terminology and even naming conventions are easy to communicate.

Once the protocols are established, the Aconex system is configured for the project and the administration team and project partners are trained, and the system is ready to go online.

Training programs are available for all Aconex functionality, from the standard mail and online document management modules that all project teams will use, to the more advanced construction project management software tools like workflows and tender modules.

b) ProjectCentre

ProjectCentre is an internet-based Project Management Systems for the Construction Industry, and was first developed in 1997 as a web-based system.

ProjectCentre provides a range of web-based products for managing construction projects throughout design, construction, and operating (FM) phases of the project. ProjectCentre Mobile allows use of PDA's to capture defect data and manage the process of closing out each defect.

The main features of ProjectCentre include:

- Uses a centralized ProjectCentre Server that can connect to other collaborative and in-house systems.

- An entirely browser-based system

- Security similar to other DMS to include login, logout

- Ability to manage workflow process, allowing documents uploaded through a transmittal system to follow a predefined Issue and Approval Process.

- As documents are Issued and Approved via a Transmittal, the information is automatically updated and tracked in the Drawing Register. The Register is displayed as a folder tree and includes a search facility, making it easy to find documents.

- All contractual Correspondence issues are communicated on a forms-based system via the ProjectCentre server, which maintains a Correspondence register.

- Information management through audit trails, notification registers and hotlists that facilitate information tracking. Similarly, a Meeting Manager allows meeting scheduling, invitation calls, agenda publication, and general tracking of related developments.

- Customisability, to match client requirements

- Users can generate custom reports and create tender packages

The Project Administrator requires in-depth knowledge of the required document flow process as well as basic Configuration and user requirements on ProjectCentre. In addition, a company administrator is appointed to coordinate with the project administrator and has access rights similar to project administrator. Training for general users is limited to the functions they need to perform on ProjectCentre.

Help is provided in form of manuals, technical support and video demonstrations for quick self education.

c) Team Binder

Team Binder is an Australian project collaboration tool that enables all parties on a project to share project documents in a controlled environment. Team Binder has been developed by QA Software, which has experience in project document control since 1995. Team Binder can act as a service provider and the Team Binder server can also be hosted in-house.

Team Binder automates the process of uploading, validating, distributing and approving documents. A series of business rules encoded within Team Binder at the start of the project automates the decisions such as which folder to upload documents to, or who to distribute documents to. Team Binder is a process based system. Documents are generally uploaded via email, and pass through a validation engine on the Team Binder server before being accepted into the document register. Uploaded documents are validated automatically via Team Binder's business rules. The documents management process is illustrated in Figure 3.31.

Figure 3.31   Document management process in Team Binder (Source: www.TeamBinder.com)
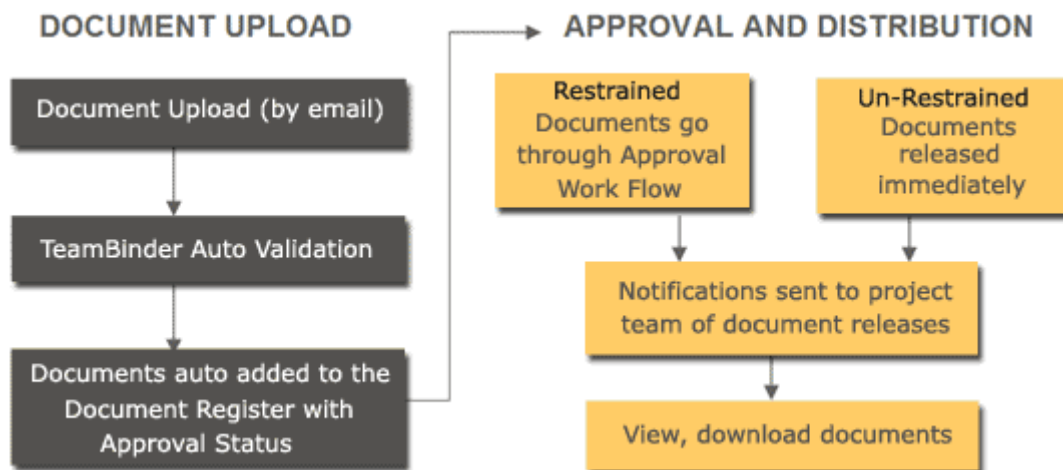
Figure 3.32   Document upload process in Team Binder (Source: www.TeamBinder.com)

80
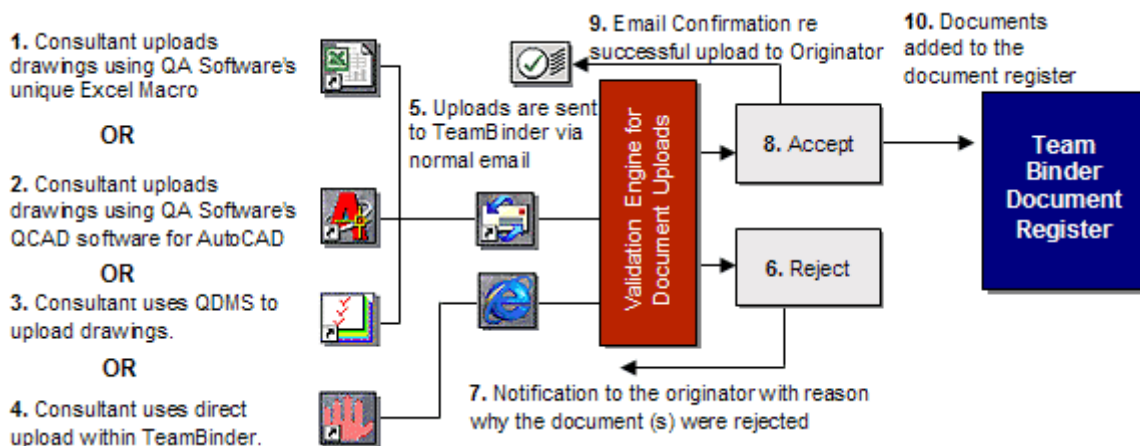
The main features of Team Binder include:

- Documents are uploaded to a central register and managed via a document register.

- Document distribution is control via Discipline and/or Package Distribution Matrices

- Documents in Team Binder are distributed via notifications and downloads, and also through transmittals.

- Document Approval is managed via the system that automatically routes the documents for approval. The document approval system is illustrated in Figure 3.32.

- All document downloads and other transactions are maintained in an audit trail.

- Team Binder has built in viewing (with auto conversion of files to DWF on the server) and red lining without the need to download additional software. Uploaded files are automatically converted to a common format on the server and viewed via Internet Explorer.

- Team Binder keeps a track of the correspondence thread, and supports any number of correspondence types that can be configured for each project.

- Project participants can be grouped into project roles or security groups such that members of each group can send and receive correspondence within Team Binder, which maintains a communication thread for later reference.

- Security measures in Team Binder are similar to other DMS including network security, access rights, and a check-in and check-out process.

- Capabilities such as FAX-IN and EMAIL-IN allow project members not using Team Binder to upload and receive documents with other members.

The inbuilt intelligence in form of business rules and distribution matrix in Team Binder would require knowledge elicitation from project partners, similar to what is proposed in a BIM project decision framework. The BIM project decision framework is expected to provide similar capabilities albeit commensurate with a BIM environment, which is expected to be more complex than a DMS environment.

3.3.3   In-house Project Management Framework at Thiess

An in-house project management framework has been adopted at Thiess, which they term as the Thiess Management Model. The Thiess Management Model details the standard process workflows adopted at Thiess at various stages of the project development.

Given, the complexity of the work processes and steps at each stages of the project lifecycle the Thiess Management Model is a fairly detailed guideline, organized in a hierarchical structure.

In order to facilitate easy reference and usage of the Thiess Management Model the hierarchical model has been implemented as an online tool with an interactive interface. This web based tool is regularly used by the design managers and project partners to align and organize their roles and practices to a common standard accepted at Thiess.

Senior officials at Thiess reported positive impact of this structured approach in managing the projects and coordinating the project collaboration. Officials acknowledged that without an online interface usage of such a detailed model may not have been as effective.

Discussions with officials at Thiess were the initial encouragement for the proposed BIM decision support framework, which is seen at Thiess as a natural extension of an interactive tool such as the Thiess Management Model that will help set-up and organize BIM implementation contingent on project requirements.

3.3.4   EDMmodelServer™

A model server is a computer application that provides a shared, persistent model repository, model management functionality, and a data access interface to project models for multiple,

concurrent client applications. Different functions of model servers include sorting, sharing, viewing, extracting, integrity, validation, merging, search engine, ownership and protection, workflow support, analysis, calculations, versioning, transactions, and auditing.

EDMmodelServer™ products from Jotne EPM Technology. It is an integrated source of model data that is applicable for ensuring the availability and usability of data regardless of hardware or software system as well as for the accessibility and secured storage for the life cycle of the product. EDMmodelServer™ allows multiple users concurrent access. Users, such as clients, designers, consultants, contractors, sub-contractors, suppliers and other business partners, may be distributed geographically, not only on a project location but also nationally and internationally.

Applying EDMmodelServer™ in the AEC industry might involve different applications at different stages:

- Create new design: Discipline-specific model is constructed respectively in each discipline using different applications, e.g. ArchiCAD for architecture, DDS-CAD and Revit-MEP for hydraulic. These models are converted into IFC file and then uploaded or checked-in to EDMmodelServer™.

- Share updates to project members: Using an IFC viewer, e.g. DDS viewer and Solibri Model Viewer, all project members can see the new changes.

- Architectural-to-structural design: In general, the architectural model and its IFC file are used as references to model and construct models of other disciplines. In structure engineering, architectural IFC file is downloaded from EDMmodelServer™ and then utilize applications, e.g Tekla, to perform structural design and analysis.

- Architectural-to-building services design: Similar to architectural-to-structural, the electrical engineers access to the building data and load the information to the software, e.g. ELCAD, to create the installations.

- Perform energy analysis: Load the model data in to an Energy Analysis Program for energy analysis, for instance, Olaf Granlund Riuska.

- Check the building: Load the data into a design "speller checker", such as Solibri Model Checker, for data and model checking, e.g. conflicts.

- Use the knowledge based systems and standard design templates: Using IFC and IFD Library to identify suppliers in product databases.

- Access supplier database: Using IFC and IFD Library to identify suppliers in product databases.

EDMmodelServer™ provides a collaboration platform for AEC industry. It supports AEC industry wide lifecycle collaboration including data compatibility and user cooperation. Some issues and questions in using EDMmodelServer™ for project collaboration were raised with Jotne EPM Technology, who provided the following information

Q1. When setting up of EDMmodelServer™ for individual projects, how do you get the specifications from the clients?

EDM: Specifications from client exist in structured, unstructured form or as a combination. The preferred option is to work with a requirement tool such as dRofus or Codebook.

Structured specifications can be imported to EDMmodelServer™ following exchange requirements to ensure the right breakdown structure and the data quality. EDMmodelServer™ will check data using exchange requirement's check-list, regulation, classification or user-defined check-lists.

Structured specifications need to (standardised) concepts from a dictionary. We believe that ISO 12006-3 and its support in Ifc2x4 is the best way to define concepts in a BIM structure and that is the basis for our implementation although other options can be used also. As a

result, it will be possible to use the specification directly as a query to find matching concepts/solutions in knowledge databases, catalogues or as-built databases.

We also link proposed solutions/recipes/products to a specification so that it will be easy to derive cost, bill of material automatically from the specification. Specifications should follow the same structure as the rest of the BIM so that it is easy to check specification against the proposed solution, e.g. if the planned space area is met by design, if energy performance is affordable, if no rainforest materials are used, if the calculated air flow sound is less than 60 dB, etc.

Structured data can also be imported from spread-sheets, but when the above applications can be certified a guaranteed by a vendor, spread sheets may be changed easily by individuals and cause unexpected errors. Unstructured information such as extracted form documents can be mapped or drag'n'dropped to the right structure.

Q2. What information do you collect?

EDM: We easily collect all IFC information, but will recommend that it is specified according to formal exchange requirements such as those currently being developed as part of buildingSMART. Data that cannot directly be mapped to IFC (or should be private) can use an extension schema in EDMmodelServer™ for such data.

Q3. Do you have a set of templates you ask the customer to complete?

EDM: [EPM] EDMmodelServer™ is delivered with an advanced report module that will include reports defined in a BIM Manual supporting the business process and its exchange requirements. This BIM Manual works with a report/data sheet layout that also can by used for data entry, e.g. to complete or change the specification. The data sheet will also report on results from constraint checking, e.g. difference between planned and designed area, function, ranges as well conflict between building objects, as well as building regulation and other knowledge rules to make better BIMs.

Q4. Do you conduct workshops with clients and the collaborating teams to collect and later validate their needs?

EDM: This is the collaboration space working with shared BIM using EDMmodelServer™. The included EDMbimManager™ is an Internet application to connect to any EDMmodelServer™ available. The user can browse all information to get BIM information. We support several browsers such as Octaga, Navisworks, etc. With your preferred browser it is possible to walk around and when finding something of interest, the user can get all information from the server. The report module and the checkers will also create a script that will take the user to a viewpoint and explain the issue. In this way, myRequirements vs. proposed solutions can be examined efficiently.

Q5. Are there any specific project management techniques that you use to organise EDMmodelServer™ services?

EDM: Not really, EDMmodelServer™ supports both the object model and the more traditional PLM approach that allow the user to add, delete, change objects based on access rights. We mostly work with the concept of a BIM Manual as the contract between the collaboration partners. The BIM Manual defines the information delivery based on buildingSMART exchange requirements and we support the workflow to send, receive, validate, compare and merge data into an integrated model.

Q6. Is there any specific pattern that you observes in Client's expectations and demands from EDMmodelServer™?

EDM: This is a difficult question. We sell EDMmodelServer™ to customers that want access to accurate and reliable information according to Open Standards. For them it is important that information can flow seamlessly between partners and the applications used in the value chain. They believe in the buildingSMART vision and get disappointed when certified applications cannot deliver this promise. EDMmodelServer™ can help them identifying problems and even correct wrong data, but they need this fixed by their vendors.

Unfortunately many software vendors are not able or willing to help them and the value of buildingSMART either used in a file-based or shared environment is not as good as it should.

Q7. Do you have any web based forms that Clients and different parties have to fill in to clarify their roles and position in the information flow, if there is one?

EDM: Normally, the role and position are identified through the server login and the actual workflow, e.g. you log in as an individual and is assigned a role, e.g. as architect. Each user and role has access rights to objects/attributes in the model and information may be uploaded concurrently to the server The workflow will use control elements to decide when data flow can be concurrent or when approval is needed to continue, e.g. no more design before conflict between cost and energy performance has been resolved.

Q8. What are the typical help requests do you get on a regular basis?

EDM: Most people have problems with wrong and/or incomplete data and need assistance in solving the chaos created by the applications that claim to be certified, but that to our experience do not deliver accurate and reliable data. This will also cause downstream problems when trying to integrate data or when trying to run analysis/simulation on such bad data. It requires deep knowledge of IFC to resolve such issues and when they get no or little help from their authoring tool vendor, they come to our help desk.

Q9. Does EDMmodelServer™ have an online tutorial or a help page?

EDM: Yes

Q10. Does EDMmodelServer™ offer or intend to offer a helpdesk service?

EDM: We have a helpdesk available through support@jotne.com or by calling +47 2 317 1700

Q11. Can the user interface of EDMmodelServer™ be modified based on the users' requirements? If yes, how can it be done?

EDM: All EXPRESS Data Manager™ products have a model-driven architecture and all functionality in the EDMmodelServer™ can be changed. This means that everything can be user-defined by adding or modifying the underlying methods that define classification, tree-structure, rule-schemas and report modules. The system uses the report module extensively and the user can easily modify the system appearance by configuring reports and data sheets.

Q12. EDMmodelServer™ provides a function in identifying different versions of a model. Can EDMmodelServer™ provide the information of the changes being made between different model versions?

EDM: Yes, EDMmodelServer™ uses a versioning system. All changes are tracked under a status added, deleted, changed, changed role(s). Object version may be applied to one object or to many objects such as those listed within an exchange requirement. There is functionality to set any version as the actual one, either a past version or a future alternative one.

Q13. How is the object ownership in a model set up and controlled in an EDMmodelServer™? How can it be manipulated to meet special needs of the project and improve the data security?

EDM: The EDMmodelServer™ support access control, i.e. only users with matching access rights can see, read, write to that object. The BIM Manager can change ownership and access rights for all objects/properties. Normally this is set up according to a reference process identifying roles and ownership to data grouped in exchange requirements. Many users can be associated to the same role, e.g. act as in the Architect role, but each change will be tracked down to the individual making that change.

Q14. To modify an object in an EDMmodelServer™ is to edit the parameter value of this object or to replace this object with another object? Both of them are possible. However, how can the modification be defined as editing or replacing?

EDM: The object versioning and the track control system will always keep status of the object and the object change, e.g. added, modified, deleted or change of role.

Q15. Objects are well defined and operated in each model. However, during model merging, object duplications or model conflictions might happen. How can these issues be detected and solved?

EDM: The best answer is to be consistent in using the GUID unique key. If this is used consequently, a lot of the duplication problem is avoided and merging can be automated. However, when the same object is created in parallel (the seven time rekeying problem) there is no guarantee against duplication. Duplication of identical objects or structures are seldom any problem because they can easily be compared and matched. The problem is when the rekeying of duplicate information lead to similar but dislike information such as room number 010f901 instead of 10F9-01 Our recommendation is based on the nature of the EDMmodelServer™ - reuse of information and knowledge and to have a clear definition of what is master data and what are copies.

Q16. Users might need to use some functions which EDMmodelServer™ doesn't provide currently. These functions might be available in the application they use. What are the opportunities and limitations in plugging in an application to EDMmodelServer™ to provide these functions which user need?

EDM: A bearing concept is to manage methods (rules, mappings, calculations, simulations) linked with the objects in the database. As a result, it will be possible to collect data from many sources and make the checking on the server side. Instead of having to calculate the area in five different applications, it can be done once by a (certified) method at the server side – and it will provide better performance since the server platform is designed for such heavy loads.

Any such method can be developed by the user or by the application developer. For example Fornax - the Singapore e-plan check web application, was developed as a set of rule schemas stored in the EDMdatabase™ and could be called over Internet either by using the Fornax application or any BIM system that needed to check their design against the Singapore regulation. The performance is good because only method calls and results need to be sent over the network. Such methods can be developed by the EDMexpressX ™ (recommended) data manipulation language or by any other programming language by linking to an external library. EDMexpressX ™ is supported by a development environment with debug and trace functionality.

Q17. How can it be achieved to develop EDMmodelServer™ to provide a function for instant direct communication, e.g. a chat room and videoconference?

EDM: It is today possible to generate a video, but for instant direct communication some development is needed. This is possible by working with us or preferably with a browser company such as Octaga, First Interactive or Navisworks. Technically this will be solved by using our API and intelligent queries to stream instant, real BIM data to the video conference. We should mention that we work with European Space Agency in Netherlands to develop a concurrent design facility with this scope. As of today, this is only for predesign and not for full 3d data. That is scheduled later in the project.

Q18. What procedures have been set up and should be followed for EDMmodelServer™ data backup?

EDM: There are several possible ways to organize th backing up of the EDMmodelServer™. The EDMdatabase™ may be backed up online at regular intervals specified when the EDMmodelServer™ is started. Online backup may also be activated "manually" by running a command script. Online means the backup is run while the EDMmodelServer™ is available to the clients.

Also, backup may be done offline. Setting up backup is explained in the EDMserver™ Maintenance Manual.

Q19. What procedures have been set up and should be followed for EDMmodelServer™ for system upgrade?

EDM: The server-side functionality of the EDMmodelServer™ is entirely based on plug-ins (extension schemata) to the EDMServer™ basic functionality. These plug-ins are upgraded from the EDMbimManager™ administrator module. Partial or full upgrade between two versions is possible.

The upgrades are organized into downloadable modules.

The client application EDMbimManager™ must be upgraded accordingly to the server upgrades. The functionality of the client is backwards compatible meaning that it works with older versions of the server. It is normal to upgrade the client to the latest version available. A message is given to the user if the client needs upgrade and the user can choose an automatic download and upgrade.

3.3.5   ActiveFacility – Collaborative BIM Platform – Review of Application

ActiveFacility is a part of an international research and development movement seeking a standard model for storing, updating, and providing ready access to the massive amount of information that relates to a building. ActiveFacility has developed a set of services and software systems, built around the use of IFCs, that provide a means of storing and managing all the building information throughout a building's lifecycle.

ActiveFacility's process for establishing the building model encompasses the following activities:

- Collating all the existing data about a building or group of buildings in either hard copy format (which are scanned to PDFs), digital files or IFC compliant data;

- Building the Unified Building Model using the complete set of documentation and range of data sources;

- Storing the building model on a secure server and providing client access to authorised personnel; and

- Interfacing the building model with other relevant data systems.

Implementation of ActiveFacility begins with gathering together all the existing data about a building or group of buildings, as follows:

- As-built drawings;

- Drawings for each floor of a building:
  - architectural drawing
  - electrical drawing (lights, power, low voltage systems)
  - mechanical drawing (air-conditioning and ventilation), and
  - piping drawing (hot and cold water, gas).

- Specifications;

- Operating manuals;

- Data in other operational systems such as accounting, human resources, facility management and building automation systems.

All the above data is collated by the client and collected from a nominated client representative by ActiveFacility staff. As ActiveFacility manages all data associated with a building, the system is designed to identify overlapping data that is stored in many of these existing operational systems.

Information for the BIM is sourced from three types of document sets:

- Hard copy as-built documents (drawings, manuals, specifications);

- Digital data; and

- IFC compliant data (which the ActiveFacility system loads).

Existing paper building-related documents are scanned to PDF files for on-line storage in the ActiveFacility system. Existing digital files remain in their current format and are copied and stored. The complete set of documentation and data is used by the ActiveFacility team to begin the process of building a Unified Building Model that describes the building, its entities and the characteristics and behaviours of the entities. This manual process involves identifying building objects in the document sets and constructing a complete set of data about that object and converting all the existing building information data to the IFC standard.

The model creation process includes:

- Identifying each entity represented in the supplied documents;

- Identifying relevant information in each document for each entity;

- Creating the entity in the IFC format;

- Modelling the characteristics (attributes) and behaviour (relationships) for each entity;

- Testing the validity of the model. The Unified Building Model is a three-dimensional model and testing involves 'wandering' around the model in virtual space to ensure the data is complete and valid; and

- Loading the data into the ActiveFacility servers.

The technology and services in ActiveFacility's way of managing building data is provided in a modular format as follows:

ActiveFacility Data Management

- Stores data in an open format for viewing, editing and analysing.

- Uses industry standard relational database technology on secure servers, hosted and managed by ActiveFacility.

- Controls access to the data and ensures data remains available only to those with appropriate access approval via firewalls.

ActiveFacility View

- Provides viewing access to all building data through a web-browser

- Ready access to the data from most computers

- All users view the same data source.

ActiveFacility Edit

- Provides tools to make changes to the building data directly through a web-browser.

ActiveFacility Analysis

- Provides tools to query, report and find information within the building data model.

ActiveFacility Export

- Provides a gateway so data can be exported to users for external applications. Data can be exported by consultants without involving the building owners, managers or facility managers.

ActiveFacility Import

- Provides tools to import data into the building data model. Data is supplied by external consultants, contractors or suppliers in the IFC file format and loaded into a staging area where it is checked before the final loading into the building data model.

Figure 3.33   ActiveFacility diagram illustrates how the modules relate to each other
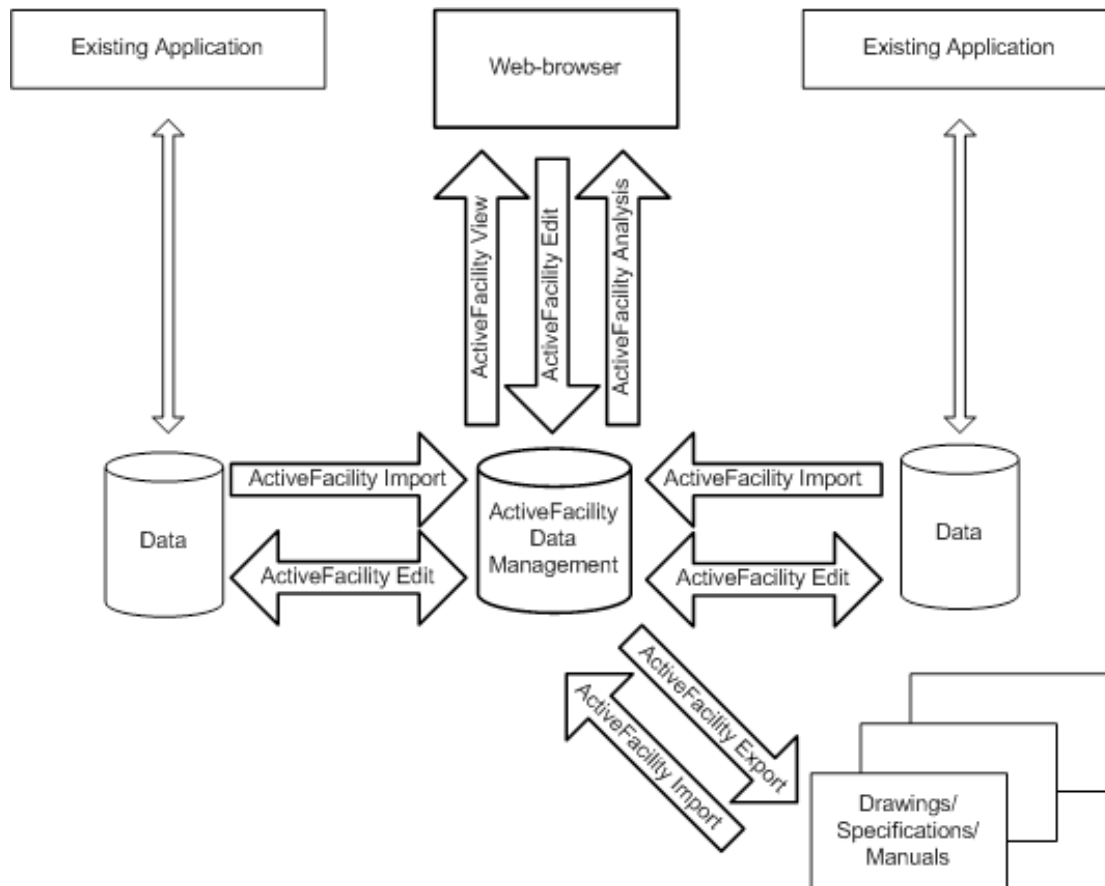
3.3.6   Architectural Design Collaboration at Woods Bagot

Woods Bagot is a large architectural design firm with more than 1000 staff and studios across multiple regions including cities such as Abu Dhabi, Bangkok, Beijing, London, Melbourne, San Francisco and Sydney.

An open-ended interview with a senior architect at Woods Bagot was conducted. The main findings from this interview are:

- Woods Bagot has adopted multiple design collaboration strategies to facilitate design development across its different offices.

  - All the project documents are managed using Aconex, which is a document management system. Aconex is used to exchange drawings, manage files and access controls. A well developed file nomenclature standard has been developed for record keeping and version management.

  - Woods Bagot also uses FTP servers at each of its offices to maintain and update the work in progress. Use of FTP servers from each of its offices allows easy sharing of data across the distributed team. Having multiple FTP sites from which data is copied at other sites also ensures an additional data backup system. Local FTP servers enable easy control on role based access and accountability on stored data.

- Woods Bagot uses both object oriented models (ArchiCAD) and traditional CAD packages (AutoCAD) in its practice. At Woods Bagot an in-house technical support

and development team develops the necessary plug-ins and customization for the software used.

- while the firm uses a range of software they are not very keen on adopting new applications for specific projects. Sticking to a specific set of applications for all its projects means
  - o Greater expertise is developed in the specific applications across the team
  - o Uncertainties in data compatibility and exchange are avoided
  - o The senior architect argued that if a multitude of applications are used then they may need to have different people with expertise in different applications. In such a scenario, the tacit knowledge and experience of individuals may be lost due to attrition, which may not be as severe a case if most people in the firm use the same applications and develop expertise in them.

- The senior architect expressed the need for tools and means to capture design intent and communication. Discussions on possible ways to accomplish this hinted towards enterprise-wise discussion forums, instant messaging, tags and object properties.

- The senior architect mentioned the existence of a structured approach to design management and collaboration at Woods Bagot, but acknowledged that most of the initial project set-up is ad-hoc and dependent on tacit knowledge of the project leaders. Reviewing the proposed BIM decision framework the senior architect said that such a framework may be useful to translate some of this tacit knowledge into explicit enterprise-wise knowledge. This may allow them to adopt other useful and specific tools that they may have avoided thus far to prevent attrition bottlenecks.

3.3.7 Experiences at Sydney Opera House

Sydney Opera House (SOH) located in Sydney, New South Wales is a world wide known famous building. It houses a multi-venue performing arts centre, rather than a single Opera theatre. Building facilities of SOH, in addition to architectural and building structural systems, consists of different building service systems, such as hydraulic, mechanical, HVAC, electrical, lighting, fire services, communications, security installation, vertical transportation.

The main findings about project management and facility management from the Sydney Opera House on-site visit and an interview with the BIM manager are as follows:

- Different applications and tools are adopted for project management and facility management include
  - o AutoCAD and Microstation for 2D design, drawing and 3D modelling;
  - o TRIM for internal file document management and Aconex for project document management and collaboration.

- Security management controls users' accessibilities, including user account and authorization, of the computer system at SOH. Users of the computer system are mainly divided into internal users and external users.
  - o Internal users have direct access rights to the computer system. User's login and logout to the computer system is controlled by IS group.
  - o External user access is managed by Aconex systems. External users have no direct access to the computer system.

- Data management regarding data operations, including internal and external data operation, data storage and data transfer.
  - o Internal data operation related to day-to-day coordination of work requirements is based on established CADD Guidelines and BIM Guidelines to manage projects and drawings including layering, colours, naming conventions, line-weights, cataloguing and archiving.

- o DWG files are coordinated internally between team members.

- o External data operations should obey CADD and BIM Guidelines. Guidance to external parties given by CADD and BIM Guidelines documentations form part of awarded contracts. Successful tenders should comply with guidelines otherwise they may be put on hold until compliant.

- o All major project work is out-sourced for design, development and delivery. Data management is the responsibility of external parties until hand-over, as-built or as-installed stage of project. SOH is responsible for the management and incorporation of new data, as provided, into the existing system.

- o Drawing files stored on the central computer network. All data is checked upon receipt for compliance with guidelines.

- o Files are transferred internally and externally by email, Aconex or DVD with associated control documentation. FTP sites are utilised where available.

SOH BIM model is in the process of being built and a part of the model is already generated. BIM model construction for SOH is a part-to-whole (bottom up) process. Different organizations are building models for different parts. These organizations are not commissioned specifically to build the model. Rather, the BIM model is a by-product of the renovation, design and construction works being contracted to these organizations.

3.4 Conclusion

This section presents case studies of both using BIM based and document based collaboration platform.

Using BIM approach for collaboration platform includes Seawater Chamber – controlled testing case study in which EDMmodelServer™ is used as a collaboration platform, and The Ark Building Project – industry case study in which NavisWorks is used to merge different discipline models.

Document based collaboration platform case studies include inquiries and interviews at INCITE, ProjectCentre, Thiess, EDMmodelServer™, Woods Bagot and Sydney Opera House.

The discussions are categorized into user management, visualization control, data management, system management and technical support. These discussions should then combine with industry needs and decision framework to develop technical requirements of model server.

In general, using EDMmodelServer™ as a collaboration platform while it is still under development raises issues including:

- Budget management of BIM cost, including software and hardware

- Training

- Enrichment of the user manual and help function of BIM Model Server

- Data management including the management of file size and running time, additional storage for storing project data and specification, and linkage of information

- Data ownership management

- Operation and Management manual (O&M) / link to detailed information of the objects in the model

User management

- Current EDMbimManager™ user management provides users and groups controls with different authorities including create, delete, execute, private, write, read and none.

- It is suggested that

  - User management could be more flexible and applicable for different users in different project life cycle.

    - Give some users the authorities only in some specific project life cycles which are applicable to them

  - It can also provide some linked functions and extend functions, e.g. contacts and messenger, for uses of server not limited to data sharing but also online user communication.

Visualization control

- All EXPRESS Data Manager™ products have a model-driven architecture and all functionalities in the EDMmodelServer™ can be changed.

  - EDMmodelServer™ consists of two main parts, including text-based information windows and a 3D model viewer. Currently, Octaga Modeller is plugged for instant viewing 3D model. Jotne EPM Technology is now modifying EDMmodelServer™. Other model viewers could be plugged into EDMmodelServer™ in the near future.

- It is suggested that

  - Customizability of system configurations with a flexible user interface to be suitable for and easily adopted to different needs of:

    - different users including designer, contractor, facility manager and client,

    - different building project life cycle ranging from project identification to bid, start up, design, contract, operate and manage, and

    - different scales of collaborative projects

  - User interface with drop down menus, forms, charts and so on to assess information in a collaboration project.

  - EDMmodelServer™ should not only be limited in an operation window. Pop out windows might be used to accompany with the main operation window. It will increase the flexibility, usability and interactivity of EDMmodelServer™.

Data management

- Data management of EDMmodelServer™ includes object properties and information delivery management (IDM). Objects of the model are presented by text-based information in repositories and 3D object-model in Model Viewer.

- Jotne EPM Technology is currently in the process of finding the solutions for GUID, IDM and scaling problems encountered in merging different discipline-specific models using EDMmodelServer™.

- It is also suggested to provide plug-in applications or mechanisms to achieve the following functions

  - Ownership and control mechanisms of objects and models authorities could provide more options to different users, user groups or users in different hierarchies. It is to enhance the security of data and workflow.

  - Improvement of interactivity between the text-based information and 3D models of objects to control the accurate interrelationships between objects and the model.

System management

- Currently, EDMmodelServer™ is set up and controlled by EDMsupervisor for user control and authority settings. There are still some issues which need to be addressed in using EDMmodelServer™ as a collaboration platform, such as data back up and instant communication.

- It is suggested to

  - Adopt industry needs with the support of specific discipline, domain knowledge and IT technique. Therefore, the industry can easily understand the tool capability and reflect its usability in practice.

  - Add "Conflict detection mark-ups" function to highlight possible tool compatibility issues, access right and information flow clashes.

- It is also suggested to provide

  - Instant direct communication, e.g. chat room and videoconference, and indirect communication, e.g. broadcasting and email, to improve the communication for project development and control.

  - Project wiki to share project information and tool usage information

  - A look-up tool capability matrix, where users can search, query and check functionalities and capabilities of all BIM supporting tools such as CAD packages, analysis tools.

  - Command to create tool-compatibility matrix to determine the scope of BIM usage in a project, based on the tools chosen by project partners.

Technical support

- Current Jotne EPM Technology provides helpdesk through email and telephone for EDMbimManager™.

- It is also suggested to

  - Improve the help function in EDMbimManager™, e.g. interactive help window, for users to seek and obtain solutions and assistances for the problem they have in using a model server.

  - Online helpdesk in case where Model server facilities are provided by a service provider.

  - May also be applicable to large scale in-house projects, where this helpdesk service is supervised by a BIM manager.

  - Provide interactive tutorial such as Graphisoft's BIM tutorial

Table 3.2 compares in a summarised manner each case study in relation to key elements of Decision Framework and clearly indicate a need for each of the elements to be developed in more detail. Interestingly no case study appears to conduct a capability analysis and few firms conduct a specific BIM scoping step nor analyse tool compatibility.

Table 3.2   Cross Case Comparison in relation to elements for a Decision Framework

Case	Key challenges	CAD vs DMS approach	Project scoping approach	Tool compatibility	Model server usage	Work process maps	BIM Capability	BIM Decision Framework Integration
INCITE	•Integration of BIM environment with DMS •Providing Training & support •Creating cultural change	DMS	Yes	No	No	Yes	No	Potential
Newforma Project Center	•Integration of BIM environment with DMS •Creating cultural change	DMS	Yes	No	No	Unknown	No	Potential
Thiess	•Integration of BIM environment with DMS •Culture change not an issue as Thiess makes it mandatory for collaborators	DMS	Yes Project scoping is done but sans BIM	No	No	Yes	No	Potential– alignment with current TMS
Arup	Representative from Arup believed separate models may be needed for specific purposes. e.g. Design, Facilities management and construction. Opinion on IFC and collaboration model servers was not very positive.	CAD	No	Yes	No	Unknown	No	Potential- particularly with alignment to current KMS
Woods Bagot	Focus is at present on intra-disciplinary model. Exchange with consultants is through 2D documents. Challenge in future would be exchange of information with consultants through models.	CAD	No	No	No	Yes	Yes	Potential for intra-disciplinary exchange of 3D data
SOH	Adopt KM strategies that are sustainable and accepted across the organization	DMS (more of information management than documents)	Yes	Yes	No	Yes	No	Potential
HEWVC	• Isolated approaches to CAD and project information management • Key challenge is to integrate CAD & DMS and extend it to BIM	CAD & DMS	No	No	No	No	No	At present isolated efforts. Hence integration will require a fresh effort

The experiences and findings from case studies will be now be used for the development of technical requirements of a BIM model server as a collaboration platform.

4. PROJECT LIFE CYCLE COLLABORATIVE BIM DECISION FRAMEWORK

4.1 Industry context

The adoption of a fully integrated multidisciplinary seamless Building Information Model to describe a construction project has not been implemented completely in the Australian property and construction industry even by early technology adopters who are market leaders. This would require a collaborative platform Model Server. The lack of adoption with market leaders is due to:

- a lack of operational technical knowledge of Building Information Modelling

  - low and/or varying levels of awareness, knowledge, skills and capabilities across disciplines

  - low levels of confidence in Building Information Model adoption due to lack of experiences

  - lack of clarity on how to develop and integrate Building Information Modelling into current work practices

- a lack of high level strategic guidance to address the varied levels of adoption across different disciplines as discussed earlier

There is a recognition of the need to develop guidelines in relation to *technical* (software and hardware tools, data compatibility, interoperability) operational project decision making and *non technical* (procurement strategies, model ownership, contractual obligations, information management) strategic project and organisational decision making. However the adoption of innovative technology and the diffusion throughout the industry is challenging without a starting point to guide decisions for project managers, architects, clients, facility managers, contractors, engineering consultants, specialist subcontractors and suppliers. When innovative BIM technologies have been implemented and have become more diffused throughout the industry BIM implementation will be seamless and implicit in everyday work practices but until that time decision making and roles need to be explicit.

One of the key early decisions in developing and using BIM Models which needs to be addressed for the Model Server environment is the extent to which the various software products are IFC compliant and/or interoperable when converting from the native format to IFC. This impacts on model creation primarily however it also impacts upon how the models are integrated and managed within the Model Server environment.

Limitations have been identified with the current practice in IAI's certification of IFC compatible applications (Bentley 2007). For example, the IFC specification does not cover export of certain proprietary data types that support application functions. As these cannot be exported, an IFC-file re-imported (round tripped) cannot create the original application data, thus certain features can no longer work. This leads to inefficiencies and complexities in managing an integrated database at the model server in the form of IFC files.

Given this scenario, IFC based model server may not always be the best choice. Hence, the decision support framework considers the possibilities of direct data exchange between proprietary tools using other approaches such as APIs and XML formats. Thus, assessment of the BIM tool compatibility is considered as an important step in the decision making process.

4.2 Purpose of Decision Framework

A *Project Life Cycle Collaborative BIM Decision Framework* is proposed to facilitate fully integrated BIM model adoption using a model server, through informed selection of tools based upon project collaborators' readiness, tool capabilities and workflow dependencies. The *Decision Framework* is cognisant of the potential to integrate and collaborate across all

phases of the project life cycle. The focus of the *Decision Framework* tends towards the technical requirements however early and concerted attention to the non technical strategic project and organisational decision is critical to provide the necessary supporting cultural and business environment for adoption of BIM technologies.

The *Project Life Cycle Collaborative BIM Decision Framework* provides the information aimed at those who are BIM 'ready' or actively implementing BIM including those industry participants who would tend to be at Level 1 ,2 and 3 according to the following levels (refer to Figure 1.2 AIA diagram for digital design technology in Architectural practice in Section 2)

- Level 0 : CAD based [2D and 3D] - design disciplines who are designing, documenting and creating visualisations but who have not yet fully embraced object modelling and the concept of embedded information and/or appended/linked object information

- Level 1: Modelling – single disciplinary use of object based 3D modelling software within one discipline

- Level 2- Collaboration - sharing of object based models between two or more disciplines

- Level 3- Integration – integration of several multi disciplinary models using model servers with the ultimate aim of moving from local servers to a web based environment

The *Decision Framework* is primarily aimed at multi disciplinary industry participation at Level 3 Integration; however there are varying levels of adoption and on projects where a Model Server is being utilized it will be necessary to move participants at lower levels towards Level 3 Integration.

The *Decision Framework* provides a project life cycle view to support all industry participants including design and non design discipline. The aim is to present a way forward to bring together the CAD and DMS perspectives of BIM technologies to attempt to realise the full potential of BIM implementation by including models with embedded information, and also appended and linked information.

The *Decision Framework* provides information for clients and facility *managers* to understand the full resource implications of BIM technologies on projects and the impact of their decision making on BIM implementation.

The diffusion of innovative technologies is influenced by the positive experiences of adopters and the ability to modify the technologies to suit individual organisational own needs to successfully maintain and/or enhance business competitive advantage. This means that the Decision Framework needs to be customised for individual organisations or unique projects. As such the *Decision Framework* is intended to be adapted by the following organisations to suit both their organisational requirements and project requirements:

- architects, engineering consultants, quantity surveyors, design managers, etc who may not make project decisions but create, update, review, collaborate and integrate models

- clients/project managers/facility managers - those who make project decisions about BIM implementation on a project and who can influence resourcing for project teams

- senior technical managers senior managers and executives of organisations who make decisions about technology investment, human resourcing, project bidding and organisational strategic direction

4.3   Decision Framework Overview

The four sections of the Project Life cycle Collaborative Building Information Model Decision Framework for Model Server Implementation and a brief overview are now provided:

1. **Defining scope, purpose, roles, relationships and project phases:** critical early decisions in the Model Server environment are required at the outset to enable a supportive business and cultural environment for streamlined data flow and information management within a knowledge enterprise.
2. **Developing Work Process Roadmaps:** guidelines for developing Model Server implementation roadmaps
3. **Identifying technical requirements of BIM Model Servers:** A comprehensive knowledge of the availab**le commercial BIM applications and their capabilities is** important. Tools and levels of interoperability are dynamic and therefore project specific requirements need to be defined at the outset. To reach Level 3 Integration stage of BIM, implementation requirements regarding tool compatibility for multidisciplinary model sharing and model servers are necessary.
4. **Implementing the Decision Framework:** guidelines for implementing the framework described in this report **Evaluating skills, knowledge and capabilities:** a definition of skills, knowledge and capabilities required mapped against current status

4.4 Defining scope, purpose, roles, relationships and project phases

In the early stages of consideration of set up for a Model Server it is advisable to consider the 9 Scoping activities that are outlined in Table 4.1 Scoping Activities, Purpose and Phase Matrix- Non Technical Requirements. This forms a Checklist for a BIM Model Server Manager.

The first strategic scoping activity is to identify the purpose[s], extent of BIM and map them to project phases. The purpose of developing an Integrated Building Information Model using a Model Server needs to be clearly defined at the outset.

There can be a spectrum of implementation from a complex fully integrated multidisciplinary Building Information Model with online collaboration with real time updating across every phase of a project's life cycle, to individual discipline Building Information Models as stand alone models specific to phase, sub phase or activity within a phase. Each project will have different requirements and thus if Level 3 Integration has been decided for the project it is necessary to develop a specification of the purpose that is required so that it is fully supported by a well thought out business plan.

The following matrices are a guide and need to be adapted to suit individual project procurement strategies. The matrix can be developed from a project perspective or from an individual collaborator's perspective. For example, if the client funds the BIM they may wish to receive a fully operational Facilities Management model which they can use for operations and maintenance and community marketing, where as a contractor funded model, may focus on detailed design analysis, design review, alternative construction methods, construction information flow, safety features. The Matrix can be customized to suit individual project needs. The first step is to identify the purposes for which the model will be used for as these then impacts upon the Model Server requirements. The next step is then to determine phases of a project may where this is a high or low priority and then communicate that throughout the project team including model developers, model funders and model users.

The second strategic scoping activity involves defining Model Server Ownership Risk Management parameters. Table 4.2 Model Server Ownership Parameters outlines 6 key factors which influence the management of risk in relation to Model Server setup and implementation. It is intended that the matrix would be customised to suit and sit within the framework of risk management systems and strategies which have already been developed for the projects and organisations. However this provides a guide to key issues for the Model Server Manager and the model server owner to consider at the outset.

Table 4.1   Scoping Activities, Purpose and Phase Matrix- Non Technical Requirements

CHECKLIST FOR MODEL SERVER MANAGER										

Scoping Activities:

9 NON TECHNICAL STRATEGIC STEPS

1. Identify purpose[s], extent of BIM and map to project phases
2. Define Model Server Ownership Risk Management parameters
3. Define model ownership, funding source, owner requirements, management structure, & boundaries of responsibilities for model and/or submodels for all project phases including;
   - contractual roles
   - obligations and protocols for model management
   - Inter relationships between collaborators
4. Develop Business Plan for BIM Integration including financial & time constraints & appropriate resourcing for training and support
5. Define level of integration between Model Builders and Model Users ie design consultants model developers with document management systems managers within the Model Server environment
6. Undertake scoping analysis of collaborator competencies according to capability Levels 0-3;
7. Conduct BIM Integration Adoption workshops for selected senior executive and project level participants towards developing a collaborative culture and creating a BIM Model Server Communication Strategy to raise awareness and identify conflicts
8. Develop BIM Technical Support Levels for collaborators:

Purpose	Project Initiation	Concept Design	Developed Design	Bid documentation	Tendering	Construct	Commission	Occupation	Refurbishment
Community Marketing	H	H	L	L	L	H	L	H	H
Client Presentations									
Discipline Design SubModels									
Inter disciplinary design collaboration									
Multi disciplinary design collaboration									
Design Review									
Design Analysis									
Subcontractor Tendering									

- Level 1: Start up Training for inexperienced collaborators
- Level 2: Tool & model server support for collaborators
- Level 3: Long term education related to Knowledge Management Strategy

9. Develop Knowledge Management Strategy for capturing learning for future BIM Integration projects

Construction Information Mgt.										
Facilities Management Operations										
Facilities Management Maintenance										

Table 4.2   Model Server Ownership Parameter

Model Server Ownership Risk Management Factors				
Model Server structural organisation				
Concentrated				**Distributed**
Model Definition Stage				
Static Phase Defined Completed Models				**Dynamic Phase Ill defined Real time evolving Models**
BIM Management Skill Sets				
Internal Inhouse				**External Sourced**
Data Protection Classification				
Low level/Barrier Simple security	**2**	**3**	**4**	**5** **High level/Layered MultiSecurity levels**
Model Ownership scope & Server Capacity				
Integrated Model working size is small Hosting capacity required is low	**Small**		**Large**	**Integrated Model working size is large Hosting capacity required is high**
Data and Information Regulatory & policy framework				
Public Full disclosure				**Private Confidential**

4.5 Developing Work Process Roadmaps

Describing and developing Work Process Roadmaps in relation to Model Server management and implementation is important to enable a shared understanding, within and across organizations of key decision points.

Typically organisations have documented key processes within their organisation as a form of quality assurance exercises and/or accreditation or simply as good business practice. This takes many formats ranging from formal and well communicated maps to simply accepted understandings of 'what we do'. If an organisation is at the stage of being engaged in a project that shall use a Model Server they would typically have some BIM capacity, either as a Model Owner, Developer and/or User. For good project management in relation to Integrated BIM implementation and associated Model Server management it is highly desirable that both strategic and operational roadmaps are developed for projects.

Organisations should individually customise their work process roadmaps to suit their involvement in a project that requires a BIM Model Server. The following is an indicative checklist for the BIM Model Server Manager in relation to Work Process Roadmaps:

Table 4.3 High Level Roadmaps Checklist

Roadmap Activity	Description	Actioned	
1	Schedule of Roadmaps for each Phase		✅
2	Develop Roadmaps as required for Project Specific needs: refer to BIM *Purpose* and *Phases* decisions made in Scoping Activities Checklist : 9 Non Technical Strategic Steps		✅
3	Distribute roadmaps to project team participants		✅
4	Upload Schedule and Roadmaps within BIM Model Server environment		✅
5	Develop Model Server Handover Process Roadmap		✅

Integrated BIM requiring Model Servers will require strategic workflow process maps to support project operational information exchange and data transfer workflow processes roadmaps. Figure 4.1 is an example of a high level roadmap for BIM implementation for the BIM Manager working on a project whereby a contractor has taken the lead for the Model Server environment has employed a BIM Manager and is responsible for design review processes. The roadmap illustrated in figure 4.1 can be undertaken by any party. There are two key issues to consider; first that other project champions and actors would have their own process map depending upon their involvement and the type of procurement relationships and associated roles and responsibilities required. Second that there are additional layers of detail for each individual project phase major processes identified in the roadmap in figure 4.1 which would involve descriptions of step by step activities, players, deliverables, resources and tools, risks and indicators for success.

Figure 4.1   Manage Design Process Roadmap: Integrated BIM Model Implementation
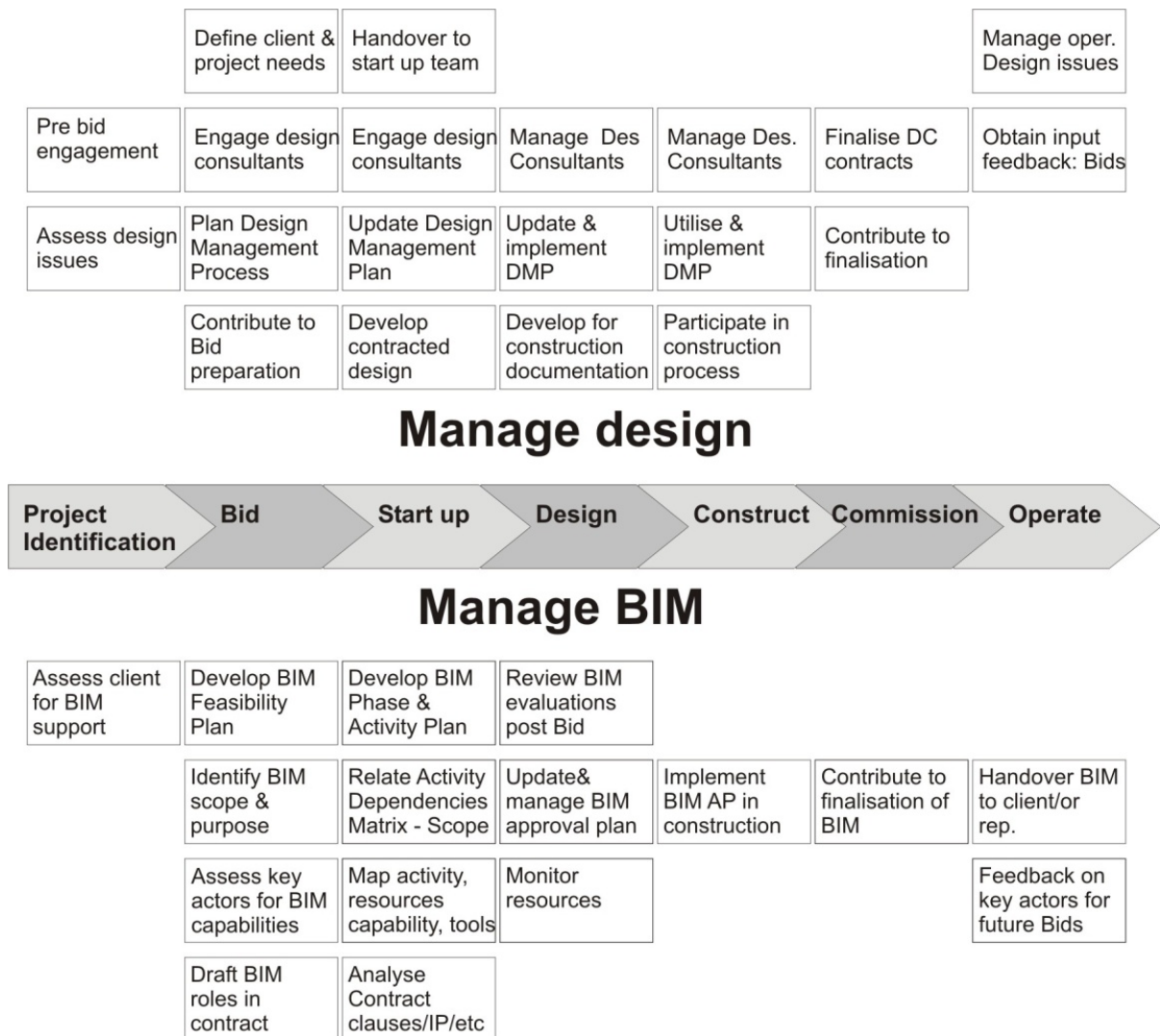

Figure 4.1 is generic and would appear to be applicable for lower levels of BIM adoption; however it is critical that such an explicit BIM Manager ensures that each of these steps is taken for a fully integrated BIM using a Model Server. In the early stages of BIM adoption it may be necessary to develop explicit work process roadmaps. If learning is transferred from project to project an organisation will gradually diffuse BIM adoption systemically and in time these will more than likely become normal behaviour and may not be necessary.

Key questions that a Model Server Manager needs to ask to begin developing such roadmaps include:

- What are the project phases the organization is involved in?

- What are the activities in each of the phases? e.g. modelling, visualization, detailing, design review, etc.

- What actors are involved and what are the authority relationships between actors, i.e. model owners, developers and users? How does the BIM Model Server Manager control the workflow?

- What are the dependencies between the activities?

- What information is required to be exchanged? What is the data transfer?

- What are the decision points for updating, reviewing, checking, signing off and uploading etc?

- What the sign off points?

- Who has authority to conduct review, update, check, sign off and upload?

The roadmap in Figure 4.2 is a sample Design management review process as a Flowchart indicating the relationship between Model Developers, Owners and Users and the central role of a BIM Manager.

Figure 4.2   Design management Review Process for Integrated BIM Model Server Environment

In Section 4.6 (Technical Requirements for Model Servers) more specific guidance is provided which describes how project activities relate to the development and analysis tools that are used by integrated BIM model users and developers. In the Model Server environment one of the key issues is exporting and importing of data from various file formats and therefore Tool Compatibility and the impact on the workability of the Model Server with regards to efficiency and effectiveness is critical.

Project collaborators would have their own process map depending upon their involvement and the type of procurement relationships and associated roles and responsibilities required. There are more roadmaps which can be developed at each phase which would involve descriptions of step by step activities, players, deliverables, resources and tools, risks and indicators for success. It may be necessary to develop explicit roadmaps in the early stages of implementing BIM initiatives. In time when learning from each project has been sufficiently diffused throughout an organisation various activities will become accepted behaviour and part of normal work practices and roadmaps may not need to be so detailed or they may be changed to suit the needs of the organisation.

4.6 Identifying technical requirements for BIM Model Servers

A fundamental principle towards achieving a fully integrated Level 3 BIM using a Model Server is efficient compatibility of tools. Although this is important for BIM development at any level it becomes critical at Level 3 Integration. Therefore the following section is concerned with providing guidance on identifying compatibility of tools to support Level 3 Integration and the use of Model Servers so that the technical requirements for Model Servers Section 4.6.3 is contextualized.

4.6.1 Identifying Compatibility of Tools:

A comprehensive knowledge of the available commercial BIM applications and their capabilities in relation to interoperability is important. Tools are constantly evolving and tool compatibility is dynamic. Firms can hire consultants to perform desktop audits. Alternatively, government agencies who are inclined to promote BIM adoption may have maintained such audit reports which can be easily accessed.

Given that 100% interoperability across the various proprietary tools is unlikely in the near future, knowledge of the degree of compatibility between the different tools will be useful in tool selection. Importing and exporting capabilities from native file formats into other file formats and associated metrics or efficiency indicators would be useful. Import and export efficiency indicators can guide BIM Model Managers decision making in the early setup stages. Early consideration of tool compatibility will typically avoid conflicts midway through the project. It is also useful to have a summary of conflict resolution strategies between tools, links to online tutorials on tool usage, and contact details of tool experts. The following Table 4.4 is one such example of a Tool Compatibility matrix. This can of course be customised to suit individual project and/or organisational needs.

The terms and representations used in Table 4.4 include:

Activity (Activity 1 / Activity 2)	Tool-compatibility matrices can be developed for specific levels.

Tool-compatibility matrices can be developed for specific levels.

For example, an interdisciplinary tool-compatibility matrix can be developed to assess the compatibility of tools across disciplines. In such cases typical **activities** could include architectural design, structural design, electrical layout, HVAC and plumbing models, energy analysis, clash detection and design review, and so on. This matrix will compare the compatibility of the tools used for each of these activities that are spread out across disciplines.

At a more detailed level tool compatibility matrices can be developed for **intra-disciplinary activities** for each of the broad disciplines. For example, typical activities within architectural discipline could include area programming and space layout, conceptual design and sketching, 3d modelling and visualization, detail design, and so on. This kind of a matrix will compare the compatibility of the tools used for each of these activities within the discipline.

Dark grey cells

Formats (or attributes) common to both tools and hence no data exchange issues or comparison is needed.

A1P1/ A1P2/….AnPi

Products available to be used within each activity. For example, there might be 3 tools (P1, P2 and P3) available for activity 1 (A1) that the assessor might consider. In case of architectural CAD design (activity 1) these three tools could be ArchiCAD (A1P1), Revit (A1P2) and Bentley (A1P3).

X1/ X2/ Y1/ …..

For each tool/product, is a list of data formats supported by the given tool/product is listed (e.g. X1 (DWG) and X2 (DXF) are data formats supported by A1P2 (Revit). Instead of data formats we can have other factors that are critical, depending on what attributes of products (tools) are to be compared.

Cells with dash line borders

These cells list down the summary of the relationship between two tools. These cells are created at the interaction of any two tools (tool 1 moving along the row, and tool 2 moving down the column). Useful information summarized in these boxes may include contact details of experts on corresponding tools, links to online tutorials, compatibility conflict resolution strategies (if any), useful tips on preferred data exchange formats, and so on.
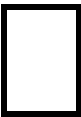
Bold border across multiple cells along the diagonal

The region bounded by bold borders along the diagonals represents intra-activity / intra-disciplinary tool-compatibility matrix. For example if Acitivity 1 was Architectural design for example, then within an architectural team the designer may only be interested in looking at the tools bounded within this region. However, if the information is to be exchanged with some other discipline, say Structural consultant then they may have to look at tools in the region overlapped by activity 1 (architectural design) and activity 2 (structural design).

	X1			
Y1	√	√	100	100
Y2	√	√	100	50

For example, Here X1 format of tool A1P1 is matched against data formats Y1 and Y2 of tool A1P2. Each cell to compare (for example X1 and X2, while checking product A1P1) can be divided into sub-cells corresponding to the number of elements to compare. In this case, four dimensions are checked. This could mean a vector representing values for <export possible (Yes/No), import possible (Yes/No), export efficiency (%), import efficiency (%) >. Hence, a

cell with values (√, √, 100, 50), as is the case while mapping X1 and Y2, would mean that both export and import are possible. While export efficiency from Y2 to X1 format is 100% the import efficiency from Y2 to X1 is only 50%.

Figure 4.3 shows a schematic layout of the tool-compatibility matrix.

Table 4.5 is a sample tool chart used at ARUP, which is primarily a spreadsheet to gather and maintain relevant information. For the proposed tool-compatibility matrix, simple programs such as Macros for MS Excel can be written to automate the look-up and search process, as well as for data input and populating the matrix.

Figure 4.3   Schematic layout of tool- compatibility matrix
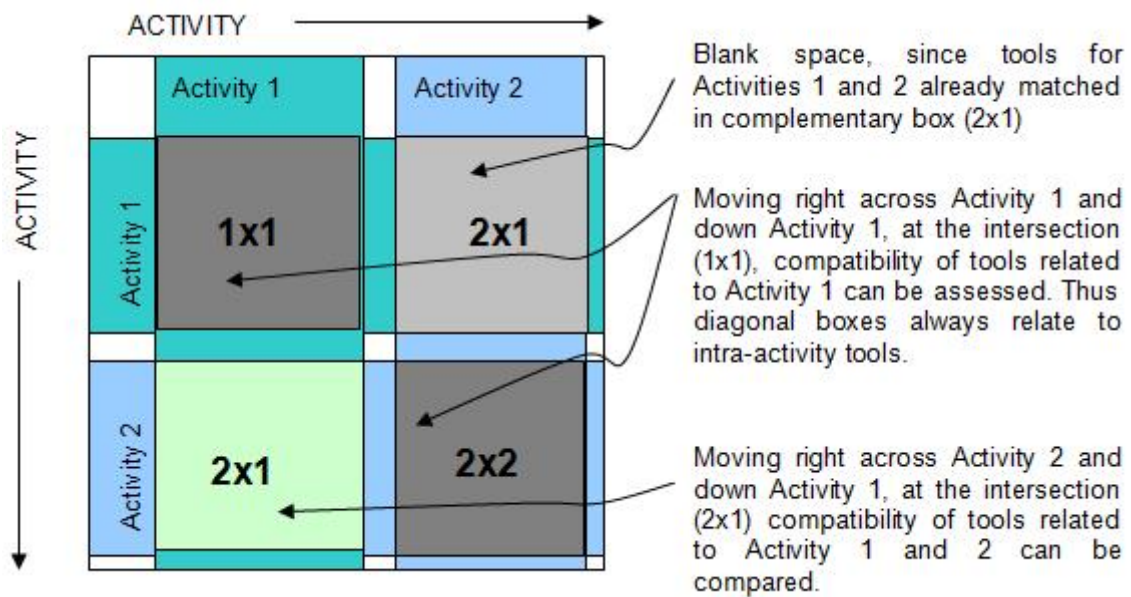
Table 4.4   Tool compatibility matrix

		Activity 1						Activity 2			Activity 3	
		A1P1			A1P2			A2P1		A2P2		
		Summary of tool A1P1 by itself e.g. experts details, links etc	X1	X2		Y1	Y2		Z1	Z2	Z3	
Activity 1	A1P1	X1	(dark)									
		X2	√ √ 100 100	(dark)								
	A1P2	Summary of exchange issues between A1P2 and A1P1	X1	X2	Summary of A1P2 by itself							
		Y1	√ √ 100 100	√ √ 100 0	Y1	(dark)						
		Y2	√ √ 100 50	X X 0 0	Y2	√ √ 100	(dark)					
Activity 2	A2P1	Summary of issues between A2P1 and A1P1	X1	X2	Summary of issues between A2P1 and	Y1	Y2	Summary of A2P1 by itself				

			A1P2									
		Z1	√ √ 100 50	√ √ 100	Z1	√ √ 100	√ √ 100	Z1				
		Z2	√ √ 50 50	X X 0	Z2	√ √ 50	X X 0	Z2	√ √ 100			
	A2P2	Summary of issues between A2P2 and A1P1	X1	X2	Summary of issues between A2P1 and A1P2	Y1	Y2	Summary of issues between A2P1 and A1P2	Z1	Z2	Summary of A2P2 by itself	
		Z3			Z3			Z3			Z3	
Act 3	A3P1											

Table 4.5   Part of the tool matrix used at ARUP

Software 1	Type 1	Software 2	Type 2	Contact name(s)	File Formats	Successful	Possible Methods (if not successful)	restrictions on outgoing info (out of Software 1)
Catia	Parametric geometry creation + more	Microstation	CAD	Steve Downing and Yamin	IGES	Yes		Unwanted geometry to be hidden in CATIA before export
Catia	Parametric geometry creation + more	Strand	Analysis	Steve Downing and Yamin	IGES	?		
Catia	Parametric geometry creation + more	GSA	Analysis	Steve Downing and Yamin	IGES/DXF	?	IGES to Microstation then DXF to GSA	Possibly only simple wireframe geometry, not surfaces etc
GSA	Analysis	Bentley Structural	CAD/3D Structural Modelling	Steve Downing	GWB/GWA	Partially		Steelwork models only at the moment
Strand	Analysis	Microstation	CAD	Steve Downing	DAT / programmed interfac	Yes		Custom text file format, suitable for steelwork models
Strand	Analysis	Bentley Structural	CAD/3D Structural Modelling	Steve Downing	ST7	under development	To be developed based on the GSA -> Structural link	
Autocad	CAD	SAP	analysis	Judith Leuppi	dxf	Partially	we fairly reguraly start out with a dxf file to create a model in an analysis program. Points and lines usually transfert successfully, everything else is not reliable	
Autocad	CAD	Enercalc	analysis	Judith Leuppi	dxf	Partially		
Autocad	CAD	Risa	analysis	Judith Leuppi	dxf	Partially		
Autocad	CAD	RamSteel	analysis	Judith Leuppi	dxf	Partially		
RamSteel	Analysis	Autocad	CAD	Judith Leuppi		Partially		
Catia/Digital Project	Parametric geometry creation + more	GSA	Analysis	Martin Simpson / Tristan Simmonds	FAF	Yes		Wireframes done so far - looking at methods for surfaces but need a mesher first (probably look at hypermesh)
GSA	Analysis	Optimisation	Optimisation	Martin Simpson / Tristan Simmonds / Rob Livsey	FAF	Yes		
Digital Project	Parametric geometry creation + more	MS Project	Project Management	Martin Simpson / Forest Flager	MS Project	?		Only works at the part or assembly level - Just started so more info will be known in a while
Digital Project/Catia	Parametric geometry creation + more	Autocad	CAD	Martin Simpson / Forest Flager	DWG/DXF	?		Just about to start this work now
Digital Project / Catia	Parametric geometry creation + more	Elcocad	Electrical Design	Martin Simpson	These are topics for this year - not started yet but will keep you posted			
Digital Project / Catia	Parametric geometry creation + more	?	Mechanical	Martin Simpson				
Digital Project / Catia	Parametric geometry creation + more	?	CFD	Martin Simpson				
Digital Project / Catia	Parametric geometry creation + more	Mass Motion	Crowd Sim	Martin Simpson				
Catia	Parametric geometry creation + more	discreet 3d max	3d modelling	Matteo Codignola	iges/stl to max	Partially		sometimes error on surfaces imported
Catia	Parametric geometry creation + more	GSA	Analysis	Riccardo Abello	IGES to DXF	Partially	IGES to 3d max then DXF to GSA	only wireframe and triangular 2d elements
3D+	Geometry creation	Tekla (Xsteel)	3D modelling/Fabrication	Peter Debney	SDNF	Mostly		Curved elements not translated properly
3D+	Geometry creation	Tekla (Xsteel)	3D modelling/Fabrication	Peter Debney	SDNF	Mostly		Curved elements not translated properly
GSA	Analysis	Revit	CAD/3D Modelling	Oasys				
GSA	Analysis	ASCII (GWA)	ASCII Format	Oasys	GWA	Yes		
GSA	Analysis	DXF	Data Exchange Format	Oasys	DXF	Geometry only		Centre-line geometry only
GSA	Analysis	CIS/1 (CIMSteel)	Data Exchange Format	Oasys	CIS/1	Yes		
GSA	Analysis	SAP v6	ASCII Format	Oasys	S2K	Mostly		
GSA	Analysis	NASTRAN	Analysis	Oasys	Bulk file	Linear properties only		
GSA	Analysis	LS-DYNA	Analysis	Oasys	KEY	Linear properties only		
GSA	Analysis	OpenSees	Analysis	Andrew Mole / Stephen He	Tcl text file	Preliminary		
ASCII (GWA)	ASCII Format	GSA	Analysis	Oasys	GWA	Excellent!		
DXF	Data Exchange Format	GSA	Analysis	Oasys	DXF	Geometry only		
CIS/1 (CIMSteel)	Data Exchange Format	GSA	Analysis	Oasys	CIS/1	?		
SAP v8 and later	Analysis	SAP2000 v8 .s2k text file	ASCII Format	CSi	S2K (v8)			
SAP v8 and later	Analysis	Microsoft Excel workbook	Spreadsheet	CSi	XLS			
SAP v8 and later	Analysis	Microsoft Access database	Database	CSi	MDB			
SAP v8 and later	Analysis	CIS/2 Step file (CIMsteel)	Data Exchange Format	CSi	CIS/2			
SAP v8 and later	Analysis	Steel Detailing Neutral file	Data Exchange Format	CSi	?			
SAP v8 and later	Analysis	AutoCAD DXF file	Data Exchange Format	CSi	DXF			
SAP v8 and later	Analysis	Frameworks Plus file	Analysis?	CSi	?			
SAP2000 v6 and v7 .s2	ASCII Format	SAP v8 and later	Analysis	CSi	S2K (v6)			
SAP2000 v8 .s2k file	ASCII Format	SAP v8 and later	Analysis	CSi	S2K (v8)			
Microsoft Excel workbo	Spreadsheet	SAP v8 and later	Analysis	CSi	XLS			
Microsoft Access datal	Database	SAP v8 and later	Analysis	CSi	MDB			

4.6.2　Technical Requirement Development for BIM Tools

This research primarily focuses on the technical requirements of a BIM model server and hence technical requirements for other BIM applications are not specifically explored. Since, a wide range of the BIM requirements exist, as reflected in the variety of BIM supporting applications, this research assumes that differences would exist across similar proprietary tools in their technical capabilities and approaches. However, some technical features that are generally found to be absent in most BIM supporting applications are listed here:

- Ability to export/ import information appended to objects:

All object oriented models have embedded information stored in object properties. In general, such information is copied during data exchange (export or import). However, when additional information is tagged to the objects those are generally left out during import or export. The ability to export or import such appended information will be particularly useful in model refinement and rework based on the design review mark-ups and RFIs tagged to the objects.

- Alignment of product libraries to actual product manufactures catalogues

Product libraries are critical to object oriented model development. Product library vendors often cater to specific proprietary CAD tools. Efforts are being made to generate digital representations and libraries of standard manufacturer's products that are available in the market. This requires a collective effort from CAD vendors and manufacturers such that design development, constructability and design specifications can be improved in the digital models.

- Design rule editors

The core of BIM model development lies in the intelligence of the object oriented packages that constrain object relationships. Since requirements and regulations vary across different projects and regions such object relationships change as well. Hence, CAD packages should allow CAD users to modify and edit such object relationships and constraints in form of simple design rules. Language of such rules should be simple enough such that building regulations can be easily copied and inserted to get desired modelling constraints and checks.

- Standard names and labels for features and tool capabilities

It may be useful to have a common agreement on the labels and names for various features and tool capabilities such that two different proprietary tools can be compared directly. Lack of such standards may lead to different names for similar features and similar names for different features across different products, making comparisons and benchmarking difficult.

This is an indicative list and other similar features and technical requirements for BIM supporting applications need to be explored.

4.6.3　Technical Requirements for BIM Model Servers

In terms of their importance, the technical requirements for a model server can be categorized as operational technical requirements and support technical requirements.

Operational technical requirements refer to the features needed during usage of the model server. Some of operational technical requirements relate to user log-in and access, data import and export, data management and organization, version management, user interface, navigation and visualization, and so on.

Support technical requirements such as help menus, tutorials, FAQs, and so on are required to facilitate usage of the model server. Support requirements have traditionally been a part of all technological tools and have been critical to technology adoption and user support. In collaboration-based tools such as some of the DMS (e.g. Aconex, Team Binder, Project Centre, INCITE) templates, assessment matrices are other support technical requirements that have been included to facilitate set-up and implementation of the collaboration platform

for project needs. Hence, one of the important support technical requirements of a BIM model server designed to function as a collaboration platform includes project decision support features and functionalities.

In general, the technical requirements (see 4.6.3) related to groups 2, 3 and 4 have more or less been included and partially or fully developed in the model server studied in this research. However, only a few of the technical requirements related to group 1 have been considered thus far in the existing model servers.

A summary of the technical requirements for a BIM model server that can be used as a collaboration platform is provided in Table 4.5.

Technical requirements for each of the categories 1, 2, 3 and 4 are detailed in Tables 4.6, 4.7, 4.8 and 4.9 respectively. Column 2 provides a description of the requirement and sub-requirements. A check in column 3 suggests that this requirement is completely met (M) in existing model servers. A check in column 4 means the requirement is partially met (P). If neither of columns 3 or 4 is checked, it means the requirement has not been considered in existing model server, as tested in the case studies.

Table 4.6   Non-functional requirements for BIM model server

Non-functional Technical Requirements		Compliance
BIM server based collaboration platform set-up assistance tool		M, P or X
	Project BIM decision support application • Software Tool compatibility matrix • Project- BIM scoping support	X
	Server administrator support • System configuration manager • System configuration layout viewer • System status viewer	P
	Training and support	P
	Legal and contractual	P
BIM Model management		
	BIM model organization • model repository • sub-models and objects at different levels of details • Public and private model space • GUID, Information Delivery Manuals and problems encountered in merging different discipline-specific models	P
	IDM related specifications	M
	Model access and usability • secured log-in with access rights • Hierarchical model administration structure • Download/Upload model/ Check- in/ Check-out/ Check-out with lock • Version lock and archiving • Model viewing and screenshots • Documentation and reports	M
	Interface • Customizable window layouts and interface • On line viewing, printing and markups	P

• On-click object property check/edit/modification		
Distributed/ virtual design review		
Interaction and communication		X
Navigation		P
Data Security		
Certified network security		P
Encrypted passwords and access		P

Table 4.6 Technical requirements and features related to BIM decision support application, lists the technical requirements related to Category 1 i.e. BIM server based collaboration platform set-up assistance. It would be desirable that within the BIM Model Server environment a Project BIM Decision Support Application is developed. The main technical requirements related to BIM collaboration platform set-up include:

- **Project BIM decision support application:**

Data collection for the project requirements

- Initially workflow process maps/flowcharts should be developed as discussed previously. Further to this more specific data collection on information flow and workflow dependencies should be developed. Various charts/forms would be a useful way to gather this data from project team members and client. These should be accessible online through a web-based interface with secured log-in, such that data integrity is maintained. It should be possible for users to download the forms, work offline and upload it when they are filled. In addition, users should be able to save partially filled forms and log-in at a later session to complete and submit the same.

Identification of information and workflow dependencies

- Once the data has been collected, it would be ideal if users could **generate dependency matrices** automatically, however it may be necessary to develop these manually in the first instance. Graphical representation of the dependencies for easy comprehension and viewing is advisable.

- **Text-based search** of required dependency data is desirable. For example, if the user enters an activity say "design review", the viewer should show various dependent activities and people, based on what dependency is being sought to observe. Such dependencies can be based on activity, people or resources (tools).

- Once the dependencies are approved and agreed upon, application facility to allow setting up **reminders and automated notifications**. These notifications should be sent across the medium of communication preferred by the target user, i.e. through SMS, FAX, EMAIL or any other medium.

Analysis of tool compatibility

- It would be ideal if the Tool Compatibility Matrix resides on the Model Server and can be accessed online. It would require data collection forms and GUIs for representation, viewing and editing of the data.

- A directory of tool experts, and related online tutorials and FAQs would provide useful support. .

Scoping for BIM usage in the project

- In a typical project there are various levels of association and roles. Some of the personnel in the project may not have direct access to the BIM Model Server for various reasons. However, in order to successfully use BIM as a collaboration platform it should be possible to receive and upload information (not necessarily model) to the BIM server through other media. Such, technical capability is supported by document-based collaboration platforms and hence similar expectations exist from a BIM-based collaboration platform. These requirements enhance the scope of BIM usage in a project.

- Some technical capabilities such as ability to capture real-time data from site are important for on-site/ off-site project coordination.

Server administration support

- A BIM Model Server integrates with other tools and applications such as CAD tools, analysis tools, discipline specific applications, DMS, etc. This integrated system can be configured differently to suit the project requirements. Hence, in order to facilitate the BIM administration a **System Configuration Manager** (**SCM**) is required. The SCM should ensure that the System configuration complies with project dependencies (as identified from dependency matrices), allows interactivity between models, documents and linked information. It will be useful if the configured system supports automation of the integration of discipline-specific models to a merged project model to improve the effectiveness and accuracy of the model construction.

- SCM should have a flexible user interface. It should support rules that regulate the information provided to be suitable for, and easily adopted to needs of:

  o different users including designer, contractor, facility manager and client,

  o different building project life cycle ranging from project identification to bid, start up, design, contract and operate, and

  o different scales of collaborative projects

- **Instant direct communication**, e.g. chat room and videoconference, and indirect communication, e.g. broadcasting and email, should be supported by the system to improve the understanding of project development and control.

- A **System configuration layout viewer** is required that graphically shows how different types of data are linked. Similarly, a System Status viewer is required for notification of errors, activities update, update on system performance, and user status e.g. how many users are logged-in at a given time.

- A **Data Change Register** is required to maintain the history of the changes made to the data.

- The administrator should be able to generate reports, **back-ups** and archive data either manually or through a pre-set default value (time or size) for automated activation.

Training and support

- Training and support is critical in the initial phase of BIM server based collaboration platform set-up. Training support varies with the roles and responsibilities of the users. For example, administrator or sub-administrator training needs to be more detailed and intense than other users. Various types of training materials and approaches can be used in conjunction such as

  o Traditional training and support tools that include **FAQs, help menus and helpdesk.**

  o **Technical support blogs** that maintain threads of earlier complaints and resolution methods reported by other users and experts. Such blogs allow

users to learn from each others experience, and are commonly used in open source software development.

- o Similarly, **Project-wiki** can be created on the server to share project information and tool usage information.

- o Online tutorials can be linked to technical support blogs. It will be useful to have **interactive tutorials** such as those already available from various proprietary tools.

- o The **expert directory** maintained in the tool-compatibility matrix can provide another point of contact for training support.

Legal and contractual

- The model development, reviewing, uploading, downloading, and analysis activities could be quite complex within an integrated BIM model server environment. Specific ownership, updating liabilities and responsibilities would need careful consideration. A Model Server Use **contract agreement** is required which should be signed and agreed upon by the project partners at project initiation. B**usiness rules** are then also needed as a technical feature for model management and data organization such as archiving, record keeping, backups, and so on. It should be possible to automatically check if these rules conform to **IDM** specifications [ie information Delivery Manual, which is a comprehensive document that details the approach to using and developing an BIM model] and national BIM guidelines.

- Alternatively, a conflict check feature should be provided to ensure that the business rules generated from IDM and national BIM guidelines do not conflict with the contract agreements.

- Among other aspects, the legal and contractual agreements should account for

- o **Intellectual property** agreements and policies for data exchange

- o Classification of **public and private data**, and

- o **Correspondence protocols**

Table 4.7 indicates if EDM provides the various features and also is a useful checklist for the BIM Manager operating within the Model Server environment.

Table 4.7   Technical requirements and features related to BIM decision support application

Project BIM decision support application	M	P
Project information and workflow dependency data collection charts and forms	x	X
Dependency assessment matrices	x	X
▪ Graphical interface and dependencies viewer with visual edit capabilities		
▪ Dependency conflict highlighter and marker		
▪ Dependency rule editor		
▪ Text-based dependency search		
▪ Automated dependency notifications and reminders		
▪ Automated information distribution based on approved dependency matrix		
Software Tool compatibility matrix	x	X
▪ Tools data collection charts and forms		
▪ Graphical interface and viewer with visual edit capabilities		
▪ Tool compatibility conflict marker and highlighter		

- Text-based Tool query and search
- Directory of tool experts and support contacts
- Links to online tutorials, blogs & forums specific to each tool & application

Project- BIM scoping support   x   X

- Server access through other media such as FAX and EMAIL
- Register real time site data through on-site installations (e.g. cameras) and mobile devices (PDA).
- System setup support

Server administrator support   x   √

- System configurations manager with flexible user interface:
  - Ownership and control of objects and models
  - Interactivity between the text-based information & 3D models of objects
  - Automation of integration of discipline-specific models with merged model
  - Links to external databases and repositories
- Instant direct communication.
- System configuration layout viewer
- System status viewer
- Data change register (maintain history)
- Periodic report and archiving of system use and data change
- Automatic data backups
- Maintain backup thread
- Options to set/edit/modify default settings for users/administration structures
- Options to set/edit/modify default settings for model objects (nomenclature, sub-model affiliations based on creation time and date, and so on)
- Automatic notifications &instructions for changes to model server project set-up properties
- Model development protocol based on IDM & recommendations from BIM national guidelines
- Back-up administrator log-in

Training and support   x   √

- Technical support blog
- Online tutorial linked to technical support blog. Project wiki
- Expert/ user directory and hotlinks
- FAQ's for common queries
- Helpdesk

Legal and contractual   x   √

- Model server use contract agreement
- Business rules to comply with contractual agreements
- Correspondence register

- Public and private data
- Intellectual property agreements and policies for data exchange

Table 4.8 lists the technical requirements related to Category 2 (BIM Model management). The main technical requirements related to model management on a BIM server are:

- **Data organization related features**

  o Centralized **data repository**

  o **Hierarchical model structure**

    - Flexibility to choose model structure. For example, at present the model-tree in EDM has the following hierarchy: project > site > building > building storey. Users may want the structure to be based on their requirements, for example a client may want to group projects within a site rather than the other way round i.e. site > project > building > building storey, and so on. Such ability to customize the model structure should be supported by the model server.

    - The model server should support cross-project information exchange, if desired by the client.

- **Standard naming conventions:** Features should be provided that provide easy edit/ rename/ modification to nomenclature system mid-way through the project, with appropriate edit rights.

- Ability to store and present objects of the model as text-based information in repositories and 3D object-model in Model Viewer.

- Object and model **ownership records** should be maintained

- The model server should provide ability to **overlay additional object properties** to each object if a customized object property is desired and not available in standard data formats. For e.g. IFC property may not have Quality of survey as an object property. In such a case for each object, this can be an overlayed property linked with each object. Technical issues may arise if the data is downloaded and uploaded again. Additional technical measures may be required to deal with such issues.

- The model server should provide ability to **map objects at different detail levels** of detail through automated nomenclature standards. For e.g. If detail level 1 only shows a rectangular volume for a room, and level 2 detail of same volume shows all openings and doors and windows, then such switch should be possible by a single click. This requires mapping of objects at different levels of detail. For this to be feasible the model development process needs to be defined.

- Ability to maintain **public and private model**. Public model is accessible to all users with access rights. Private model could be model in progress, but not ready to be shared with others.

- Solutions are required for **GUID**, Information Delivery Manuals (**IDM**) and scaling problems encountered in merging different discipline-specific models using EDMmodelServer™.

Model access and usability features

  o **Secured log-in with access rights:** it should be possible to import roles and personnel data from information flow dependency matrix generated in the BIM model server set-up phase.

- **Hierarchical model administration structure** should be possible to comply with the project team structure.

- Various combinations of **access rights** options should be possible based on the following options: create, delete, execute, private, write, read and none.

- **Download model:** Various modes of interaction for model download are possible to include download buttons as well as drag and drop options. It may be useful to explore download straight to an email account, which is possible in some of existing DMS when downloading documents.

- **Upload model:** As with download, various modes of interaction for model upload are possible to include upload buttons as well as drag and drop options. It may be useful to explore upload straight from an email account, which is possible in some of existing DMS when downloading documents.

- **Check-in** options should allow adding in new partial model or merging with existing model. Again, different modes of interaction are possible to include buttons and drag and drop capabilities.

- Similarly **check-out** should allow download of complete model or partial model using different modes of interaction.

- A **check-out with lock** feature should be provided to notify other users that the checked-out data has been locked and deemed not-usable.

- A **version lock** feature should be provided to lock version of the model after sign-off, as a form of archiving.

- When downloading a part model from model server, options should be provided to **generate reports** on parametric information, linked information, and external information for included objects and objects in the rest of the model. This information can be in form of a checklist, where users can choose to get details of only those objects they intend to modify, delete or replace. Ideally, a facility to append this information to objects (again by selection) will be helpful, but that would be useless until the native applications can receive those additional data.

- Features should be provided to **validate IFC rules** or other similar rules while uploading the files. Users should have the option to switch validation check on or off.

- Technical provision for **data ownership transfer** and handover should be provided. These should account for security measures to deal with such change of hands and log-ins and passwords.

- Ability to **generate and export PDF** or other document formats should be provided. This is specifically useful for users' not needing model but only documents. This capability also allows direct offloading of ready to use information to DMS, in which case some users may not need to access the model server at all. They can continue interacting with DMS as they have been doing at present.

- Ability to **capture screen shots** and store them for later use and reference should be provided. This should include ability to capture manually rotated and navigated views as animations. These should be offloadable and readable from external database.

- Option to choose the **level of detail for viewing** should be available at the click of a button i.e. sub-sets should be managed such that by single checklist level of detail for viewing can be selected e.g. conceptual block model, space layout model, etc . Such sub-models can be maintained based on detail levels discussed in BIM national guidelines project.

- o It may be useful to have the ability for **shared document development** such as the one provided by Googledocs.

- o Ability to **integrate information from product libraries** should be provided. It should be possible to create a comparison report for alternative product options. This feature can be a web-based plug-in to the model server.

- **User interface:** Other than the standard user interface features (command line interface, customizable toolbars, etc) the model server interface should include

  - o IFC tree view position and 3D viewer position

  - o Support for on line viewing, printing and markups

  - o Ability to click on an object and check what all sub-sets it belongs to, and

  - o Ability to click on an object and switch between the sub-sets it belongs to for sub-set selection. Users should be able to switch this option off.

Table 4.8   Technical requirements and features related to BIM model management

BIM Model management	M:X	P:√
BIM model organization	X	X
Centralised model repository	√	√
Flexible, hierarchical model structure	X	√
Standard editable model naming conventions	√	√
Text-based information in repositories and 3D object-model in Model Viewer.	√	√
Linked text-based information and 3D models of objects to control the accurate interrelationships between objects and the model.	X	√
Maintain data ownership label	√	√
Option to overlay additional object properties	X	√
Map related objects at different detail levels	X	X
Maintain public and private model.	√	√
Solutions for GUID, IDMs and scaling problems encountered in merging different discipline-specific models using EDMmodelServer™.	X	√
Model access and usability	**X**	√
Secured log-in with access rights	X	√
Hierarchical model administration structure	√	√
Access rights options: create, delete, execute, private, write, read and none	√	√
Download/Upload model (using buttons or drag and drop option)	X	√
Check- in/ Check-out (complete model or partial model) (modes: button, drag and drop)	√	√
Check- out with lock (complete model or partial model) (modes: button, drag and drop)	√	√
Version lock (lock version of the model after sign-off, as a form of archiving)	√	√
Option to generate reports during data transfer (report on parametric information, linked information, and external information for included objects and objects in the rest of the model)	X	X

Option to validate IFC rules or other similar rules while uploading the files (option to switch validation check on or off)	√	√
Provision for data ownership transfer and handover	√	√
Export PDF and other document formats	X	X
Capture screen shots and manually rotated and navigated views as animations	X	√
Option to choose the level of detail for viewing	X	√
Shared document development capability	X	X
Integrate information from product libraries and option to create a comparison report	X	X
Interface	**X**	√
Command line inputs and editing	√	√
Modular and customizable tool bars	X	√
Customizable window layouts and interface	X	√
IFC tree view position and 3D viewer position	√	√
Support for on line viewing, printing and markups	X	√
Multiple object selection for creating sub-models or groups using hot keys	X	
On-click check for object membership (sub-sets it belongs to)	X	X
Optional on-click switch between the sub-sets related to object membership	X	X

Table 4.9 lists the technical requirements related to Category 3, which is distributed/ virtual design review. Table 4.10 lists the technical requirements related to Category 4, which is data security.

Table 4.9   Technical requirements related to distributed/ virtual design review using BIM server

Distributed/ virtual design review	**X**	√
Support parallel video conferencing and similar interaction media	X	X
Ability to capture real time interaction data from meetings and online reviews	X	X
Lightweight navigation and viewing of 3D data	X	√
Instant document/ message exchange window parallel to review window		
Instant, online mark-up, tagging and highlights on a shared document or model		
Ability to tag comments to objects and related documentation		

Table 4.10   Technical requirements related to data security on BIM server

Data Security	**X**	√
Certified network security	√	√
Encrypted passwords and access	√	√

The Model Server is one of the more innovative BIM tools and is not yet widely adopted in the industry. There are changes occurring all the time with regards BIM tools, some incremental and some quite significant. One of the more interesting innovations in recent times is the development of an open-source Model Server. The Building Information Modelserver, or BIMserver, enables you to centralize the information of a building. It is open source (GPL) and uses open standards (IFC). For further information: BIMServer.org. A brief summary of technical features of BIMServer.org, is repeated here and presented in Table 4.11.

Table 4.11   Technical features BIM server. Org (Source: http://www.bimserver.org/features/)

feature	free version	plugin	more info
Simple Merging	✅		Merge your own model into the shared model.
Simple Versioning	✅		Go back in time. See who made which changes and when.
Filtering	✅		Get only the windows from a model, or get one specific wall. These simple filterqueries are possible.
Userinterface	✅	✅	The free version has a great userinterface. Get a plugin for extra features.
Objectlinks	✅	✅	Link to objects (free version) or manage advanced features (plugin).
Change-triggers		✅	Sends a mail or SMS message when someone changes something you are tracking.
Advanced Merging and versioning		✅	Advanced, intelligent merging- and versioning capabilities.
PMO (Private Mobile Office) compatibility		✅	Interact with this high end technology.
IFD compatibility		✅	IFD compatible data processing.
CAD connectors		✅	Connect live with commercial software (like Revit for example) without converting from and to IFC.
Advanced Querying		✅	Make use of the query language to alter you model.
Sketchup export		✅	Exporting collada data for use in Sketchup.
GIS link		✅	Linking BIM to GIS
ifcXML export/import		✅	The free version uses the STEP format for IFC. This plug-in lets you use ifc XML too.

4.7   Integrating the Decision Framework

This section is presented to stimulate discussion and thought about how best to integrate the Decision Framework into existing work practices. It is primarily a tool for reflection of practice. Clearly our challenge with BIM Model Servers is that *it is not just a technical solution*, it is a *business process*, an *education program*, a *changing of work culture*, and a *procurement and contractual dilemma.* It is a combination of elements which will facilitate the move to collaborative Model Servers. At the core of the Decision Framework has been the Technical Specification for a Model Server. However it is the non technical contextual environment to

support and facilitate Model Server implementation that should also be considered by clients and industry participants as model developers, owners and users in practice have many decisions to make along the way towards achieving Level 3 Integration.

Online collaboration and web-based services are increasing. The scope of BIM applications in such a scenario is bound to change. In order to achieve the goal of Integrated BIM model development, BIM supporting technologies should be able to manage all the information related to the project. This includes information stored within the object properties, communication exchanged during the project development, mark-ups and comments, and other data linked to the project and the model at different phases of the project development. Thus, BIM approach of the future will not only include information embedded into the models but also the information appended and linked to the models. BIM approach of the future will require integration of the experience and technologies from CAD as well as document management systems. BIM Model Servers are likely to emerge as the future collaboration platforms for integrated digital design development and management. The BIM Model Servers will combine the capabilities of object-oriented CAD packages and document management systems or at the least support bi-directional link between object-oriented models and all related and appended information, which can come from a set of plug-ins and add-on tools.

A number of BIM supporting tools have already emerged and this number is likely to increase. In such a scenario, a variety of tools will co-exist with specific capabilities and limitations. While ideally, interoperability can be achieved at some point but market competitiveness and business alliances may prolong the goal. In the meanwhile, the AEC industry will continue to be dependent on proprietary tools. Hence, amid this growing number of specific applications with varied capabilities and compatibility the selection of the right tools will be critical to project effectiveness.

With more distributed design and greater inter-firm specializations the need for coordinating project resources and capabilities is likely to increase. As can already be seen, some of the ad-hoc processes in technology integration and selection may prove detrimental to project success. The higher role of technology will necessitate better decision making for technology and tool management across the firms and specific to project requirements. This is where a Project Life cycle Collaborative BIM Decision Framework will be useful. However, given the increasing number of tools and factors dependent upon tool selection this framework itself should develop into a BIM management tool, preferably accessible to project partners with a web-based online interface. A technical implementation of the decision framework is envisioned as the BIM managers' tool that can interact with other project information management tools to support collaboration set-up and coordination for integrated digital design development.

4.7.1 Business process

In general it is expected that the Collaborative BIM Decision Framework can be implemented through one or more of the following business channels:

- Client as the driver: The client may identify the benefits of a structured BIM project management approach to implement a Model Server and require a report on strategy and analysis of the project collaborators capacity to operate within Model Server environments. In such a scenario, the decision framework will prove to be a useful tool in assessing project implementation risks and opportunities at a very early stage of the project.

- Leadership of parent/dominant organization: large firms involved in design and construct that have to manage the project complexities will benefit from the decision framework. The Thiess Management System is an example of such a detailed framework and as mentioned earlier, discussions with representatives from Thiess was the initial encouragement for the BIM project decision framework.

- Application vendors and market opportunity: A number of project information management tools have evolved in the market (e.g. Newforma Project Center) with

some success and acceptability. From the recent developments it is it is evident that new roles such as BIM Model Managers and BIM Model Server managers are emerging. Analogous to project management tools (for project managers) a BIM management tool (for BIM model/server managers) implementing the BIM project decision framework is a very likely possibility. Such applications may eventuate as plug-ins to existing project management tools, embedded in Model Servers or be developed as standalone applications.

- Government regulation: Government agencies intending to promote BIM usage and adoption may promote and/or require an initial BIM project plan as part of the project assessment and approval process. This will be particularly useful for government projects requiring project participants to deliver BIM models and to work at high levels of integration and use Model Servers. The BIM project plan would become a necessary part of the project bidding stage. For such strategic and significant projects a BIM project decision framework in some format will be critical to development of such a BIM project plan.

- Requirements for loans, insurance and financial agencies:

Financial agencies that approve and finance construction projects may consider a BIM project plan to assess the inherent risks and opportunities in project collaboration and development. 4D- 5D models are desired because they provide greater cost estimation and detail before the construction phase. Thus, an understanding of the project collaborators BIM capabilities will allow such agencies to judge if such expectations of detailed and accurate models is realistic or not.

4.7.2   Evaluating skills, knowledge, behaviours and capabilities:

The use of BIM Model Server as a collaboration platform requires various levels of skills, knowledge and capabilities. Some of the indicative roles and responsibilities are listed here with the expected skill, knowledge and capabilities:

- Server feature developers and technicians
  - o Intermediate/ advanced programming and coding skills
  - o Advanced internet and networking skills
  - o Familiarity with project management processes and approaches

- Server management and administration
  - o System administration and troubleshooting skills
  - o Basic programming and coding skills
  - o Project management and organizational skills
  - o Advanced internet and networking skills

- Model management and administration
  - o Project management and organizational skills
  - o Familiarity with 3D and CAD packages
  - o Familiarity with design development processes and regulations
  - o Basic internet skills

- Model users and model developers
  - o Modelling skills and competence in 3D/ CAD packages
  - o Domain expertise and knowledge (e.g. thermal analysis, structural analysis, etc)
  - o Basic internet skills

- Document users and model viewers
    - Basic internet skills
- Others: e.g. on-site workers, tradesman, etc
    - Basic technological skills such as handling Cell phones, SMS texting, etc

4.7.3   Support, Training and Education

Support, training and education for BIM Model Server implementation is required at various levels including:

- Formal courses in schools
    - Designers
    - Modellers
    - Project managers
    - Analysis tools within various disciplines
    - BIM experts e.g. BIM manager
- Training of project staff and new recruits
- Continuing education and professional development programs for existing users
- Information sessions and briefings for decision makers
    - Clients and senior executives
    - Stakeholders and suppliers
- Online resources and collective learning through blogs, discussion forums and open source development

The Framework has concentrated on the specific technical requirements for Model Server implementation. It is too large a topic to deal specifically with support and training however suffices to say that the appropriate level of training and support is required and after a skills audit some plan should be developed. It is also worthwhile to note that as most participants [model builders] would be operating at a reasonably high BIM knowledge level and so it is only that specific training that is required to move into a collaborative environment. Model users may require a certain level of training and support with Model Servers and the Model Server manager would need to ensure that this happens. Finally a certain level of 'education' and awareness is necessary for the client but only to the level that is necessary and this is probably one of the next challenges for the future.

4.7.4   Steps to customise the framework

When working through this Decision Framework organizations should consider how it can best be incorporated into their project. There are so many different scenarios on projects that it is nearly impossible to account for all the different decisions that would be needed to implement a Model Server. Figure 4.4 displays a flow chart of the process that an organization charged with the responsibility of setting up a Model Server should follow when integrating the material in this Framework.

What to implement, how to implement, who pays, etc are all questions that model owners will need to grapple with. Many of the activities discussed in this Framework are common sense – whilst some are not and are quite technical. Regardless of whether or not it is common sense it is surprising how often we "jump in the deep end" with poorly thought out plans of how we will swim to the other side or whether we can. Leadership is required in the early stages of a project. We have suggested that a BIM Manager is required and strong support from senior executives and the client – in time such an explicit role may not be necessary. One of the challenges we face is that there is little experience to draw from in the industry and so with many innovations it takes time to become more widely adopted. Such a step

wise and systematic approach advocated in this framework will more than likely not be necessary once Model Servers have been in use and have become an accepted practice. Further to this, it is strongly advised that the Decision Framework is incorporated online as an additional tool within the Model Server environment and various charts/forms/matrices are customized to suit specific project and/or organizational needs; along with any national guidelines and/or codes of practice that have been developed. With increased knowledge will come increased diffusion of the use of BIM Model Servers.

Figure 4.4   How to Customise the Decision Framework
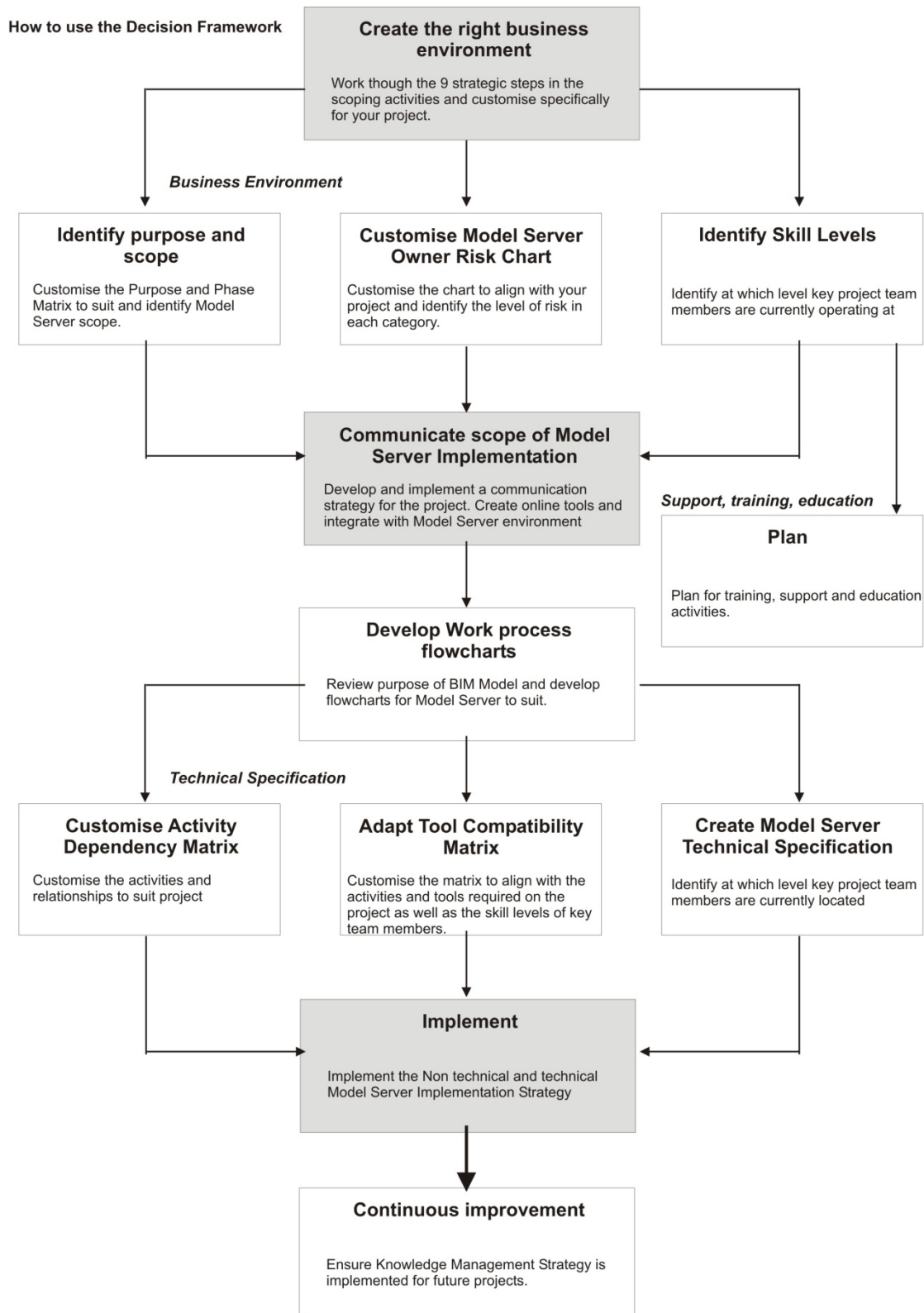
5. MODEL SERVERS AND PROJECT COLLABORATION TOOLS

While the capabilities of model servers have been discussed in the previous sections of this report, two issues that have not been addressed are:

- How model servers currently fit with existing project workflow/collaboration tools; and
- How the use of model servers will impact on the implementation of workflow/collaboration tools in the future.

Responses to these questions will be provided through examinations of:

1. INCITE (developed by Nexus Point Solutions, http://www.incite.com.au/) an online project collaboration system;
2. EDMmodelServer™/IFC (http://www.epmtech.jotne.com/built-environment.79297.en.html), a model server implementation that supports the IFC information exchange standard; and
3. the IFC specification itself (http://www.iai-tech.org/products/ifc_specification/ifc-releases/summary).

5.1 Nexus Point INCITE

INCITE has two products which suit different sizes of contract – Project Collaboration for large projects across any infrastructure projects, and Project Office for smaller projects up to AU$20M in value. The general approach is illustrated in Figure 5.1.

Figure 5.1   INCITE project relationships (Nexus Point, undated-D)
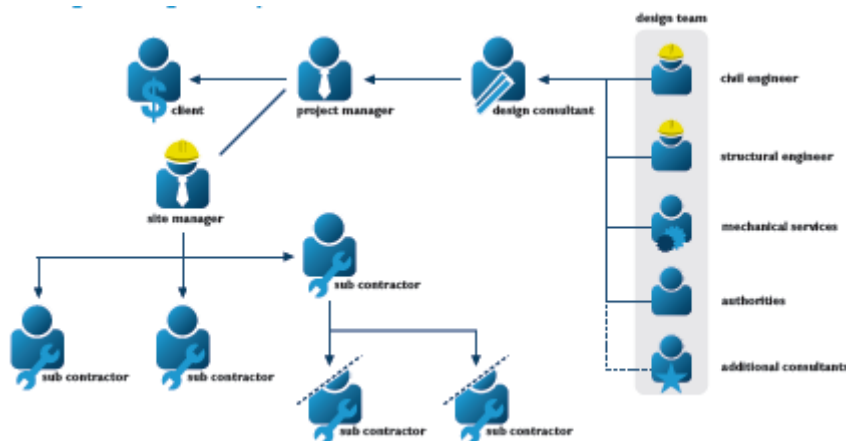

Project Collaboration contains five modules:

1. Design Management Module
2. Correspondence Module
3. Instruction Module
4. Variation & Approval Module
5. Reporting Module

The Design Management module supports the distribution and management of drawings through participant notification via predefined workflows, live drawing lists, records of drawing movements and archiving. These processes are supported through drawing number schemes, filing systems, search functions, drawing lists (Figure 5.2), distribution lists, defined workflows, design schedule management, connection to print services providers to support printing of drawings, online drawing viewing and conferencing around shared drawing views.

Figure 5.2   Drawing schedule (Nexus Point, undated-B)
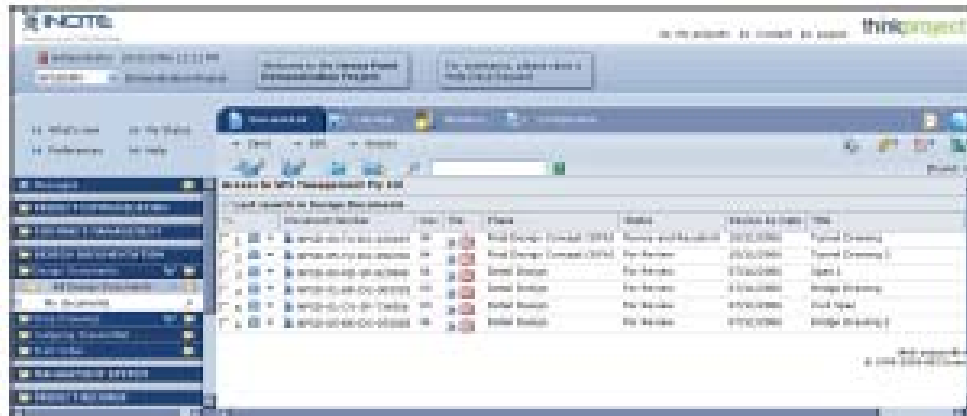

The Correspondence Module handles the following forms of communication:

- emails incoming and outgoing
- faxes incoming and outgoing
- scanned incoming correspondence
- letter creation

Microsoft Office templates can be used to generate correspondence documents, including company logos, letterheads, etc (Figure 5.3). Processes can be linked to document receipt functions so that incoming documents are automatically forwarded as either email or fax. All documents are automatically stored with date stamps and archived with full audit trail. Full text indexing is available on all correspondence; although it is not clear whether incoming paper correspondence is converted to text when scanned. Key words can also be added to documents to assist in identification and retrieval.

**Figure 5.3   Generation of letter from standard INCITE template (Nexus Point, undated-A)**
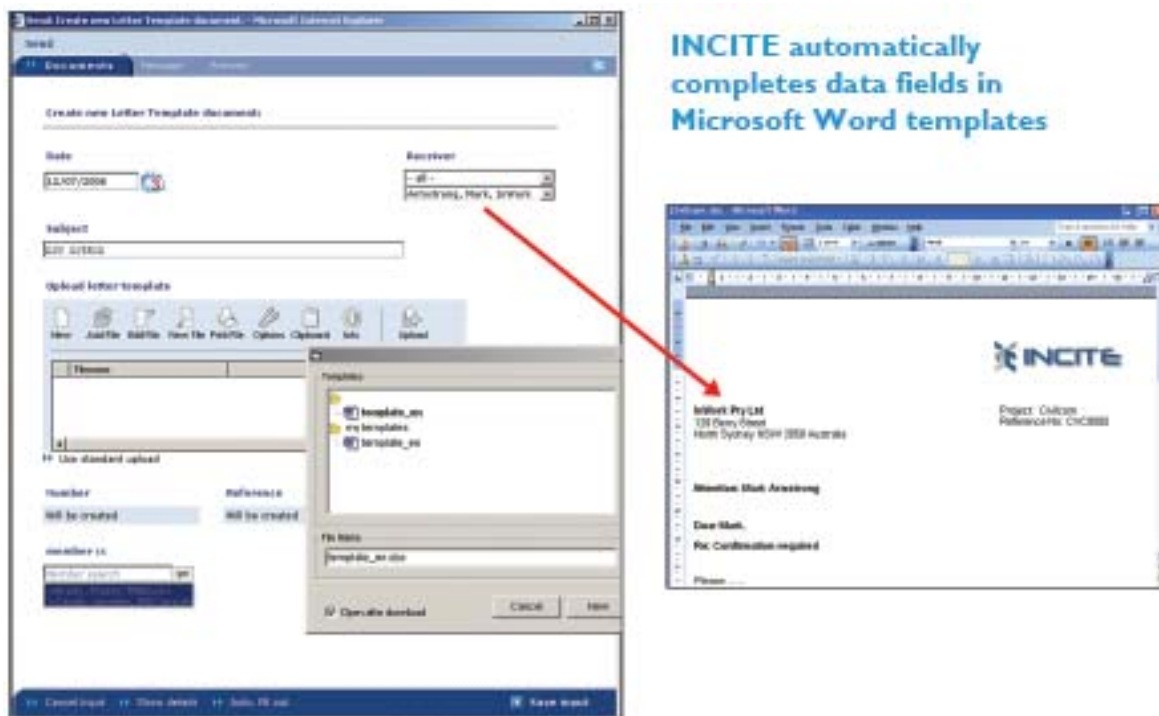
The Instruction module handles the standard Requests for Information - site instructions, client instructions, hold point notifications, notifications of inspection & testing and notifications of delay.

INCITE tracks the workflow around RFIs and variations (Figure 5.4). Due dates can be assigned to each process to support tracking and identification of delays. Access permissions can be applied to individual fields in forms to restrict visibility of sensitive information. Reports can also be generated.

Email can be used a communication mechanism to people who can not access INCITE.

Figure 5.4   **Workflow from RFIs (Nexus Point, undated-C)**
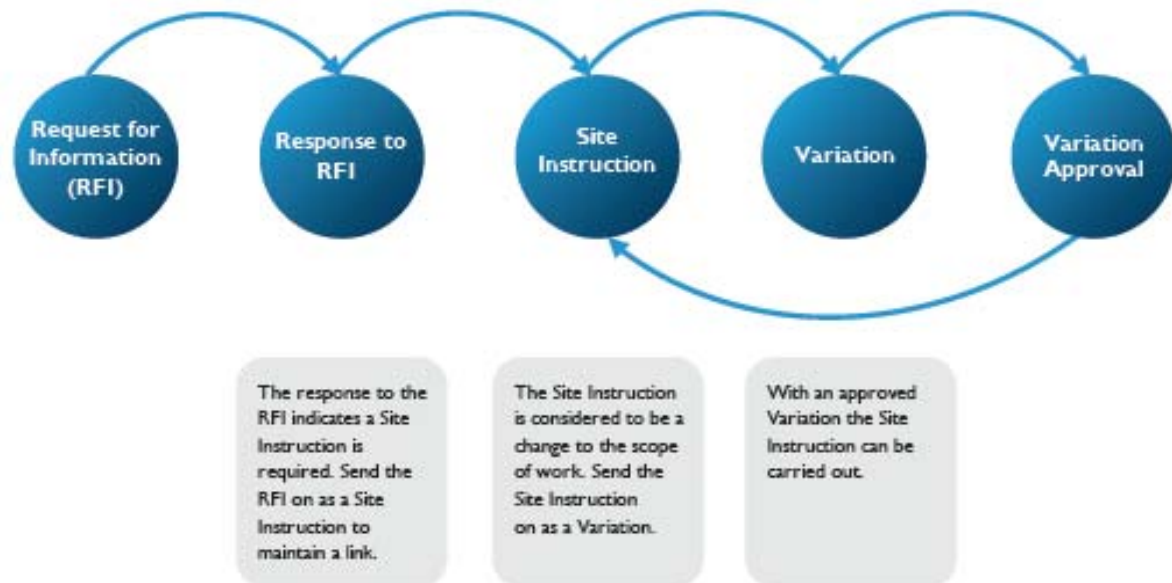
The variation module completes the workflow of the Instruction module by supporting the various approvals - design change approval, contractor variation, client variation, quality plan approval and extension of time. The generation of an approval is shown in Figure 5.5.

Figure 5.5   **Creation of an approval (Nexus Point, undated-F)**
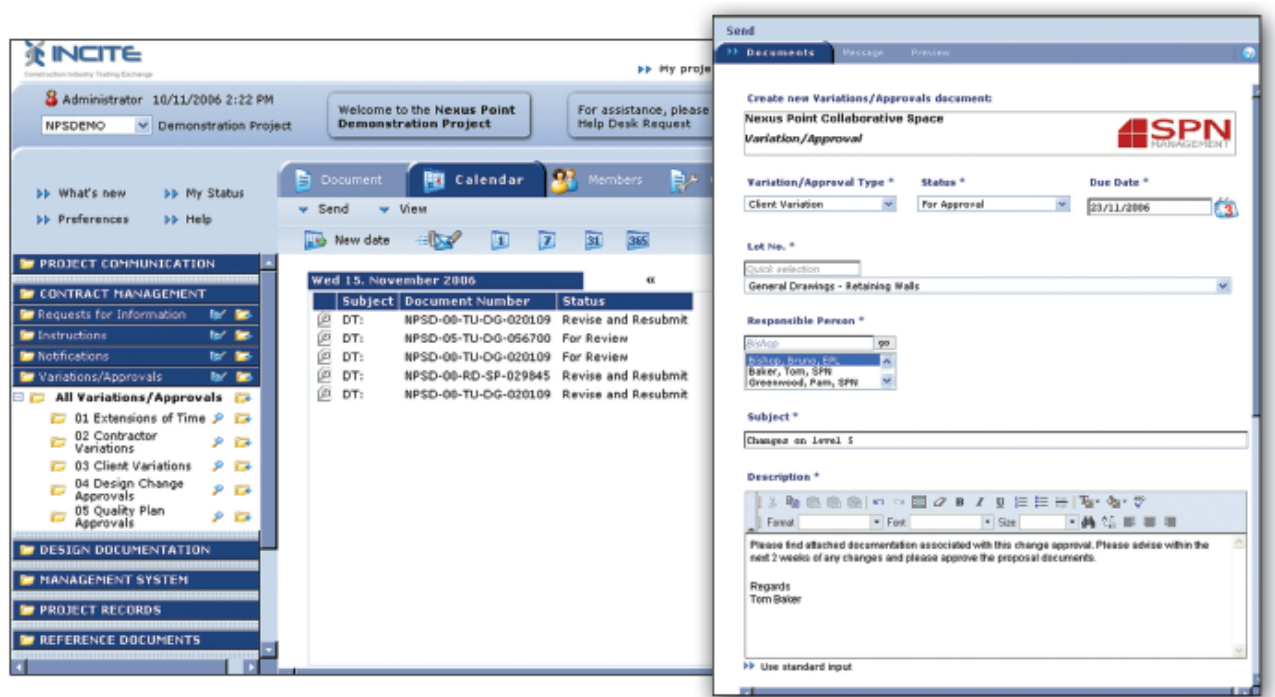
Queries against outstanding or completed variations can be used to generate reports to support tracking of costs (Figure 5.6).

Customised reports can be defined and generated from the Reporting module, including reconciliation reports to support comparisons of planned versus actual performance.

Figure 5.6   Generating report on variations (Nexus Point, undated-F)
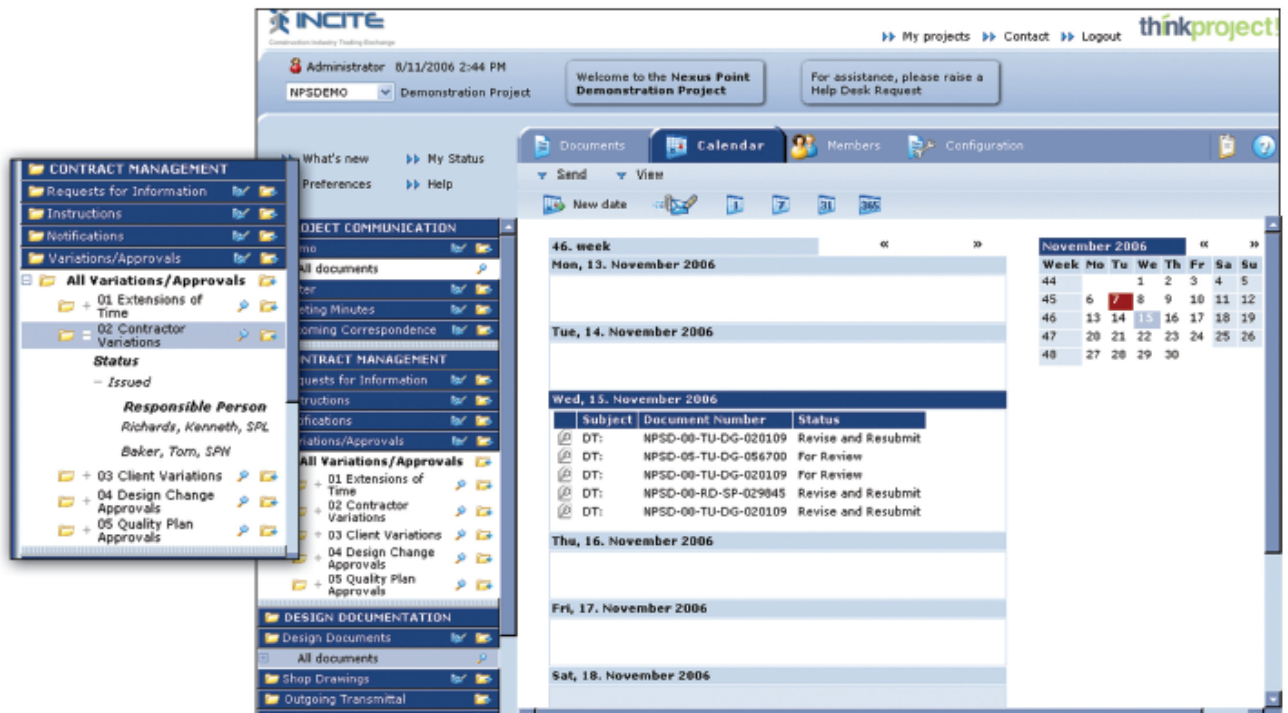
The IFC Object Model and INCITE

The IFC object model was designed to support interoperability - the seamless exchange of information between software for the building construction industry. Consequently there are a wide range of objects defined within the IFC model. The IFC model uses the Express modelling language (ISO 1003) which also supports the archiving of information. Archiving is important since the expected lifetime of most buildings exceeds the total time that the IT industry has existed, let alone any data storage formats.

The IFC model contains objects that can be used to represent buildings, actors (people and organisations), resources (actors or plant) and processes. Importantly, the IFC model supports the definition of relationships between these objects, so that a variation request could have an embedded link that could allow viewer software to automatically display the relevant object(s) and highlight them with respect to the surrounding objects.

IFC models support interoperability in two ways – file based exchange and query based access through an SDAI. An IFC file contains a "snapshot" of the current state of the model, while the SDAI interface allows direct software interaction with the current state of the model. The IFC model does not support different "versions" of the model within one file. It was intended that versioning would be handled externally.

The discussion of the INCITE modules above does not explicitly mention either people or organisations. However, storing information on people and organisations is implicit in the operation of INCITE.

It is useful to understand how the information requirements of INCITE are supported by the IFC model. Table 5.1 maps the various high level objects from INCITE onto the top level constructs within the IFC model. There are implementation details below these top levels but these do not impact significantly on this discussion.

Table 5.1   Mapping of objects from INCITE into the IFC model.

INCITE Document	IFC Definition
People	IfcPerson IfcActorRole – definition of role(s) within project
Organisations	IfcOrganization
Email	Address stored with IfcPerson
Fax	Address stored with IfcPerson and IfcOrganization
Letter	IfcDocumentInformation
Date stamp	Handled as a field within relevant objects
Site instructions	IfcProjectOrder
Client instructions	IfcProjectOrder
Hold point notifications	IfcProjectOrder
Notifications of inspection & testing	IfcProjectOrder
Notifications of delay	IfcProjectOrder
Design change approval	IfcApproval
Contractor variation	IfcOrderAction
Client variation	IfcOrderAction
Quality plan approval	IfcApproval
Extension of time	IfcOrderAction

There is the capability to store workflow information and the content of reports within the IFC model. Given that this functionality is already implemented in INCITE this would only be useful for archival purposes.

5.2   EDMmodelServer™/IFC

Model servers provide a central hub for managing Building Information Models (BIM) through

- merging data from multiple sources into one common BIM
- extracting partial BIMs for use in specific external applications
- versioning
- handling large quantities of data

Model servers support typical information management operations such as:

- browsing BIM through objects, property sets, ownership, etc
- reporting to support business processes

EDMmodelServer supports these activities through a Windows client (Figure 5.7). The detailed functions are:

- Storing
- Sharing
- View (partial datasets)
- Extraction (direct or through views)
- Integrity/consistency, formal definition
- Validation
- Merge
- Search engine
- Ownership and protection
- Workflow support
- Analysis
- Calculations
- Versioning
- Transactions
- Auditing

EDMmodelServer is based on the Express (ISO10303) standard and can consequently handle files created under any Express standard, including the IFCs. EDMmodelServer provides several "views" of information (Figure 5.7) ranging from tree views of repositories and models (the internal structures for handling models, versions and discipline views), to tables of properties and data, and graphical representations through a number of third party viewers.

Figure 5.7   EDMModelServer client (EPM Tech)
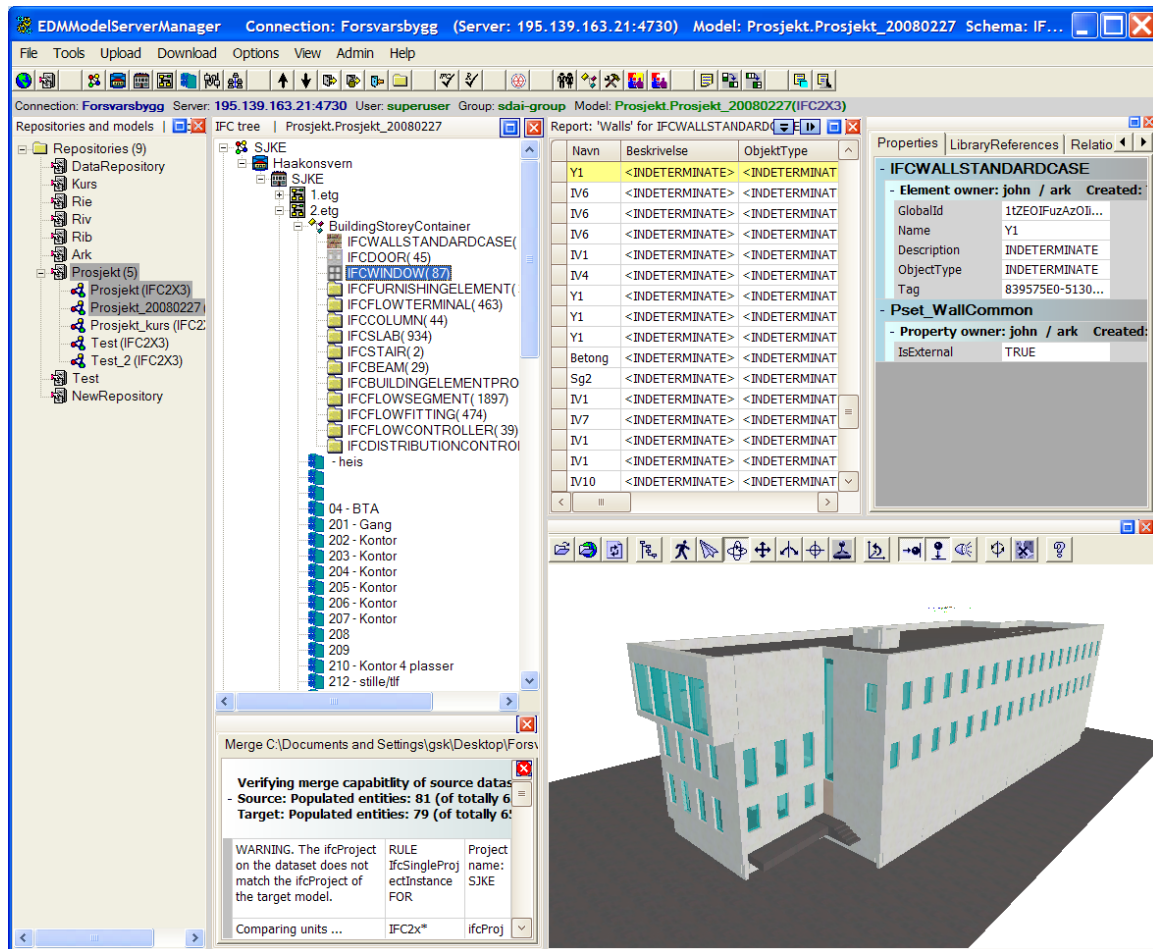
EDMmodelServer also supports multi-lingual access to information through the IFD (International Framework for Dictionaries) where this is supported by the client software.

The EDMmodelServer Manager software supports the following management operations:

- Organize BIMs
    - Repository/Model treeview
        - Creating new model (new BIM), Rename, Delete
        - Export/import (whole models) (Upgrade to newer schema version)
- Users, groups and access rights
- Browse inside a BIM
    - Basic MSM functionallity/windows
        - Organise windows in manager,
    - Browse objects, property sets, etc
        - IFC treeview (fixed)
        - 3D viewer (Octaga, DDS viewer)
        - Datasheets (GridControl, HTTP or 3D configurable)
        - Report (configurable)
- Extracting partial models
    - Get-out / Check-out
    - From IFC treeview, report or property sheet
- Check- In / Merge
    - Validation - IFC and IDM

Rules can be defined to check incoming information for validity against internal standards where these are more constrained than the standard IFC definitions.

A wide range of software was tested with the EDMmodelServer within the HITS project (Figure 5.8).

Figure 5.8   Software used within the HITOS project (EPM Tech)
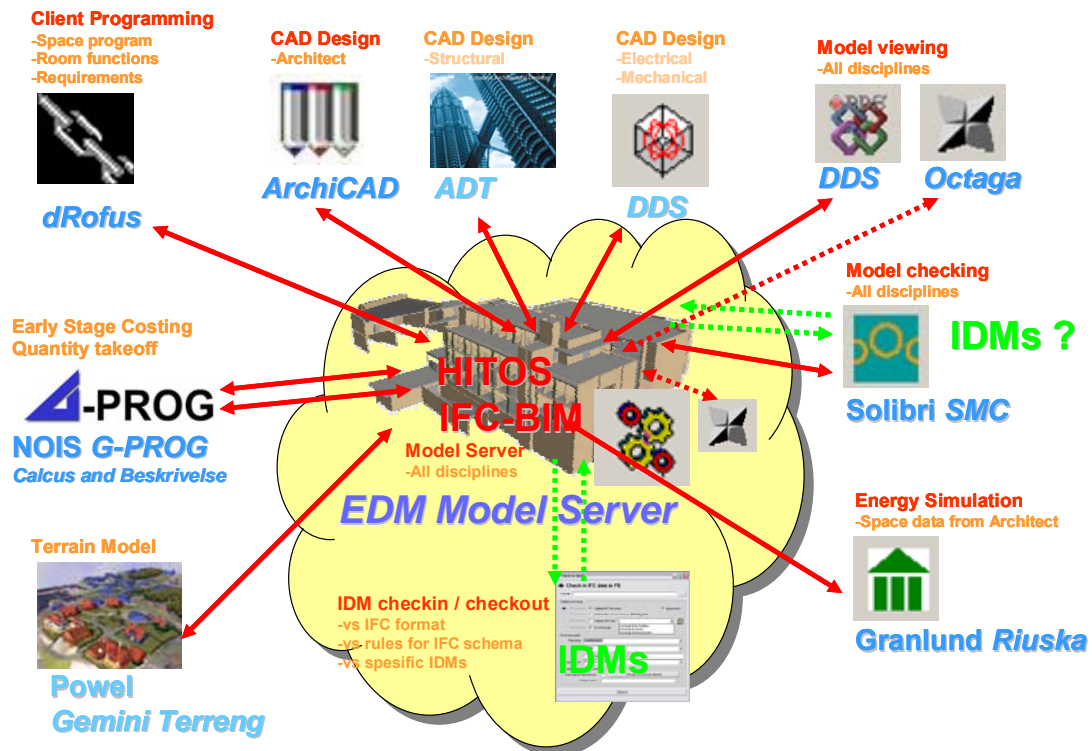
EDM claim a high level of reliability since their model server is used widely throughout Europe.

5.2.1   Placing a Model Server within the INCITE Environment

A model server can potentially perform many of the functions carried out by existing project collaboration environments. How would an IFC model server fit within an existing collaboration environment?

The minimal support from a model server supporting the IFCs would be to provide visualisation support. This is not a matter of adding the software to a server. When dealing with 3D information the system requesting a view will need to provide enough information to allow the view to be defined. This includes the look-from point, look-to point, angle of vision, front and rear cutting planes and, to be truly useful, visibility settings for objects within the view Figure 5.9). This can be considered as adding "just another viewer" to a system like INCITE. However, placing an object within a 3D context allows users to explore the context for information rather than rely on their ability to interpret plans, elevations and sections. The user interface for checking in, checking out, model merging, etc could be built behind the INCITE user interface using the EDM API, which supports a range of languages.

Viewing capabilities could be extended by embedding links to particular objects from within other documents. For example, references that showed the current position and configuration of an object could be added to a change request together with references showing the proposed modification.

Higher levels of integration could be added by using the EDM reporting capabilities within the INCITE framework and rule-based conformance testing.

EDM have produced a conceptual diagram showing how EDMmodelServer could fit within a project collaboration framework (Figure 5.10).

Figure 5.9   3D view of building (HITOS project)
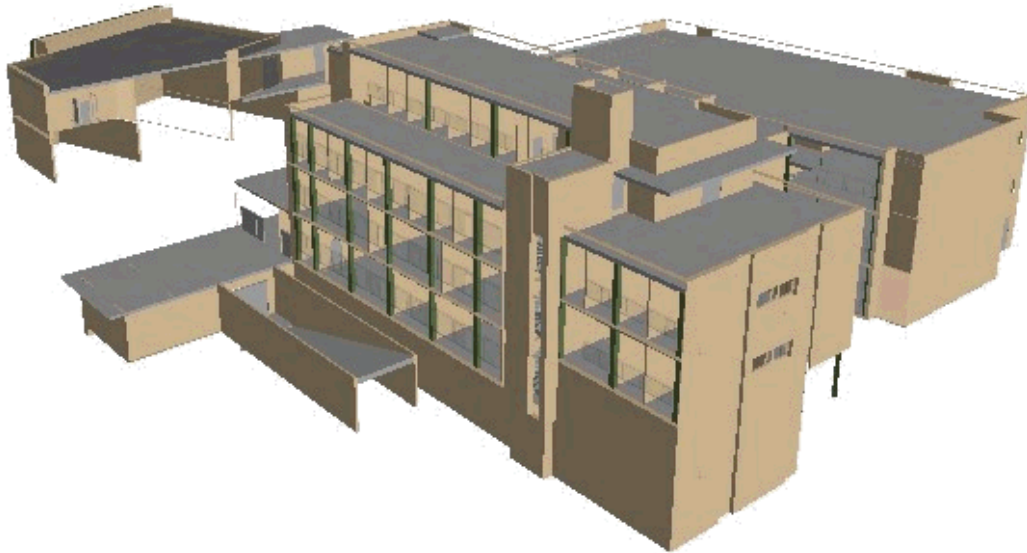
Figure 5.10   EDMmodelServer supporting a project collaboration framework (EPM Tech)
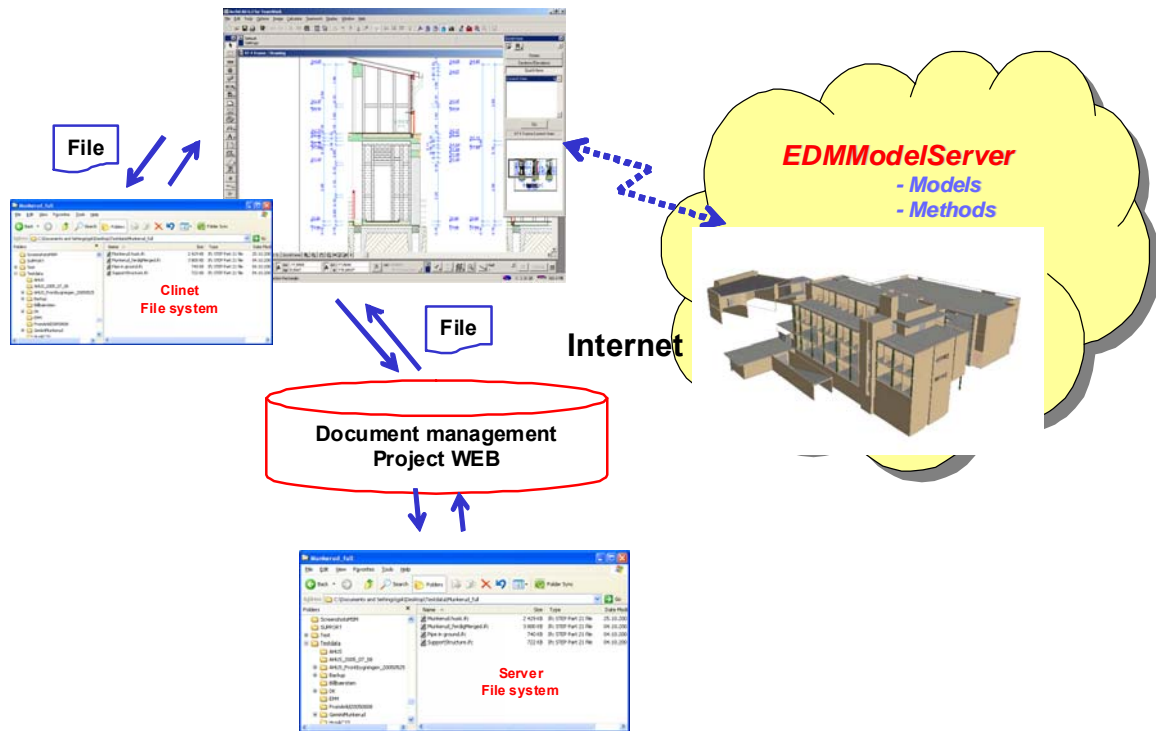
5.3   Acknowledgements

The text and images in the sections describing Nexus Point INCITE and EDMmodelServer rely heavily on material made available by the respective organisations.

6. CONCLUSIONS

The project develops a decision framework to set up a BIM environment for current practices and collaboration server, explores how the technology is being used now and how the model server will improve current practice, identify barriers and steps for moving towards the BIM model server.

6.1.1 Industry Needs Analysis

Knowledge, awareness and readiness for BIM and BIM server based collaboration vary across the different disciplines involved in a typical construction project. An analysis of available BIM applications suggests that the BIM server technology is itself not matured. However, even in its present form these technologies are usable and can significantly improve project collaboration.

At present the industry is caught in a loop. Low usage and lack of experience is inhibiting technology enhancement, and development of appropriate work-processes and work-culture. In turn, technical limitations, lack of appropriate work-processes and work-culture are inhibiting BIM technology usage.

There is a general agreement across the industry on the need for specific roles related to BIM model management and BIM server management. Besides technical features, training materials and training programs are required to assist BIM adoption, management and implementation.

6.1.2 Summary of Technical Requirements of Collaboration Platform

In terms of their importance, the technical requirements for a BIM model server can be categorized as operational technical requirements or support technical requirements as listed in 4.6.3.

Operational technical requirements refer to the features needed during usage of the model server. Some of operational technical requirements relate to user log-in and access, data import and export, data management and organization, version management, user interface, navigation and visualization, and so on.

Support technical requirements such as help menus, tutorials, FAQs, and so on are required to facilitate usage of the model server. Support requirements have traditionally been a part of all technological tools and have been critical to technology adoption and user support. In collaboration-based tools such as some of the DMS (e.g. Aconex, Team Binder, Project Centre, INCITE) templates, assessment matrices are other support technical requirements that have been included to facilitate set-up and implementation of the collaboration platform for project needs. Hence, one of the important support technical requirements of a BIM model server designed to function as a collaboration platform includes project decision support features and functionalities.

The technical requirements for a BIM model server are listed in 4.6.3.

6.2 Recommendations

Recommendation 1: Longitudinal case studies with direct involvement of industry based tool experts should be conducted in Australian pilot projects. Such case studies are likely to explore greater coordination challenges.

Recommendation 2: CRC for *Construction Innovation* should take the findings to model server vendors highlighting the need for improved training materials and regular helpdesk to encourage and support new users.

Recommendation 3: An interactive version of parts of the National BIM Guidelines and IDM should be developed as a plug-in to aid model server and BIM implementation.

Recommendation 4: While IFC standards should be part of long term goals, model servers with flexibility of data formats should be pursued. This is because an entirely IFC based collaboration platform may not be feasible in near future because of errors in interoperability with dominant proprietary tools.

Recommendation 5: Extensive training of BIM managers and experts with technical and organizational knowhow is needed to facilitate customized system configuration and administration.

7. REFERENCES

ActiveFacility: 2004, ActiveFacility white paper, Brisbane, 2004.

Aranda-Mena G, Wakefield R (2006) Interoperability of building information - myth of reality? In: eWork and eBusiness in Architecture, Engineering and Construction, Martinez & Scherer (eds), Taylor and Francis, London (ISBN- 0-415-41622-1): 127-133.

Autodesk: Building Information Modeling (white paper), *Autodesk Building Industry Solutions*, URL: www.autodesk.com/buildinginformation

Autodesk: Revit Structure and BIM (white paper), URL: http://usa.autodesk.com/adsk/servlet/index ?siteID=123112&id =8447106

Bengtsson, K: 2005, Using IFC's and EDMmodelServer™ for BIM implementations (presentation slides), Conference on Building Information Modeling, Georgia Tech, April 2005, URL: http://www.epmtech.jotne.com

Bentley, K and Workman, B: 2003, Does The Building Industry Really Need to Start Over? A Response from Bentley to Autodesk's BIM/Revit Proposal for the Future (white paper), Bentley.

Bentley, 2007: IFC White Paper revision: Mar 11, 2009 - 22:58, Bentley Systems, Incorporated, URL: ftp://ftp2.bentley.com/dist/collateral/whitepaper/Building_IFC_Position_Paper_whitepaper_eng.pdf

Bentley News: 2006, ARUP wins 2006 BE Awards, URL: http://www.bentley.com/en-US/Corporate/News/News+Archive/2006/Quarter+3/Arup.htm?WBCMODE=Authoring PrevSite+MapSite+MapSite+MapSite+Map (Article dated: September 20, 2006: Access date: January 15, 2009)

BE Magazine: 2004, Creating a Water Cube, BE magazine **1**(2), URL: ftp://ftp2.bentley.com/dist/collateral/User_20Story_3A_20Arup_20_2D_20Water_20Cube_2C_20Low_20Respdflo.pdf (Access date: January 15, 2009)

Bernstein PG, Pittman JH (2004) Barriers to the adoption of Building Information Modeling in the building industry, Autodesk Building Solutions.

Cheng Tai Fatt (2002): An IT Roadmap for Singapore's Construction Industry (presentation), URL: http://www.corenet.gov.sg

Christensen, CL and Gruppen, S: 2005, Low friction information logistics enabled by the Information Delivery Manual (IDM) framework (presentation), *IAI Conference in Oslo, Norway*, *Government and Industry Day –June 1st*

CyonResearch: 2003, The Building Information Model, A Look at Graphisoft's Virtual Building Concept (CyonResearch white paper), URL: http://www.cyonresearch.com

Eastman, C, Sacks, R and Lee, G: 2004b, Functional Modelling in Parametric CAD Systems, *Generative CAD Systems G-CADS 2004*, (Ed.) O. Akin, Pittsburgh PA, Carnegie Mellon University.

Eberg, E, Turi, H, Olsen, J, Eidissen, S, Eriksen, ,S, Haakon, K, Christoffersen, O, Thi Le, M, Mohus, F, Experiences in development and use of a digital Building Information Model (BIM) according to IFC standards from the building project of Tromsø University College (HITOS) after completed Full Conceptual Design Phase, 2006, Stasbygg, Norwegian Agency of Pubic Construction and Property.

EPM Technology: 2004, *EXPRESS DATA MANAGER™*, *Information* **1**(6), URL: http://www.epmtech.jotne.com

Gehry Technologies: Construction Industries Transformation (Brochure), *Gehry Technologie,* URL: http://www.gehrytechnologies.com

Graphisoft: A Strategy for Design, Construction and Management Services Collaboration, Sharing information based on the Virtual Building^{TM} and the IFC^{TM} object sharing protocol: IFC brochure, *Graphisoft.*

Graphisoft: ArchiCAD 11 Reference Guide,

Graphisoft: GDL Reference Guide,

Graphisoft: ArchiCAD 11 Training Guide Level 1

Graphisoft: ArchiCAD 11 Training Guide Level 2

Holzer D (2007) Are You Talking To Me? Why BIM Alone Is Not The Answer. In: Proceedings of the Fourth International Conference of the Association of Architecture Schools of Australasia.

Howard R, Bjork B (2008) Building information modelling – Experts' views on standardisation and industry deployment. Advanced Engineering Informatics, 22: 271–280.

IAI: The EXPRESS Definition Language for IFC Development (white paper), IAI, URL: http://www.iai-international.org/Model/documentation/The_EXPRESS_Definition_Language_for_IFC_Development.pdf

IAI: Data Modelling Using EXPRESS-G for IFC Development, URL: http://www.iai-international.org/Model/documentation/Data_Modelling_Using_EXPRESS-G_for_IFC_Development .pdf

Kalny O (2007) Enterprise Wiki: An Emerging Technology to be Considered by the AEC Industry. AECbytes Viewpoint 31, March 19, 2007. URL: http://www.aecbytes.com/viewpoint/2007/issue_31.html (Access date: September 15, 2007)

Khemlani, L: 2004, The IFC Building Model: A Look Under the Hood, *AECbytes Feature*, March 30, 2004, URL: http://www.aecbytes.com/feature/2004/IFCmodel.html

Khemlani, L: 2006a, AIA 2007 National Convention and Expo, *AECbytes Newsletter* #30 (May 10, 2007), URL: http://www.aecbytes.com/newsletter/2007/issue_30.html

Khemlani, L: 2006b, BIM Symposium at the University of Minnesota, *Building the Future (Article) AECbytes*, February, URL: http://www.aecbytes.com/buildingthefuture2006/BIM_Symposium .html

Khemlani, L: 2006c, Bentley Architecture and Bentley Structural V8 XM, *AECbytes Product Review*, October, URL: http://www.aecbytes.com/review/2006/BentleyArchStructV8XM.html

Khemlani, L (2007a) Supporting Tech. for BIM Exhibited at AIA 2007, Building the Future, AECbytes.

Khemlani, L: 2007b, Top Criteria for BIM Solutions, A survey conducted by AECbytes, URL: https:// community.aeccom.com/v30/download/e977867ec69fc8fd/cBs_57pzlVT2F P2WaT2_JVpUQ2QMn7_wqQAorqzuio8nJO8AVEDYkd9ZOc07IreC6Bk/AECbytesSur veyReport.pdf

Khemlani, L: 2007c, Revit Architecture 2008, *AECbytes Product Review*, June, URL: http://www.aec bytes.com/review/2007/RevitArch2008.html

Khemlani, L: 2007d, Autodesk Revit, Implementation in Practice (white paper), URL: http://usa .autodesk.com/adsk/servlet/item?siteID=123112&id=8127972

Kymmell, W (2008) Building Information Modelling: Planning and Managing Construction Projects with 4D CAD and Simulations, McGraw-Hill, New York (ISBN- 978-0-07-149453-03).

Lee G, Sacks R, Eastman CM (2006) Specifying parametric building object behavior (BOB) for a building information modeling system. Automation in Construction 15: 758 – 776.

Mitchell, J, Wong, J and Plume, J (2007) Design Collaboration Using IFC, A case study in thermal analysis, In: Proceedings of CAADFutures 2007 (Eds.) Dong A, Vander Moere A & Gero JS, Springer; pp: 317-329.

Mitchell, J and Jorgensen, KA (2007) EDM Model Server User Guide (Draft version 6.16), April 2007.

Navisworks: JetStreamv5 from Navisworks, URL: http://www.navisworks.com

Nexus Point, undated-A, Correspondence Module brochure, www.incite.com.au (accessed 13 June 2009)

Nexus Point, undated-B, Design Management Module brochure, www.incite.com.au (accessed 13 June 2009)

Nexus Point, undated-C, Instruction Module brochure, www.incite.com.au (accessed 13 June 2009)

Nexus Point, undated-D, Project Collaboration Overview brochure, www.incite.com.au (accessed 13 June 2009)

Nexus Point, undated-E, Reporting Module brochure, www.incite.com.au (accessed 13 June 2009)

Nexus Point, undated-F, Variations & Approvals Module brochure, www.incite.com.au (accessed 13 June 2009)

Pentilla, H: 2007, Early Architectural Design and BIM, *Proceedings of the Computer Aided Architectural Design Futures (CAADFutures) 2007* (Eds.) Dong A, Vander Moere A & Gero JS, Springer; pp: 291-302.

Schaffers H, Brodt T, Pallot M and Prinz W: 2006, The Future Workspace, Perspectives on Mobile and Collaborative Working, MOSAIC Consortium, Information Society.

STATSBYGG: 2006, Experiences in development and use of a digital Building Information Model (BIM) according to IFC standards from the building project of Tromsø University College (HITOS) after completed Full Conceptual Design Phase (report), R&D project no. 11251 Pilot project, Tromsø University College (HITOS) for testing IFC.

Wakefield R, Aranda-Mena G, et al. (2007) Business Drivers For BIM, RMIT, Australia.

You, S, Yang, D and Eastman, C: 2004, Relational DB Implementation of Step Based Product Model, *CIB World Building Congress 2004*, Toronto, Ontario, Canada.

8.   GLOSSARY

ACONEX	a document management system
AEC	Architecture Engineering and Construction
AIA	Australian Institute of Architects
API	Application Programming Interface
ARCHICAD	Graphisoft CAD system
Ark	Office tower project in Sydney
BIM	Building Information Model
CAD	Computer Aided Design
CADD	Computer Aided Design and Documentation
CORENET	Construction and Real Estate Network system (Singapore)
DDS	Data Design System
DMS	Document Management System
DBMS	Data Base Management System
DXF/DWG	CAD data exchange formats
EDM	Express Data Manager
EXPRESS	information modelling language specified in STEP
EXPRESS-G	graphical notation for EXPRESS
FAQ	Frequently Asked Question
FGI	Focus Group Interview
FM	Facility Management
FTP	File Transfer Protocol
GIS	Geographic Information Systems
GPL	Graphical Program Language
GUI	Graphical User Interface
HTML	Hypertext Markup Language
IAI	International Alliance for Interoperability
IDM	Information Delivery Manual
IFC	Industry Foundation Class
IFD	International Framework for Dictionaries
INCITE	Construction Industry Trading Exchange system
Microstation	Bentley CAD system
MS Excel	Microsoft spreadsheet software
ODBC	Open Data Base Connectivity
PDA	Personal Data Assistant
PDF	Print Document Format
PLM	Product Lifecycle Management
Project Centre	a project management system
Revit	Autodesk CAD system

RFI	Request for Information
SCM	System Configuration Manager
SDAI	Standard Data Access Interface
SOH	Sydney Opera House
STEP	Standard for The Exchange of Product Model Data
SVG	Scalable Vector Graphics viewer
Team Binder	a project management system
XML	Extended Markup Language

9. AUTHOR BIOGRAPHIES

Dr Ning Gu

Dr Ning Gu is a lecturer in the School of Architecture and Built Environment at the University of Newcastle, Australia. He researches in the broad areas of design computing, particularly, in generative design systems, virtual worlds and BIM. Ning is a pioneer of applying leading-edge information technologies in design and learning, and has established an international collaborative design studio using *Second Life*. He has also designed and implemented a wide variety of collaborative virtual environments and applied them in his teaching and research in numerous Australian and international tertiary design institutions including the University of Newcastle, University of Sydney, MIT and Columbia University. He has published extensively in the field of design computing and design education. His career highlights include being the Research Leader of the Collaboration Platform project in the Cooperative Research Centre for Construction Innovation (CRC-CI), and the Chair for international conferences of CONVR 2009 and ANZAScA 2008.

Professor Kerry London

Professor Kerry London holds a Bachelor Degree in Science[Architecture] and Architecture and a Masters of Building from the University of Newcastle, as well as a PhD in Construction Management and Economics from the University of Melbourne, Australia. For the last 8 years she has been teaching extensively Architecture and Construction Management programs. Her main research interests include construction supply chain theory and practice, design management and construction futures decision making. Kerry was the first female appointed as Chair in Construction Management in Australia. She wrote the seminal work "Construction Supply Chain Economics" published in the acclaimed invited Spon Research Series. She is currently the Regional Chair of the Chartered Institute of Building Education Panel and CIOB Vice President Australasia region.

Claudelle Taylor

After completing her Master of Arts from the University of New South Wales, Claudelle Taylor began her career in construction in 1999 at John Holland. Here she managed the development, implementation and management of online collaboration systems, paying particular attention to their use for information and process management on construction projects. In 2005 Claudelle was awarded the Peter Allen Memorial Award, which recognises the most outstanding individual in the John Holland Group. From John Holland, Claudelle moved to Nexus Point Solutions to manage an online collaboration application, Incite, at an industry level. As the General Manager, Product Marketing, Claudelle has focused on growing the current Incite suite of applications and harnessing emerging technologies. Claudelle is currently the project leader for the CRC for Construction Innovation on a Collaboration Platform which will allow multiple parties to work with Building Information Models.

Vishal Singh

Vishal Singh is a PhD candidate at The University of Sydney working in the area of agent based modeling of teams. He received a masters degree in Product Design from Indian Institute of Science, and a bachelors degree in Architecture from Birla Institute of Technology, India. His research interests include: Agent-based modelling, adaptive agents, design processes and methodology, information systems and management, innovation and product development, learning, situated and social cognition, technology-mediated interactions, teams and organizations.

Associate Professor Ljiljana Brankovic

Associate Professor Ljiljana Brankovic holds a Bachelor Degree in Electrical Engineering from the University of Belgrade and a PhD in Computer Science from The University of Newcastle. For the last 15 years she has been with The School of Electrical Engineering and Computer Science, The University of Newcastle where she taught extensively into Computer Science and Software Engineering Programs. Her main research interests include data security, statistical disclosure control, privacy preserving data mining and discrete mathematics. Ljiljana is currently the chair of ACS National Committee for Computer Security.

Professor Robin Drogemuller

Professor Robin Drogemuller holds a Bachelor of Architecture from the University of Adelaide and a Bachelor of Applied Science (Maths & Computing) from Capricornia IAE. Since 2007 he has been Professor of Digital Design, Faculty of Built Environment & Engineering, Queensland University of Technology. Prior to this he spent 9 years as Principal Research Scientist with CSIRO. Robin is a   Member of Building Smart (ex International Alliance for Interoperability) International Council and International Technical management Committee and also a Board member of BuildingSmart Australasian Chapter. Robin's major research interest for the last 20 years has been in the area of virtual design and construction. Robin's most significant success was building a research team from scratch within CSIRO that contributed collaboratively across a large number of research projects within the CRC for *Construction Innovation*. The outputs from these projects have had significant effects on collaborating industry organisations and the development of international standards. The outputs also provided a significant number of potentially commercialisable tools. The significance of this work both nationally and internationally was recognised by the various panels that reviewed the CRC and led to a strong role for the ICT Platform within the CRC.

John Mitchell

John Mitchell is the principal of the consulting company CQR Pty Ltd which focuses on the application of Construction ICT, specialising in BIM and open standard model sharing such as IFC. Concurrently he has a part time appointment as Associate Professor, at the Faculty of Built Environment, NSW, where he is leading a course in multi-disciplinary design collaboration using an IFC model server, and a suite of IFC compliant applications. He also supports an Object Based CAD course which has a new focus on the emerging object model or BIM based, IFC compatible applications. He is a Research Fellow on an ARC Research project developing an IT framework to integrate GIS, BIM and other statistical, demographic data for improved support for planning analysis. John is the Chairman of the buildingSMART Australasia Chapter, and was to April 2009 Deputy Chairman, IAI International as well as a member of the IAI Executive Committee. John graduated from the University of Adelaide (BArch) in 1968, and completed a postgraduate Diploma in Architectural Computing from the University of Sydney in 1986. Trained as an Architect, the central thread of his professional activity has been the application of computing in the field of architecture and design, and later to the wider industry context of information technology (ICT). He has always taken an interest in the broader context of the industry; he has lectured widely nationally and internationally for the International Alliance for Interoperability (IAI) and others. John was from 2001-2004 an expert reviewer for several projects in the European Commission's IST Construction Research program.