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Project 2007-003-EP
Collaboration Platform

Report

Project Title	Collaboration Platform
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Document Title	Industry Consultation Report	
Date/Time		
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Contents

1. Introduction

This report is divided into two parts. Chapters 1, 2 and 3 cover the background study. A summarized review of the main BIM applications is presented. This section discusses the current state and capabilities of the products and applications supporting BIM. This includes discussion on BIM model servers as well as discipline specific applications, for which the distinction is explained below. This section is aimed at giving a broad overview of the tools and applications with respect to their BIM capabilities. An indicative summary of the main BIM tools considered here is presented in Table1 at the beginning of chapter 2.

The outcomes and observations from the workshops conducted with the industry focus groups are discussed in chapters 4 and 5. The workshops provide a forum for uncovering and discussing important issues of BIM adoption in design practice; in particular, current industry perceptions, changing work, role of technology, and expectations from BIM. This report discusses the patterns observed in the discussion. An analysis of the industry data is presented. The method used for analyzing the workshop data is discussed in detail. Chapter 4 discusses the data observed from the workshop in detail. A summary of the main issues emerging in the workshop is provided in Table 11 at the end of chapter 4. Plan for the case studies and priority issues to be tested are discussed in chapter 5.

1. What is BIM?

a. BIM is the process of maintaining a 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 through out 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 as well as non-geometric data. Geometric data includes 2D drawings, 3D models, dimensional and spatial relationships. Non-geometric data could mean 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. The 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. Figure1 shows how a model server is used along with the other BIM applications that form native tools for the collaborating disciplines.

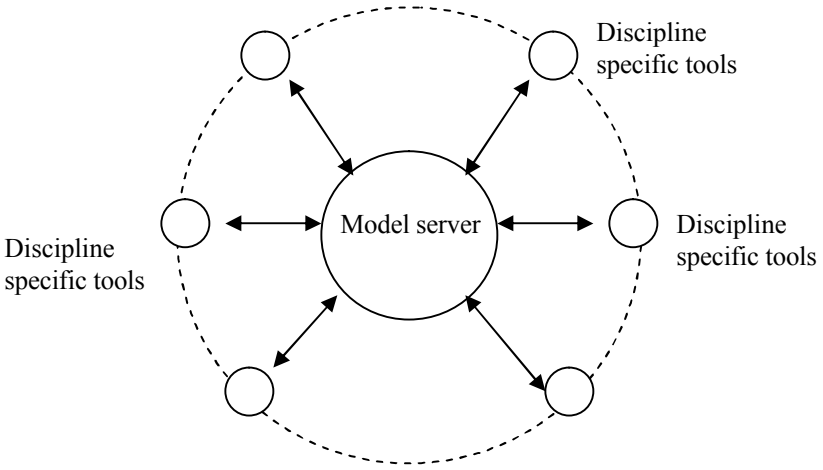

Figure1: BIM model server allows import/export of data to BIM application tools

2. Why BIM?

a. How it is different to geometric data model? (Khemlani 2004)
- It 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.
- Gives ability to extract the relevant information from the representation that is needed for design, analysis, construction management, operation, and so on.

b. Some of the benefits:
- BIM allows integration of all the relevant documents and data generated and required by various disciplines involved in a given project.
- Instant, controlled and distributed access to data.
- Facilitates easier update, maintenance and retrieval of data. Long-term programming, maintenance and operation.
- Facilitates resource utilization by reducing rework and avoiding duplication.
- Automated extraction and processing of data that required dedicated effort 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.
- Analysis and visualization of product performance over the building life cycle (Mitchelle et al. 2007).
- Facilitate and smoothen legal and regulatory processes. e.g. Corenet (Tai Fatt)
- Content development for electronic building component objects including product data and links to manufacturer Websites

3. Applications and products supporting BIM?

Since BIM aims to provide an integrated documentation 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 AEC industry (Pentilla 2007, Khemlani 2007, Eastman et al. 2004b). The BIM tools are classified here as:

a. Preliminary Tools
    - Preliminary Space Planning Tools- *e.g. Trelligence Affinity*
    - Preliminary Massing and Sketching Tools- *e.g. Google SketchUp*
    - Preliminary Environmental Analysis Tools- e.g.
    - Preliminary Cost Estimation Tools- e.g.
b. BIM Design Tools- *e.g. ArchiCAD, Revit*
c. Structural Design Tools- *e.g. Revit Structure, Bentley Structure*
d. BIM Construction Tools- *e.g. Graphisoft Constructor*
e. Fabrication Tools- *e.g. Digital Project (Gehry Technologies)*
f. Environmental Analysis Tools- *e.g. Riuska*
g. Construction Management Tools- *e.g. JetStream Timeliner*
h. Cost Estimation Tools- *e.g. Calcus*
i. Specification Tools-
j. Facility Management Tools- *e.g. Active facility*
k. Mechanical Tools- *e.g. DDS mechanical, Bentley Mechanical Systems*
l. Model checkers – *e.g. Solibri Model Checker*
m. Product libraries- *e.g. ADSearch, FormFont*
n. Design review/ Model viewers - *e.g. JetStream Roamer, Octaga*

2. Review of desktop audit

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 design 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 (Mitchelle 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 that the tool caters to and for what purposes and usage is the tool meant for.
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 here. For a detailed desktop audit see appendix 1.

Table 1: Indicative summary of main BIM tools

Application	Type	Approach	Purposes	Features and strengths	Limitations	Comments
BIM APPLICATION TOOLS (DISCIPLINE SPECIFIC)						
Acrobat 3D	Standalone		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 projects
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
BIM 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	Suite	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		Service provider and product supplier

Observations from desktop audit:

Examples of the use of BIM approach in practice suggest that in the present state as well there ar e 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 m ore specific BIM applicat ions are developed for specific aspects of design process , and allow integration with each other . Accordingly, a s the desktop

audit suggests a wide array of applications are being developed to facilitate the BIM approach. Within this itself 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.
- **Model size vs distributed database:** Is 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 information 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 an integrated database as adopted by other vendors like Archicad and Autodesk Revit.
- How much intelligence is good? **Modelling constraints vs flexibility** (Eastman et al. 2004b, Khemlani 2007). The object-oriented modelling using intelligent objects is the core of the BIM approach. This allows associations and relationships. Such associations and relationships also 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.

3. Discussion on BIM:

This section discusses some of the theoretical and research issues related to the BIM approach. Literature and the trend in BIM application development suggests that the pri me enablers of BIM approach are:

- Technology and tools
  - Distributed access and sharing
  - Import/ export
  - Management
  - Operations
  - Control and validity
  - Coordination
- Data associativity
- Common platform for data exchange (e.g. IFC)
  - Format
  - Terminologies (vocabulary) (e.g. IFD-International Framework for Dictionaries)
- Specification
  - Relevance (minimum and sufficient data) (IDM- Information Delivery Manual)
- Customizability and flexibility
- Comprehension and legibility
- Multi- modal representation

IFC (Industry Foundation Classes)

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)

- Another object-based building data model. However, it is non-proprietary.
- Being an open data exchange format that captures building information, it 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, act ivities, 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):

- **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, i f 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 IFC model is not designed to work with one particular app lication, it is deliberately abstract. There are no direct relationships between entities.

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 b e 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 individua l 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)
- IFC might not be the best interoperability sol ution under all circumstances.
- 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 benefi ts can go a long way towards eliminating the inefficiencies and waste in the building industry.

Issues with certification of IFC compatible applications
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 very serious concern for managing an integrated database at the model server in the form of IFC files.

IDM (Information Delivery Manual)

The Information Delivery Manua l (IDM) provides a state of the art approach to connecting BIM 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

BIM and the AEC industry- a status check

BIM has hardly picked up in practice. T here are some examples from larger firms like ARUP and Gehry Technologies, which have developed their own processes and systems somewhat similar to a BIM approach . How ever, in general the adoption rate has been rather 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 prac tice. 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 an important inhibiting factor.

Some of the main characteristics of the AEC industry that may be attributed to low adoption of BIM by the AEC industry, as compared to some other industries like automobile and aircraft industry, where similar technologies like 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 has a very few but big players, and with very competitive capabilities.
- **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 put in 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). 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. This requires additional effort. This may be in conflict with the economic interests of certain disciplines. These disciplines 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 may be at helm of the data, where as 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 industries 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 big players that are high on power relationships. 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 (Tai Fatt). 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 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 u p 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 capabil ity 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.
7. Support on analysis, performance simulations and interoperability has been discussed, but the survey suggests it is not a burning issue.

4. Industry workshop:

Two workshops were conducted in different cities (Sydney and Brisbane) with active participation of representatives from various sectors of AEC industry. This includes architects, contractors, vendors, consultants, project managers, academicians and people from government agencies. The workshop discussions were recorded on tapes and then segmented. The segmented data and background study were analyzed firstly using an open-ended approach to identify the main themes. Based on the main themes identified a coding scheme has been developed and applied to the workshop data for detailed analysis.

Discussion on the coding scheme:

The workshops provide a forum for uncovering and discussing important issues of BIM adoption in design practice; in particular, current industry perceptions, changing work, role of technology, and expectations from BIM. Discussions in the workshop and the literature on BIM suggest that the reasons for low adoption of BIM in the industry are not only technological. Other factors include: work practice, the kind of training available to the users, the organizational structure, and the business interests of the parties involved. It has been recognized that the introduction of BIM would require a different approach to data organization and structuring. Some legal/ contractual measures will be required to deal with safety and work practice related issues.

Knowledge about BIM varies significantly across the different disciplines within the AEC industry. **Discipline** category is used to segment the data based on the disciplinary and functional background of the speaker. Marking of each segment based on the disciplinary background of the speaker gives useful information about the importance of the different aspects of BIM (in terms of the content) within each discipline types.

Context category is used to mark the circumstances under which a given segment of data had come up. Classifications within the 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); **"follow up"** (if the segment of data was in continuation of the ongoing subject initiated some point 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 used by the moderator). These classifications imply the following:

- A subject **initiated** by a specific discipline is in general expected to be higher in priority for that discipline. For example, the discussion on lack of conceptual design support is initiated by an architect. Similarly, the issue of the changing format of IFC specifications is initiated by an application vendor, who as a service provider has been undertaking the management of IFC data for the clients.
- Most often, identification of the discipline from which the **reply** to a specific query or statement comes, suggests which discipline has knowledge and awareness of the specific topic. For example, as expected when the issue of security of the data on model server is raised an application vendor gives the reply.
- **Follow up** allows identification of the other disciplines that participate in a specific topic of the discussion. For disciplines that do not participate in a specific topic at all, it may suggest lack of relevance or interest in the specific topic. For example, the discussion on the tool support for conceptual design phases has very little or no participation of the contractors and civil engineers. Main participants are the architects, design practitioners and teachers, and the application vendors.
- The **"chair"** marked segments means that the statement is used to moderate the discussion. Even if that meant starting a new topic, it may not be suggestive of the

priority of the speaker for the topic. Rather, such change in discussion topic is either forced due to time constraints, or to keep the discussion within the scope of the research.

The classification within **content** category is expected to provide clustering of the data to identify the keywords and the points discussed based on the aspect of BIM approach. The content category therefore segments the workshop data based on the subject of discussion. This allows identification of dominant topics. Accordingly, there are eight classifications within the content category as shown in Figure 2 and discussed in Table 2.

The Discipline, Context and type categories are used to cluster the data such that we can identify the pattern of BIM awareness, interest and knowledge across these disciplines. **Keywords** allow identification of major issues across the categories for which we can set priority, as evident by the frequency of occurrence in the data. For example, the categorization may suggest that technological issues are the most prevalent topics of discussion; or that there are more concerns on data management issues raised by the architects and application vendor. However, while it does suggest priority of topics, the specifics within each category need to be identified. This is where keywords are useful. A detailed analysis suggests that most concerns on data structuring and organization are related to version management. This is done by listing the keywords in each segment. In this case, version management has the highest frequency of occurrence. Similarly, other specific issues within each category are identified such that we can set priorities for the aspects to be tested during the case studies. Coding scheme for workshop analysis is shown in Figure2 and the terms are explained in Table2:

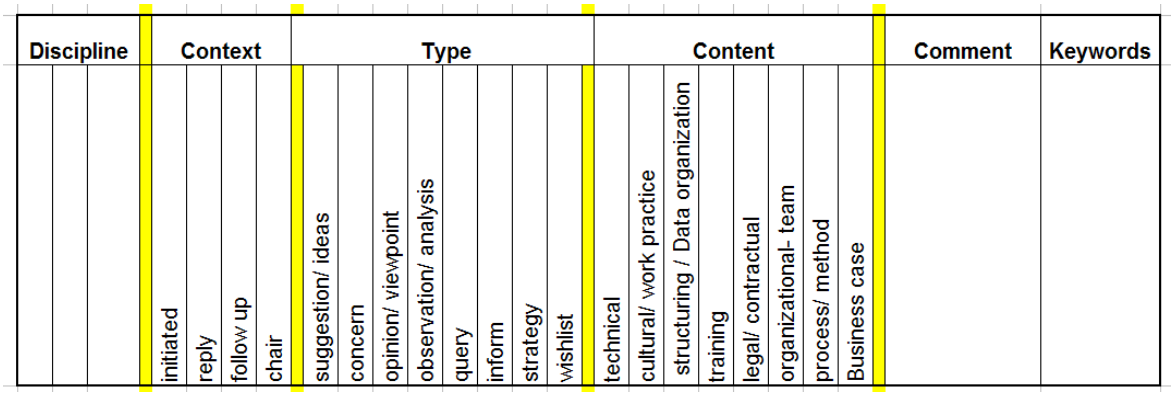

Figure2: Coding scheme

Table 2: Annotation of the terms used in the coding scheme

Criteria	Categories	Annotation with examples
Discipline		The role/ work background of the participant. E.g. architect, facilities manager, application vendor, etc
Context		In what circumstances was the statement given
	Initiated	Starting a new subject of discussion e.g. "*Let us discuss role of BIM in conceptual design*"
	Follow up	in continuation of the ongoing subject e.g. "*yes, for example…*"
	Reply	in response to a specific statement e.g. "*for that automated model checkers are there..*"
	Chair	Statement to control the flow of discussion, most often used by the moderator e.g. "*let us move to other issues"*
Type		The purpose of the statement
	Suggestion/ideas	Discussing solutions e.g. "*replace document by information as document has a*

		connotation to it"
	Concern	Doubts and inhibitions e.g. "*frustrating part is having different regulations across states* "
	Opinion	Indicative statement e.g. "*as industry picks up they will be forced to adopt..*"
	Observation	Information based on experience e.g. "*In civil works, disciplines tend to work in isolation*"
	Query	Asking about e.g. "*What happens when the project phase changes?*"
	Inform	Information on as-it-is e.g. "*for that automated model checkers are there*"
	Strategy	Discussing measures and approach e.g. "*one way is to force them*"
	Wishlist	Expressing wants "would like to" e.g. "*20 yrs down the line you should be able to say what paint you had on the wall*"
Content		The main subject of statement
	Technical	About tools, formats/standards, features and capabilities e.g. "*current systems not capable of dealing with different levels of detail*"
	Cultural/work practice	About the way or working e.g. "*...not willing to change the way they work* "
	Structural/ data organization	What is way to organize data, what form, grouping of data, and so on. e.g. "*we can have things like private and public space* "
	Training	Skill and knowledge acquisition e.g. "*architects learn many techniques in training that are not used with these tools*"
	Legal/ contractual	Regulatory e.g. "*organization that owns the information has the rights to change permissions* "
	Organizational- team	About the team-responsibilities, roles and collaboration e.g. "*that would be related to the access rights. Isn't it? What you will see is relevant to what your role is*"
	Process/ method	Protocols, procedures and methodology e.g. "*you often start with the architect ..in the sense it starts with a 3D model with diff disciplines adding info*"
	Business case	Economic and market feasibility- benefits e.g. "*who builds the model...who benefits from it ....there is something about willingness*"

An example of coded segments is shown below in Table3 to demonstrate the coding scheme and the categories. Let us take the first segment for example. Here the design manager starts a discussion, which is a concern related to legal/contractual issues. This statement is based on his observation. Accordingly a value of one is added under these classifications , and rest are filled in with zeroes (as shown in figure 3) . Similarly each segment is coded and marked. By counting the number of ones marked against each class, we get the total number of segments falling under each class. Keywords are noted and grouped under common themes. The number of occurrences for each theme is noted to set priorities.

Table3: Example of a chunk of coded segments

Comment/ segment	Discipline	Context	Type	Content	Keyword
Frustrating part is having different regulations across states ….	Design manager	Initiated	Observation	Concern	Isolation
How do we get one agreed standard?	Contractor	Follow-up	Query	Concern	Standard
Force them….	Design manager	Reply	Opinion/ strategy	Culture/ work-practice	Force

Figure 3 shows a snapshot of how the coding was done. For each segment the classification for each category was marked with a value one. By adding the values under each term the overall values were obtained.

	1												1				1		1								avoid additional checking	efficient
	1						1					1		1													civil work slower in adoption	adoption
	1												1				1			1							as industry picks they will be forced to adopt	force
1							1								1					1							**why a fear of additional work?**	additional work
	1							1						1						1							not willing to change the way they work	change
	1													1										1			resistance is at operational level	resistance
		1							1					1						1					1		one justification given: recreating models lead to re-	additional checking
		1							1				1								1				1		change from documentation as exchange of information to model as exchange of information	change information representation
		1							1			1		1						1							confidence in accuracy of model	model accuracy
		1							1			1							1						1		issue of completeness of models	model completeness
		1							1					1						1					1		typically modesl are partially complete - multiple	multiple models
		1							1			1		1											1		constant upgradation of models - control is difficult	model control
		1					1						1						1								BIM is vritual representation-CAD+analytical data	CAD/analytical da
		1							1				1				1								1	1	FM is most important benefit of BIM	FM
		1							1			1													1		design development and documentation is still a manaul process	design phase manual rt now
		1							1			1		1					1						1		interoperability allow using native tools but co-ordination is still manual: needs support	coordination still manual
		1							1			1	1				1			1							until standard is followed co-ordination won't work	standardization
	1						1						1	1		1			1						1		GIS starts after all info is provided. This where BIM is diferent	GIS
			1						1							1									1		GIS consortium & IAI recognize the issue	GIS & IAI
			1						1			1															no solution as yet	
			1				1							1					1								current systems not capable of dealing with different levels of detail	levels of detail
		1					1						1						1						1		architecture design diff to civil	arch vs civil
		1							1				1												1		architects conceive design out of nothing	designing
		1							1				1												1		architects need to provide lot of info to others	info trasnfer
		1							1			1							1	1					1		if IFC- property sets need to be filled: awful lot of work	additional work
		1							1				1												1	1	3d modeling/ documentation is fine: but property sets is	
			1						1			1								1							most architects believe 3D modeling dosnt help conceptual design	conceptual design
		1							1			1		1						1					1		many think CAD inhibits intial design	
		1							1					1								1					architects learn many techniques in training that are not used with these tools	training
		1							1				1												1		BIM models can be used at various levels of details to generate design	levels of detail
		1							1				1							1							it is a matter of cultural training	culture/training
				1					1							1						1					training students in design sessions to use CAD tools	training
			1						1			1										1					not many teachers who can teach this approach	training staff
			1						1					1								1					most still use paper and pencil	
		1							1			1										1			1		can't loose all techniques learnt over 100's of yrs just because of taking a new paradigm	design techniques
		1							1		1		1				1			1		1			1		tools need top be integrated in design process	integrated design process

Figure 3: A snapshot of coding sheet

Summary of workshop observations:

The two workshops have slightly different composition in terms of the industry representation. Active participation of the disciplines varies in the two workshops. While, overall the discussions have similar patterns, and raise the same points, there are some differences as has been discussed below under the following main headings:

1. **Participation:** The discussion on participation is provided to inform the readers of the composition of the workshop 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:
    a. levels of knowledge and awareness about BIM approach
    b. levels of interest in BIM
    c. the content of discussion
2. **Discipline vs content:** The distribution of the segments under each of the content category is mapped according to the discipline of the participant. Discipline vs content mapping of the workshop data allows:
    a. Identification of issues that specific disciplines actively discuss about and
    b. Identification of disciplines that are interested in specific aspects of BIM.
3. **Type vs content:** The distribution of the segments under each of the content category is mapped according to the type of the data. Type vs content mapping of the workshop data allows:
    a. Identification of aspects of BIM that participants need information about (query/ concern) or
    b. Have knowledge and experience to share about (opinion/ observation/ inform) or
    c. Expressed interest and desire to see in BIM approach (suggestions/ wishlist).
4. **Discipline vs type:** The distribution of the segments under each of the type category is mapped according to the discipline of the participant. Discipline vs type mapping of the workshop data allows:
    a. Understanding the levels of knowledge, awareness, interest and apprehensions about BIM approach across each discipline.
    b. Identification of disciplines those are apprehensive of the BIM approach and those that lack awareness and information on BIM.

Participation (Table 4, figure 4):

Discussion:

1. Participation of the disciplines is equated in terms of the frequency of statements and data coming from the representatives of each discipline.
2. In both the workshops **BIM consultants and application vendors have higher active participation**, mostly providing information.
3. Relatively higher participation of academic research in the second workshop is a result of the observations made from the first workshop and bringing those issues in discussion for the second workshop.

Table4: Breakup of the number of segments in the two workshops by discipline

Participation (Sydney)	no.		Participation (Brisbane)	no.
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		application vendor	84
FM	14			

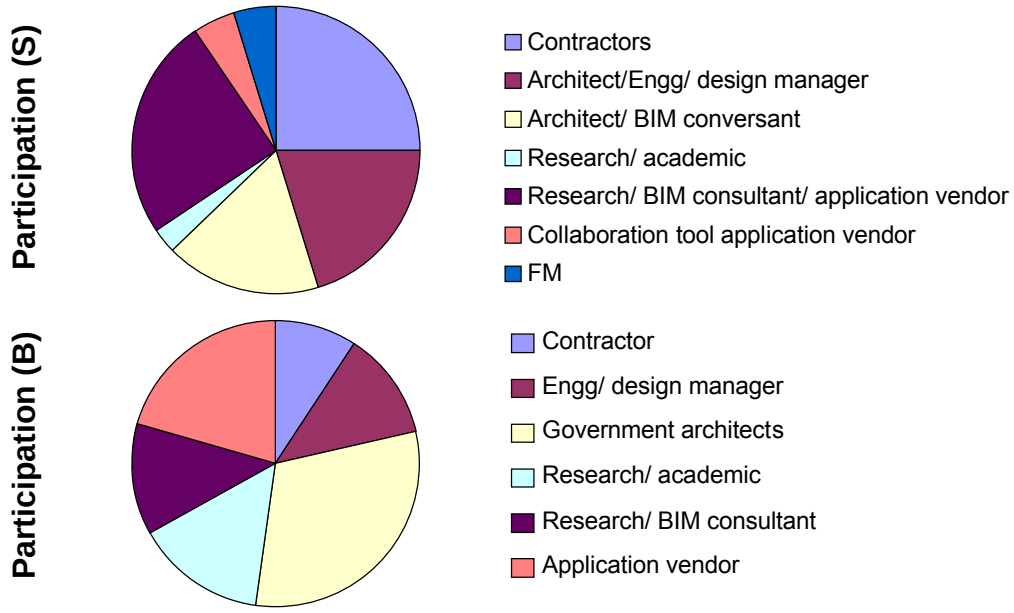

Figure 4: Charts showing participation of disciplines

Discipline vs content (Table 5, Table 6, figure 5, and figure 6)

In both the workshops the subject of discussion shows similar pattern

1. **Technical aspects are the dominant subject** in both the workshops 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 BIM approach in the first workshop, which is little different in the second workshop. This can be attributed to two main reasons:
    a. Presence of government architects in the second workshop.
    b. Application vendors in the second workshop are service providers. Hence, they need greater clarity on legal agreements and contracts, while the application vendors on the first day are product suppliers.
4. **Data organization is primarily a concern for the architecture and design disciplines as well as the vendors**. Contractors are not much interested in it, as expected.

Table5: Number of segments for by content for each discipline (Sydney workshop)

Discipline vs content (Sydney)	technical	cultural/ work practice	Data /structuring organization	training	legal/ contractual	organizational- team	process/ method	Business case
contractors	17	10	4	2	1	6	13	8
Architect/engg/ 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
Collab tool appl vendor	6	1	5	0	0	1	4	1
FM	9	0	2	1	0	3	4	3

Table6: Number of segments for by content for each discipline (Brisbane workshop)

Discipline vs content (Brisbane)	technical	cultural/ work practice	Data /structuring organization	training	legal/ contractual	organizational- team	process/ method	Business case
Contractor	13	8	3	2	1	2	14	2
Engg/ 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
application vendor	59	2	13	1	4	5	22	5

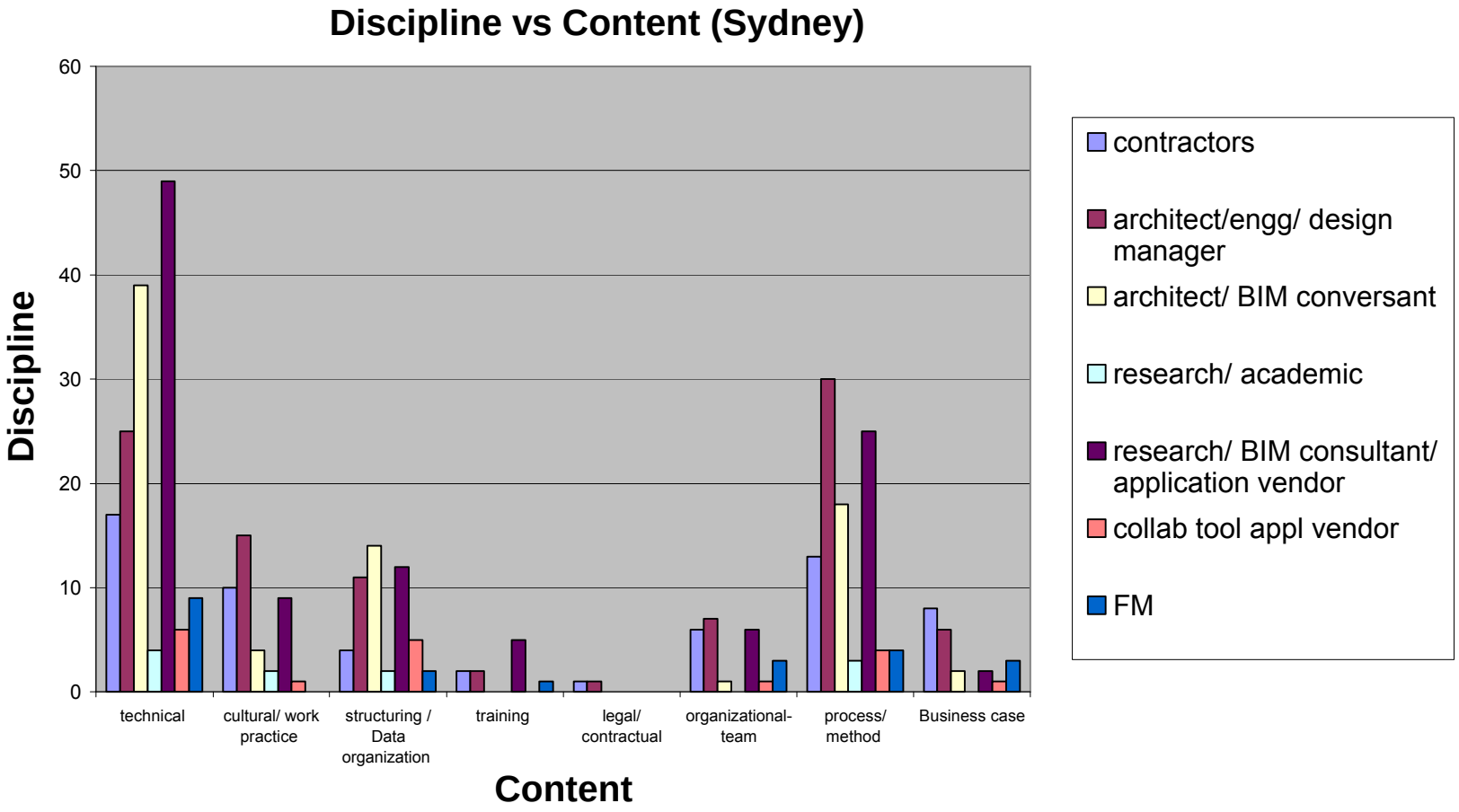

Figure 5: Contents of discussion by specific disciplines (Sydney workshop)

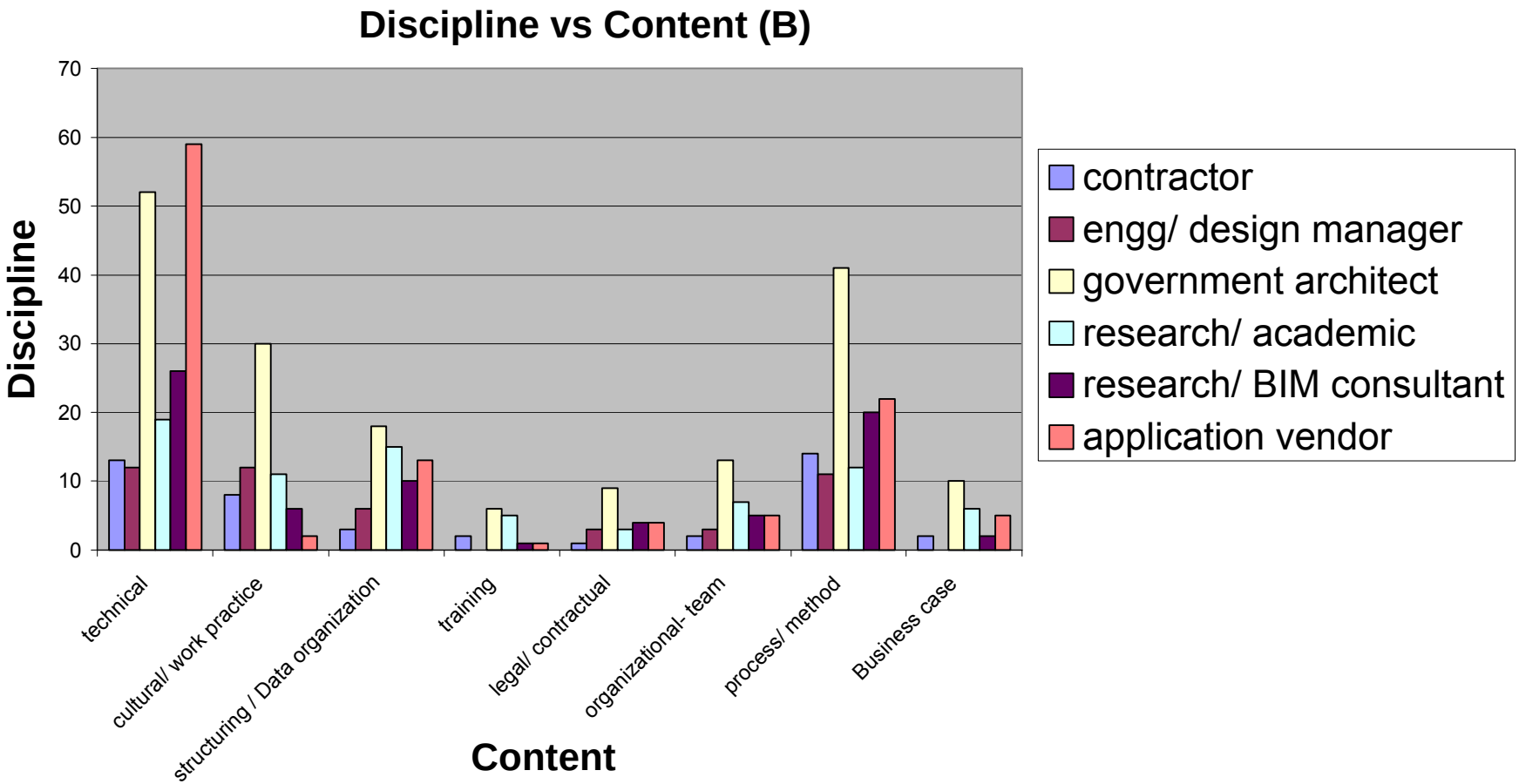

Figure 6: Contents of discussion by specific disciplines (Brisbane workshop)

Type vs content: (Table 7, Table 8, figure 7, and figure 8)

1. In both the workshops a **significant part of technical discussion is based on providing information**, quite often done so by application vendor s.
2. Opinion and views relate to "what could be done " or "what technical features may be useful" in a BIM application. In both the workshops pa rticipants share opinion on technical as well process related issues.
3. Wishlists are features that the participants would like to see and mostly relate to technical aspects. While there are very few wishlists from the first workshop the number of wishlists in the second workshop is considerably high. The greater participation of academic/research discipline in the second workshop could be a reason, as they often initiate such queries.
4. **Concerns are primarily related to technical, cultural/ work practice and process/methods**. Technical concerns are greater than the other two kinds .
5. While very few strategies are discussed in the first workshop, there are relatively **more strategies discussed in the second one. The strategies in the second workshop relate to technical aspects, processes and business**. Again the active participation of academic research disciplines could be a factor as they posed queries. Here also, the difference in the business model of the application vendor s stands out . Application vendors in s econd workshop being service provider s see greater potential in new strategies for BIM adoption. This is because they emphasize on customized services to suit client requirements. Being a service provider they are more willing to have a flexible approach.

Table7: Number of segments for by type for each content category (Sydney workshop)

Type vs content (Sydney)	technical	cultural/ work practice	Data /structuring organization	training	legal/ contractual	organizational-team	process/ method	Business case
suggestion/ ideas	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
Inform	43	7	11	0	0	5	21	5
Strategy	2	1	4	0	0	4	9	0
Wishlist	2	1	3	0	0	0	5	2

Table8: Number of segments for by content for each discipline (Brisbane workshop)

type vs content (B)	technical	cultural/ work practice	Data /structuring organization	training	legal/ contractual	organizational-team	process/ method	Business case
suggestion/ ideas	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
Inform	65	9	14	3	9	8	32	4
strategy	41	13	11	2	4	11	26	16
wishlist	26	0	10	0	0	0	6	2

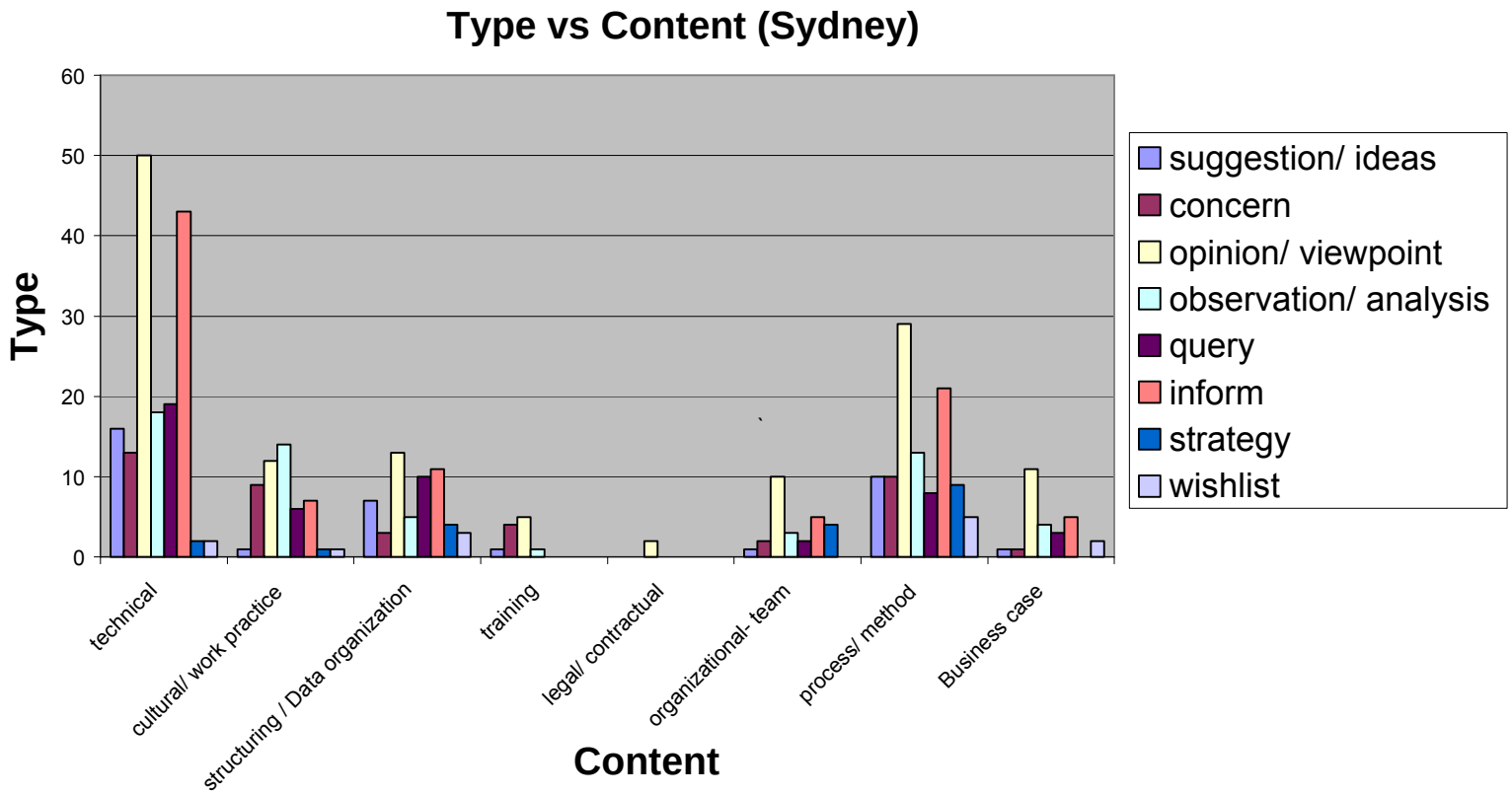

Figure 7: Types of statements on specific content (Sydney workshop)

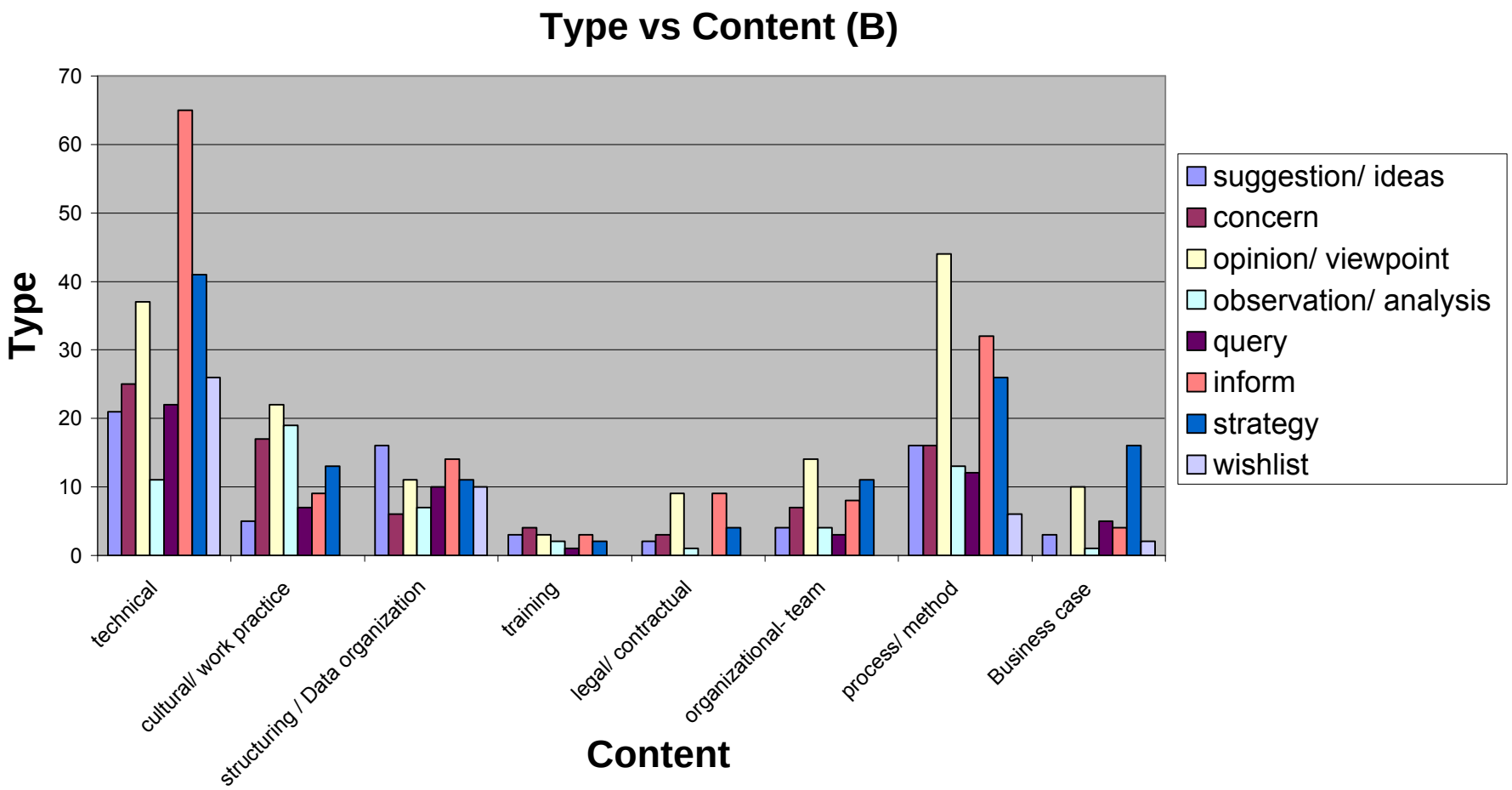

Figure 8: Types of statements on specific content (Brisbane workshop)

Discipline vs type: (Table 9, Table 10, figure 9, and figure 10)

1. **Architects share views and opinions the most, mainly on technical, data organization and process** related topics. Most of the concerns c ome fro m the architects, who also discuss strategies in both the workshops.
2. **Design managers primarily provide information on current processes and work practice**.
3. In both wo rkshops applicat ion vendors primarily provide informat ion. While in the first workshop the vendor s spend as much time giving his opinio n in the **second workshop the vendors spend considerable time discussing strategies, primarily arising from BIM as a service point of view**.

Table9: Number of segments for by discipline for each type (Sydney workshop)

Discipline vs type (Sydney)	suggestion/ ideas	Concern	opinion/ viewpoint	observation/ analysis	Query	inform	Strategy	Wishlist
contractors	1	6	18	2	9	5	1	4
Architect/engg/ 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
collab tool appl vendor	1	0	4	0	5	2	1	0
FM	0	1	3	0	5	2	0	4

Table10: Number of segments for by discipline for each type (Brisbane workshop)

Discipline vs type (Brisbane)	suggestion/ ideas	Concern	opinion/ viewpoint	observation/ analysis	Query	inform	strategy	wishlist
contractor	6	4	10	2	5	2	8	6
Engg/ 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
application vendor	8	8	8	5	4	60	28	1

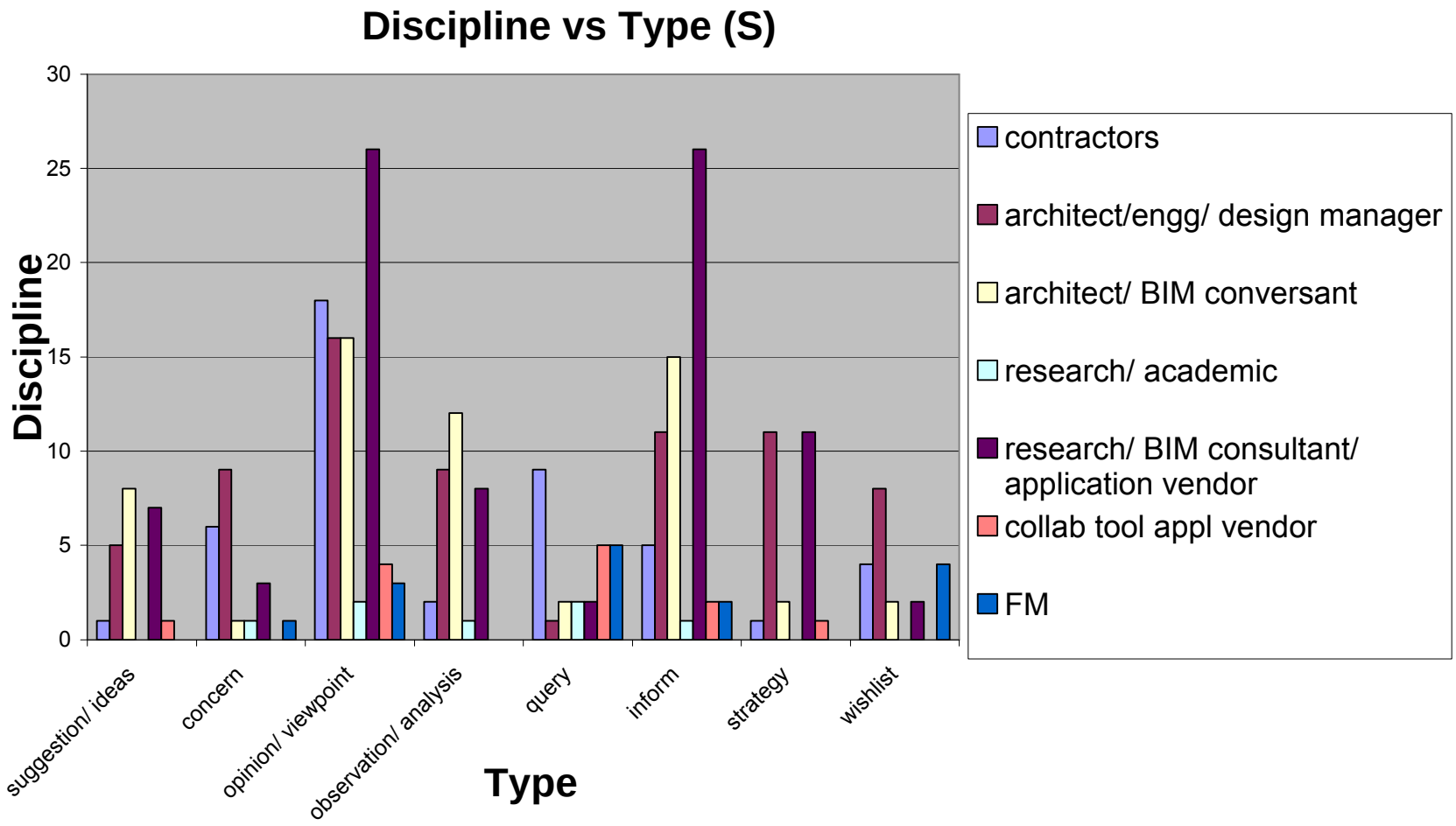

Figure 9: Types of statements on specific disciplines (Sydney workshop)

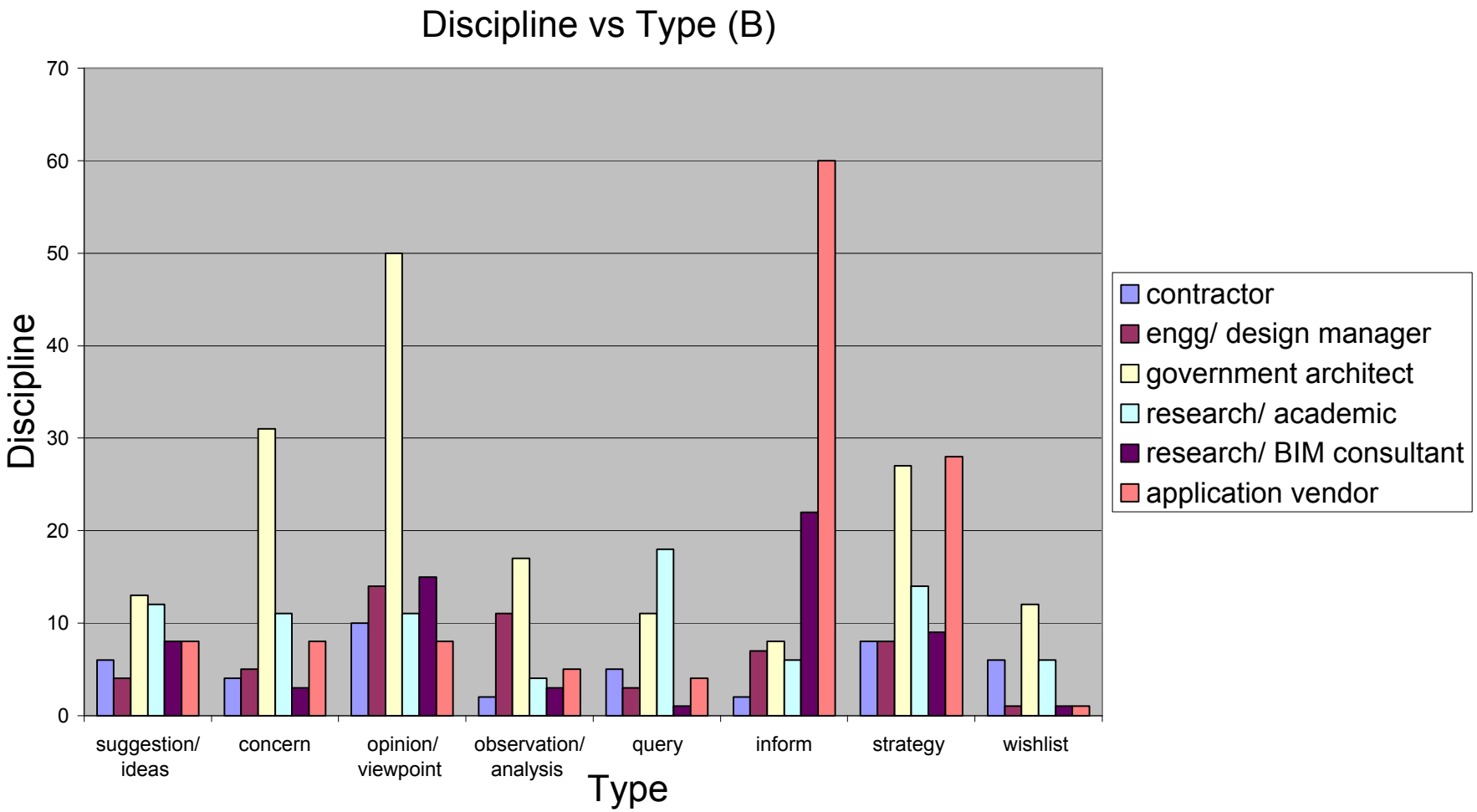

Figure 10: Types of statements by specific discipline (Brisbane workshop)

Discussion on workshop results:

Technology and processes are the most prominent points of discussion in the workshop. While many issues discussed are similar to those found in literature review, the workshop gave greater insight into the causes for the same. Some of the key issues emerging from the workshop are:

1. **Validation using 3D models:** Over the years, even though more and more 2D drawings are being generated out of intelligent 3D CAD packages (Eastman et al 2004) the **lack of trust on completeness and accuracy of models** remains a major concern for the practitioners involved. This despite the fact that within the AEC industry itself some disciplines like steel structures, in some cases rely completely on model accuracy as their outputs are CNC (Computer Numerical Control) fabricated. Developments of intelligent model checkers that are an important aspect of BIM approach have helped the cause. but 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) suggested, it is important to create awareness amongst the practitioners about the greater computability of the digital designs created by the available applications.

   When 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. This will mean that automated model checking will become important, and agreed processes and protocols for 3D validation will be required for design approval.
2. **Standards and Format for data exchange:** The AECbytes survey suggested that **interoperability** is the not a burning issue. But, the participants in the workshops emphasize the need for standards across proprietary tools. Accordingly, Industry Foundation Class (IFC) and organizations like International Alliance for Interoperability (IAI) and Open GIS (Geographic Information Systems) Consortium are discussed repeatedly.

   Participants express concern over the number of different commercial softwares available and the problems in exporting data between the same. The model server application vendors highlight the weaknesses in the IFC certification of commercial softwares. At present 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 very serious concern for managing an integrated database at the model server in the form of IFC files.

   In addition, most of the commercial product libraries and BIM applications that are coming into the market are targeted towards specific commercial applications, for example, Autodesk Revit that have a wide market base. This means that such libraries can not be used with other packages.

   Besides a standard format for data exchange, there is a greater need for standard vocabulary for consistency of data when moved from one package to another.
3. **Version control** is another important factor spread across three kinds:
   a. New **versions of the application** emerge regularly, and often with significant change. This brings in problem like data loss and compatibility issues for teams using different versions.
   b. **Version of project data:** if the BIM approach 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 in place to ensure

data integrity. This will allow different versions of the project to be maintained in the design phase.

c. **Version of IFC:** At present the IFC standards are still evolving, and the format has changed significantly in the last five years , often making many of the earlier IFC data almost unreadable in the present format. Service providers who maintain IFC data for the clients may have to update the stored data's format for the clients to be able to use it. In such scenarios if the changes are significant such updates may not be easy.

4. **Data management and organization:** Concerns are raised by the participants that as more and more data are managed and stored electronically; standard practices and procedures need to be in place to deal with data organization, storage and security. Ability to manage different **sub-sets** of the project, which r elate to compatible set of data for different purposes at specific stages of the project, will be useful . While the ability to constantly update the data gives unprecedented flexibility it also adds to the complexity relating to version management, **data explosion** and **usability**. Some of the related issues have existed in Database Management Systems (DBMS), but rather than the technological issues, these are more of organizational issues for the AEC domain and practitioner's. This poses a new challenge involving strategic decision making , which they have to take up early in the project planning stage .

   Digital data management provides new alternatives different to the traditional paper-based file management system, but a t the same time losing stored data can be a click away. For instance, while a new set of drawings can **overwrite** the earlier ones, a separate copy can be maintained altogether with no additional physical space requirement. **History** of the actions taken and t he data itself can be maintained but clients and users need to decide what data will actually be needed at any point later.

5. **Training in design schools:** CAD courses taught at design schools do not complement the present industry needs. In most architectur e 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 workshop 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 and understand and experience the potential benefits. In practice, architects work in a team and often coordina te team activities. In architecture schools although students also involve in team projects, the coordination of team projects is normally manual, and in a face -to-face setting. Students need to be trained and to explore state-of-art computer-supported collaborative tools.

6. **Key drivers:** The discussions in the workshop and the few examples of implementation of BIM in real world projects 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 partner** in the project. In general in a collaboration project there is variable power status. Quite often the bigger consultants determine and control the work practice. For example if the consultants like ARUP decide to change their work p ractice then they are in a greater position to convince other smaller partners to change. Bigger organizations have greater incentives to put new systems in place . Often, for them the scale of the project necessitated the need to implement new and more eff icient approach es to project data handling.

Government and regulatory authorities have a big role to play. Changes made in regulations and processes at the government end will force the entire community to adopt new systems. Government and regulatory authorities can set the benchmark for technological capabilities and competencies of the consultants and contractors working on government projects. If the technological capabilities are developed and implemented in government organizations to make the approv als and mandatory regulatory processes smoother, it can provide greater incentives in form of reduced project approval time, simpler submission processes, reduced paperwork, etc. CORENET in Singapore is one such example that allows electronic submission of approval drawings.

7. **New roles and relationships:** As new technologies are being adopted in the industry new roles and relationships emerge to meet the changing requirements.

   3D modelling has already become common place, 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 , particularly in large scale projects . At present with all the 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 such roles have already begun to emerge where BIM managers have been appointed.

8. **Importance of as-built data:** Ability to support **facilities management** is considered as an important value add ition for BIM approach, making s strong business ca se for it. All the information stored and maintained during the project is rendered useful for later access and retrieval. This database is useful in updating and identifying the information needed for maintaining the facility. However , in most constructio n project changes are made during the construction phase . Hence, the final output may have some variations from the initial design, represented in 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 information which is required for facilities management.

   As-built drawings may become useful 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**. This sort of comparisons will allow building greater c onfidence in the analysis tools and simulations , by providing greater evidence and data on their accuracy and tolerances.

   Quality of as -built data is important. When the surveyors provide data for the built facility the BIM manager s need to register the q uality of the surveyed data. In the workshops conducted, the professionals involved in facilities management emphasize on the need for measures to obtain and capture the accuracy and quality of such surveyed data. Measures like grouping sets of data as su b-models for different parts of the model based on the quality of survey for the corresponding parts are discussed, relating to version and data management.

9. **Civil works and architecture:** integrated technology: A number of large projects involve significan t overlap of both civil as well architectural works. For an effective collaboration support this would require **the BIM applications and GIS to be compatible**. At present this is not supported and in the workshop it was reported that (OGC) Open GIS Consortium and IAI are working together to resolve this issue.

10. **Security of data:** Putting data on an integrated database in an electronic format raises some security concerns amongst the involved players. Related to it are the concerns of **Intellectual Property (IP)** and protection of copyrights. While some concerns on **network security** from a technical viewpoint may be justified, others may be alleviated by greater awareness and legal measures. For instance, the access to data on such databases is controlled through **secured log-ins**. Data **check-in and check-outs are registered** for each interaction. Service providers manage the data under a **contractual agreement** with the data owner and the terms and conditions of data management and operation are well laid out in the document. Similarly, the IP issues are legal issues, which are no different to this format of data storage and design than what exists in practice.

A summary of the BIM related issues and relevance to the different disciplines is presented in Table 11.

Engg	Architects/ designers	Issues/ discipline	
Maintain data integrity in different design phases. Need to know what data is current.	Maintain different options of design. Maintain data integrity in different design phases.	project data	Version management
NA	NA in design phase	IFC	
Can be an issue if design collaborators are working on different software versions	Can be an issue if design collaborators are working on different software versions	software	
NA	Often needed in design phase, as design evolves iteratively	history	Data organization
Allows engg sub-teams to share information within them before publishing for others to see.	Very important in design phase. Allows multi-level design collaboration. Teams and sub-teams	public/ private	
Sub-sets very important, based on sub-team composition	Sub-teams work on different parts of the design; model should be organized to support this.	sub-sets	
Allow access based on roles. Private space can allow control over sub-team data, until published	Allow access based on roles. Architect may want control during design phase.		Data control and access
Nothing critical in design phase. IP issues to be resolved.	Nothing critical in design phase. IP issues to be resolved for design copyright.		Legal/ contractual
Generally engineering designs need more activity coordination within their team.	In design phase, architect generally coordinates the project development activities.		Activity coordination
Some engg disciplines have developed good model validation procedures. Very important aspect.	Needed in design review phase.		Model validation
Demonstrations and trials will be useful. Engg. disciplines have similar experiences using SAP and STEP	Greater awareness needed on model server. Demonstrations and trials will be useful.		Training
Extremely important for interoperability between tools used by different design disciplines.	Extremely important for interoperability between tools used by different design disciplines.		Formats for data exchange (IFC)
NA	BIM manager may also be useful in design development phase. However, will need to work closely with the architect.		New roles
NA	NA		Updating as-built data
Very important to ensure design data and controlled access to information.	Very important to ensure design data and controlled access to information.		Security of data

Table11: Issues related to BIM model servers and their relevance to specific disciplines

Issues/ discipline	Version management			Data organization			Data control and access	Legal/ contractual	Activity coordination	Model validation	Training	Formats for data exchange (IFC)	New roles	Updating as-built data	Security of data
	project data	IFC	software	history	public/ private	sub-sets									
Design manager (DM)	Very important aspect to manage design activities.	NA	Can be an issue if design collaborators are working on different software versions	NA	Needs to ensure public data is concurrent and checked	Very important for activity coordination	Allows DM to manage responsibilities	Important for clarifying responsibilities	Important for coordinating design activities across different phases of the project	NA	Greater awareness needed on model server. Demonstrations and trials will be useful.	NA	BIM manager can become an important role to assist DM activities.	NA	Very important to ensure design data and controlled access to information.
Contractor	Very important aspect to manage design activities.	NA	Can be an issue if design collaborators are working on different software versions	NA	Needs to ensure public data for construction is approved and coordinated		Very important during build and construction phase		Important for coordinating activities for project realization and construction			NA	Needs to coordinate with BIM manager.	Can provide assistance in obtaining as-built data. Important role in coordinating this activity.	

Issues/ discipline	Version management			Data organization			Data control and access	Legal/ contractual	Activity coordination	Model validation	Training	Formats for data exchange (IFC)	New roles	Updating as-built data	Security of data
	project data	IFC	software	history	public/ private	sub-sets									
FM	Only needs the final data after construction. Not very critical thereafter	most critical for FM, as the data is to be maintained for decades, and should be usable with current applications	Can be important aspect. Maintained data should be compatible to latest versions of the application	Important for FM to have history of data post-approval at each update rather than overwrite them.	NA	Important, if project develops in phases. Even for maintaining data on renovations and changes.	All with FM once facility is built	Important for data control handover and conditions of service	NA	NA	NA	NA	NA	Very important. Critical phase for FM.	Very important. Mainly for public buildings and large projects
BIM service provider	Needs to coordinate VM. Has to develop processes in place to do that.			Must have technical capabilities to support this. Choice of data is up to the client	Flexibility to customize to clients requirement will be useful	Relevant to all phases of the project.	Needs to coordinate with the client.	Very important. Service agreement defines the scope of vendors role.	According to service agreement. Useful to have a BIM manager doing this.	NA	Needs to develop training guides and sessions for clients and users	Important. Service provider may just maintain data or also convert data to standard formats. Scope defined by contract	very important to coordinate activities and data	NA	Important to ensure clients confidence. Can be a part of contract

5. Plan for case studies and priority issues to be tested:

Next phase involves case studies using the available tools and data from real world project to verify the key issues identified from the literature review and workshop analysis. These include version management, data organization and structuring, data exchange, data ownership and control, activity co-ordination and protocols for 3D model validation.

Data from two projects (a mid-size government project and a commercial project) have been obtained. A BIM approach is being adopted in these projects using two different commercial applications. EDM Model Server™ license has been obtained and ActiveFacility's service as model server will be used for the two case studies.

In using EDM Model Server™ the users can directly structure and manage building data. Main issues for verification and testing are the IFC (Industry Foundation Classes) data export and import, check-in/check-out permissions and processes in the model server, the communication flow within the team, the kind of organizational re-structuring for project collaboration, and processes that need to be in place to co-ordinate the activities and model integrity.

Working with ActiveFacility, which is a BIM service provider, the issues may be little different because ActiveFacility manages the data for the client. Main issues likely to arise in this case are legal/contractual issues, security concerns of the clients, and data co-ordination and ownership issues.

Factors relating to version management such as how to maintain history, what kind of data-subsets to generate, how to structure model hierarchy for effective usage, and so on have emerged repetitively, and therefore will also be considered in both the cases. The two types of case studies will highlight issues that arise in in-house BIM development and those where BIM service is provided by an external agent. Tested strategies and measures will be evaluated for their effectiveness in collaboration support using BIM model servers.

Those issues identified from the workshop, which are directly related to the use of model servers as a collaborative platform and that can be tested and/or demonstrated in our case study, are listed here. Along with the issues some suggestions on how that may be incorporated in the case studies are presented.

1. **Version management and data sub-sets**: As discussed earlier there are different version management issues relating to software versions, IFC standards and project data.
    a. **Software versions** are a matter of availability and obsoleteness of older product versions. As technology keeps improving newer and improved versions of the current products will keep coming. Models and data generated using older versions are generally usable in the newer versions but many a times lead to data loss. Some measures that were discussed in the workshop to deal with issue include:
        i. Vendors reach an agreement that in their product development they ensure that the newer versions of their software accepts models generated using older versions without any data loss.
        ii. As part of the service agreement the BIM service provider regularly updates the data, in keeping with the original softwares current version to facilitate data usability or
        iii. As part of the service agreement the BIM service provider will be obliged to maintain the older versions of the software for data usability.
        iv. Add-ons and plug-ins can be developed for specific packages that allow smooth upgradation of models to latest versions, preventing such data loss. However, given the wide array and large number of packages available such propositions may not be commercially viable, if such conversion plug-ins were to be developed for each.

v. A lot of this may become a non-issue if the standards like IFC become universal, and proprietary softwares are fully IFC compatible without any data loss in both import and export. However, at present this is a far fetched situation. In addition, standards need to be developed across the proprietary softwares on terminologies and object semantics.

The issues of software version management can be tested during the case study but it may not be possible to test the solutions for the same. Some of the measures discussed in the workshop can be discussed with industry partners and explored further, while other solutions can be hypothesized. However, with the proposed case studies it will not be possible to test these solutions.

b. **IFC versions** are changing as the standards are still evolving. It can be expected that as the standards mature the rate of change will reduce and the changes will be marginal, alleviating the concerns of data loss and conversions due to change in IFC standards.

Work on IFC is in progress at IAI. IFC versions are out of the scope our study, and all that this study can demonstrate is the loss of data during conversion from one IFC version to the other.

c. In terms of version management this study will primarily focus at **project data version management**. It needs to be demonstrated that project data can be organized as sub-sets in an integrated database for the different disciplines to access, modify, update and maintain the data without affecting the integrity of the data. Protocols and processes need to be in place that allows formal agreements on data integrity and approval at specific phases of project development. Some measures like notification and flagging were discussed to deal with the issue of data integrity, in case changes are made by one of the collaborating partners. As it is, there are log-ins and permissions which can allow monitoring changes through an approval process. In the case study these situations need to be tested. This may also suggest what kinds of data should be allowed to be automatically updated and what needs an approval.

Another aspect of project data version as discussed in the workshop relates to design alternatives. Architects maintain more than one design option for the same project and in general these options run in parallel. These parallel design options may be at different stages of development at any given time. Quite often the same initial design branches out to different options and such information need to be maintained. This kind of project data version management is closely related to data organization, housekeeping and archiving within the model server. Some of the alternatives for the same can be tested in the proposed case study and guidelines can be suggested based on the observations.

2. **Data organization, housekeeping and archiving**: Data organization is a critical issue as a lot of data is generated during the design development and not all of it useful later. The kind of data that may be required to be kept for later use may vary from project to project and the specific requirements. However, some aspects can be explored during the case studies and recommendations can be made from this experience. Some of the important aspects that came out from the workshop in this regard are:

a. **Pruning and history**: A lot of the data management decisions that are taken at a later stage in the current architectural practice. This data is generally distributed across the local machines or kept as archives. However, in a model server the clients (data owner) may be required to decide upfront on what data to maintain in an integrated database. At different phases of the project different kinds of data

may be required. Post construction, not all the data generated and required during the design phase will be useful. At the same time, the integrated database may be the place where the client may want to store all relevant and useful information generated through out the project lifecycle.

i. Data that may never be useful later needs to be identified and pruned.
ii. Data sets need to be organized in a structured way to allow tracking history of the project development.
iii. With an electronic database it is easy to update and modify the current data. However, this also means that it is easy to overwrite the data leaving no record of the data stored earlier. These are critical decisions that can influence the effectiveness and usefulness of the integrated database. Measures like warnings and reminders can be incorporated within the model server interface, while the user is overwriting or deleting the data stored earlier.

Some of these aspects can be explored during the case study and recommendations can be made on useful practices to deal with data organization and related issues.

b. **Public space and private space**: Suggestions can be made on when and what stages the data should be uploaded to the integrated model server. That is, it is expected that individual disciplines will be working on local machines and at some stage when they deem appropriate they may like to share the data with the rest of the team. It may be helpful to look at some of the completed projects and identify stages when 2D drawings were issued or data exchanged between the disciplines. In terms of the model server this does not prevent individual disciplines from storing their current data on the model server. Rather, a mechanism needs to be developed to allow for private and public spaces that extend the control over data sharing at different hierarchical levels rather than one administrator and other users. That is to say, the private space 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 easy to create on the model server.

3. **Data ownership and control:** At different phases of the project the control of data moves to different hands. In the initial design phase the architect is generally at the helm of the data, co-ordinating the information exchange with the other disciplines. In general, as the design matures and the project moves into the construction phase the contractor needs to co-ordinate the data and get the work done. In projects that involve tendering the client may be having the control of that data all this while. Once the project is built, the facilities manager needs the data to maintain the facility.

Workshop discussions suggest serious concerns on the procedures for data control handover, while using an integrated database. For each project maintained at the model server the data is controlled by the administrator, who determines the permissions and access rights. Hence, the different phases of the project may require that the administrative rights be given to different parities at different times. Along with the change in administrator the access and permissions may need to be changed and security of data may be a concern. These situations can be tested in the proposed case study to identify the type of issues that come in, and measures that can be adapted to deal with them.

4. **Activity co-ordination:** In using the integrated database each party must contribute the data to integrated model. It is pos sible that each discipline works on independent models and then upload the data on the model server. However, this defeats the purpose of having an integrated model, which is aimed at greater design integrity and avoiding rework. While using an integrated model team members need to identify the activity dependencies upfront and schedule activity allocation. Activity based plan for information exchange and model update can lead to greater efficiency in design development as well data organization on the mode l server. Once, the activity dependencies are identified managing the other aspects of model server like data ownership and permission rights can be planned and better co -ordinated. Such prior planning will be useful in developing the contractual agreements that best suit the specific project.

   Participants in the workshop agree that adapting a model server and an integrated database will require as much communication and co -ordination activities as in the present practice, if not more. At the same time the re will be greater automated support on conflict identification, class detection and data management.

   In the proposed case study different approaches to model development will be tested. In the first case the current work practice will be used. In another case the activity dependencies will be identified prior to the model development, and an activity coordination plan will be developed to start with.
5. **Role of BIM manager:** the need for a dedicated BIM manager is emphasized during the workshop discussions. Similar trend has been observed on large scale projects. While the importance of a BIM manager is established, the roles and responsibilities are yet to be defined. This case study will try to identify the contributions and responsibilities of a BIM manager, and make recommendations on the same.
6. **Quality assurance and as-built data:** it has been reported that the design models are rarely updated with the as -built data. In general, there are differences between the designed model and the actual built design. It is the as -built design which is required for facilities management. In addition, the performance ratings are conducted on the built facility hence the performance projections from analysis of the as -built model should be compared to the actual performan ce to check the efficiency and tolerance of the analysis tools. In the proposed case study, we can try to check the kinds of data that can be updated in the design model based on as -built data obtained from the survey. Issues relating to this process will be recorded and procedures for registering the quality of surveyed data for different parts of the building will be tested.
7. **Protocols for 3D model validation:** Lack of trust in 3D models is discussed as an important issue in the workshops as well in BIM lit erature. Despite the availability of some 3D design review tools design review is still primarily using 2D drawings. Discussions in the workshop suggested lack of standard practices as the inhibiting factor for greater use of 3D design reviews. It was sugg ested that since 2D drawings can be generated out of the 3D models a multi -modal design review may be useful. Some of these aspects can be tested in the proposed case study. In particular, it may be worthwhile exploring the level of rigour required for dif ferent aspects of the design in the different phases of design development. Based on this investigation, it is expected that for some aspects of design 3D review may be a sufficient criteria, while some others may require multi modal evaluation. Base on th is study, recommendations can be made on protocols to be adopted for model validation and design review using 3D models.

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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

Useful online resources:

www.aecbytes.com
www.gsa.gov/bim
http://bim.arch.gatech.edu/
http://www.facilityinformationcouncil.org/bim/story_111706.php
http://en.wikipedia.org/wiki/Building_Information_Modeling
http://faculty.arch.utah.edu/bim/

Appendix 1: Desktop audit

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 at end of chapter 3.

1.1 ArchiCAD 11

Overview: ArchiCAD 11 uses a single 3D building model for design development, visualization, collaboration, and producing 2D documentation.

Application: BIM design tool.

Main features: (Graphisoft, CyonResearch 2003, Khemlani 2007)

- Collaboration and organization
    - Hotlink to manage linked drawings.
    - Mark-Up features facilitate communication. It allows highlighting problematic or new elements.
    - Integrated database of construction elements, accessible from the Calculate menu. Can display the number, quantities and the elements' spatial disposition. Displays can be in list format or in an interactive schedule format.
    - Standard Library provided with the program. Allows access to additional Libraries, both from local volumes and through the Internet.
    - Worksheets: a dedicated environment for 2D drawings, either generated from the model, created from scratch, or imported from external files.
        - Allows parallel development of the model and the drawings by different team members.
        - A drawing generated from a model view maintains a link to that view, allowing it to be rebuilt from the source view.
    - Workplace: similar to conventional design and drafting environments in many ways.
- Modelling, documentation and other enhancements since previous versions
    - Complex geometries are easier to make.
    - Various options available while choosing a module file.
- Viewing:
    - Visual Compare feature to find the differences between model and drawing views.
    - Virtual Trace feature
        - Ability to display a live reference view alongside the currently active model view or drawing.
        - Allows editing the elements in the active view
        - Allows transfer attributes and parameters from the reference view elements to the active view elements.

Underlying technology: (Graphisoft)

Graphisoft's GDL (Geometric description language) is the technology used for object intelligence. GDL objects contain the information necessary for text specifications, 2D symbols and 3D models. In addition to material, style, and measurements, the objects can also store manufacturers' data. Key features of GDL are

- 2D, 3D and property data in one file
- Parametric: one object – many products
- Product-specific user interface

- Integrated links to external product data on the web
- Logic and behavior of the real product
- Compatible with common CAD formats in 2D and 3D
- Small file size

GDL Technology licenses tools and technology to create on -line and off -line intelli gent product catalogs. Product manufacturers are now developing, marketing and distributing their product on the internet via GDL technology.

Add-ons and plug-ins: to be added

- Integrates with Google Earth
- Bidirectional integration with the Google 3D Wareho use. It requires downloading and installing a plug-in from the Graphisoft website.
- Inbuilt PDF support allows saving in PDF format without relying on a PDF printer driver.

BIM and business Approach:

- ArchiCAD suggests that construction models be better bui lt from scratch rather than be based on design model.
- ArchiCAD has good 3D capabilities but realizes that the present work practice is around 2D. With Virtual Trace feature which is a 2D feature ArchiCAD is targeting current professional practice. Thus, wh ile attracting current market ArchiCAD is looking for a gentle transition to BIM.

Shortcomings:

- Lack of modelling constraints and lack of associativity between building elements
- Does not make a distinction between rooms/spaces as commonly defined by a si ngle enclosure and a larger collection of spaces that can come together as a zone; its Zone tool has to be used for spaces as well.
- Model-based interference checking or clash detection is missing.
- Though it is simple to build favourites (project director ies) such as wall type, with IFC (Industry Foundation Class) properties pre-entered the IFC properties are not included when using these. (STATSBYGG 2006)
- Several of the program's objects need more setting options for appearance and material properties. (STATSBYGG 2006)

1.2.Graphisoft Change Manager

Overview: Graphisoft Change Manager is a new application that automates the process of checking for drawing (2D) revisions across two or more complete construction drawing sets. It is focused on current profession al practice rather than the future BIM -oriented scenario in the AEC industry.

Cons: Does not work with file formats other than DWG; works only with drawings rather than models, making its long-term viability in a future BIM world uncertain.

Application/purpose: 2D drawing checker

Main features: (Khemlani 2006)

- Drawing-based rather than model-based solution
- Automated checking for drawing revisions across complete construction drawing sets
- Works with all DWG files created by AutoCAD Release 14 and above.
- Provides three different kinds of viewing modes to review the changes made to a drawing. All three modes involve overlaying the old version and the new version of the drawing and showing the changes in different ways.

- Review Assignments: allows all the assi gnments of each individual team member to be viewed to see their current status, as well as other information such as the date of assignment, assignees, and the assignment priorities.
- History commands: To know what happened to every assignment throughout t he history of the project.

BIM and business Approach:

- First of its kind, with a very specific purpose.
- Target audience: AEC professional such as a contractor, sub -contractor, engineer, or architect who often has to compare large document sets to find out what has been changed.

Shortcomings:

- Restricted to the DWG file format. As of April 2006 Graphisoft was working on adding PDF support, so that Change Manager will eventually be capable of working with both DWG and PDF files.

1.3.Graphisoft has a Virtual Construction suite comprising two products:

Graphisoft Constructor

The Constructor application includes the ArchiCAD modeling system for creating 3D construction models, a 4D sequencer for automatically linking the construction model to the project schedule and enabling different schedule alternatives to be analyzed, and a connector to the Estimator application that comes bundled with the product.

Graphisoft Estimator

The stand-alone Estimator application includes a model -based estimating system that extra cts quantity information from the construction model for producing estimates quickly and accurately, a traditional estimating system for easing the transition from manual takeoff -based estimating to model -based estimating, a module for dividing the resourc es created by the estimating application in production zones and for generating procurement requirements, and a 5D reporting system that uses the construction model as the link between cost and time and produces cost-loaded schedules for financial analysis.

1.4. Revit suite and Revit Architecture 2008

Overview: Revit consists of three discipline -specific platforms: Revit Architecture, Revit Structure, and Revit MEP. Each team member *must* be working on the same platform version and product build to effectively collaborate. This review is primarily of Revit Architecture.

Application/purpose: BIM design tool

Main functions: Parametric modelling, Quantity Take off, Rendering

Main features: (Khemlani 2007)

- Collaboration and organization
  - Ability to check interferences within a single project or linked models.
  - Each discipline creates a relationship based on their individual workflows
  - Linked models: Easy to divide up a large project into multiple linked files
  - Copy/Monitor feature:
    - Components of the linked model can be monitored for change.
    - Elements from the linked model can be copied into the host project automatically creating a monitored relationship.
- Modelling

  - Shape editing feature for roofs and floor slabs allows subdividing its surface into parts that can slope independently.
  - Groups feature
    - Elements can be combined into a larger entity.
    - Changes made to one instance of the group can be automatically updated in all the other instances.
    - Group Edit mode greys out the rest of the model.
    - Groups can be edited independently of the project or family in which they are loaded.
    - Allows conversion of groups to linked Revit models and vice versa.
- Viewing
  - Enhanced hide/isolate feature
    - Changes persist after the project is closed and also affect the printed output.
    - Reveal Hidden Elements mode allows users to see all or selected hidden elements in a view
  - Graphic overrides can be applied to individual elements to display them differently from the graphic settings associated with their categories.
  - Ability to split up a large floor plan, section, or elevation view into multiple smaller segments to place them on sheets at a readable scale.
  - Dedicated masking tool for controlling which elements will obscure other elements in a view.
  - Colour scheme enhancements
    - To create a nd manage colour schemes independently of applying a colour fill to a view
    - The colour scheme is now a property of a view that allows different schemes to be applied to different plan views.

Add-ons and plug-ins:
When exporting a 3D view for use with 3ds M ax or VIZ, Revit retains the materials when exported using ACIS solids, as opposed to showing only one material for the entire solid, as in previous releases.
As on June 2007 (Khemlani 2007) a link to Google Earth will soon be available to subscription members, allowing users to bring site information from Google Earth into Revit and export a Revit model back into Google Earth with the correct geo-referencing information, so that it can be viewed on the actual site.

Shortcomings:
- Despite having many built -in constraints that regulate the modelling to prevent inaccuracies and errors, Revit continues to allow illegal operations such as overlapping doors, columns, windows, etc., which require interference checking to be used to detect them.
- Modelling non-regular building forms is difficult.
- Conceptual modelling capabilities are not good enough to avoid the need for applications like SketchUp and form.Z.
- Built-in rendering capabilities not on par with those in other modelling and BIM application

1.5. Bentley Building V8 XM Suite

Overview: Integrated multi -disciplinary set of BIM solutions built on the MicroStation platform, and includes Bentley Architecture, Bentley Structural, Bentley Mechanical Systems, and Bentley Electrical Systems.

Bentley's vision of BIM: user need for BIM as a hierarchy of needs in following order (Bentley and Workman 2003)

- Enter/access/analyze information
- Share information
- Synchronize shared information
- Best context for information: i.e. should be able to use tools and environments rela ted to the discipline
- Secure environment for full collaboration: IP issues and so on.

Three key aspects:

- Bentley sees BIM as a superset of CAD
- has a "federated database" approach to BIM,
- Bentley believes in "not starting over" with a new solution, and so all its individual discipline-specific BIM solutions are built on top of its existing MicroStation platform and TriForma extension.

Main features: (Khemlani 2006)

- Organization
  - Implications of a federated database approach to BIM
    - Allows the separation of 2D and 3D objects
    - Change in the model does not automatically update the extracted drawing—because of the association, the change is detected and the drawing is recognized is being out -of-date. The user is then given the choice of updating it.
    - Project data but can be distributed across multiple files. This means
    - Project organization becomes crucial when working with Bentley's BIM applications. The project organization can be changed later if required, making the setup very flexible.
    - The different files mak ing up a project can be easily handled by several project members working simultaneously.
  - Link sets can be created in the project explorer. Unlike Revit's Project Browser or ArchiCAD's Project Map, the Project Explorer in Bentley Building is an optional component rather than an integral aspect of the application.
- Modelling
  - Gives the user the choice of four different 2D/3D design modes:
    - Drafting, create 2D drawings only and not a 3D model
    - Plan to Model, create 2D, but a 3D model is dynamically generated. Changes made to the model do not affect the plan
    - Plan and Model: work either in the 2D plan or 3D model
    - 3D Modelling, work entirely in 3D mode, and any 2D drawings can be extracted from the 3D model.
  - 3D modelling improvements
    - Creation of parametric 3D geometry
    - Mesh modelling
    - New handles for interactive editing; improved viewing and navigation in 3D
- Viewing
  - Task Based interface

        - § Allows the vast array of tools and commands in each application to be organized according to tasks.
        - § Possible to have multiple task interfaces open at the same time
        - § Task-based interface makes a reference to a specific tool rather than physically placing in a designated tool palette, which means that the same tool can appear in multiple tasks.
    - o Better graphics with real-time interactive shading
        - § Users can work directly in shaded views
        - § Improved visualization capabilities for photo-realistic rendering
        - § New animation tools
    - o Interface improvements
        - § dialog and element transparency
        - § integration with PANTONE colours, and display priority
        - § keyboard mapping that allows each user to configure their entire keyboard as desired

- It is also possible to run all the Bentley Building applications that are installed in the same MicroStation session by using a Bentley Building Suite Icon instead of launching the individual applications.

Integration and data exchange:

- Support for 3D PDF, allowing an entire project including 3D models, 2D drawings, specifications, and other documents to be packaged in a single PDF document
- Integration with Google Earth, allowing a building modeled with the Bentley Building applications to be exported to Google Earth with the correct geo-referencing information
- Google SketchUp and the Google 3D warehouse are also fully supported.
- Anything drawn, modeled or imported into MicroStation can have BIM information added to it, allowing virtually any kind of geometry to be BIM aware.

Limitations: (Bentley Architecture)

- No tools for conceptual design tasks or space programming.
- No sketching capabilities. Sketch can be imported and used as an underlay for developing 3D massing or detailed models.
- Though very good solid and surface modeling capabilities that can be used to model any kind of regular or freeform shape, these tools lack the intuitiveness and ease of use needed for quick 3D massing found in dedicated conceptual design tools such as Google SKETCHUP.
- Does not have the capability to automatically derive the building shell —with intelligent wall, floor, and roof "BIM" objects—from the schematic massing model.

Strengths: (Bentley Architecture)

- Extended toolset for modelling the site as well as different building components.
- Default settings are used for its type information of a newly created building element, which can be changed later when required.

Limitations: (Bentley Structure)

- The entire physical structure of the building has to be created in one model in Bentley Structural if it needs to be analyzed as a whole.

Strengths: (Bentley Structure)

- Digital model of the building structure combines both the physical model as well as the analytical model. This can be used for the different types of structural analyses engineers

need to perform to design their structures, as well as to derive the construction documentation needed to build the structure.
- Structural Snaps option makes it easy to model structural elements in 2D as well as 3D.
- Has dedicated tools for creating larger structural assemblies.
- Ability to automatically create a fully associated analytical model (optional) of the structure from the physical model, and then link it bi-directionally to popular structural analysis tools for performing different kinds of analyses.
- Allows modifications to analytical members and physical members separately, so that the analytical model can be tweaked for correct input to an analysis program, without affecting the physical model.
- Option to choose to send the entire analytical model or only a portion of it for analysis.
- Design History makes it possible to visually review any changes that are accepted.

1.6. JetStream from NavisWorks3

Overview: JetStream from NavisWorks is a complete design review solution for teams working with 3D models. It is modular in design, built around the core module Roamer with a set of powerful optional plug-ins: Publisher, Presenter, Clash Detective, TimeLiner, and RVM Reader.

Application: Design review, presentation, collaboration

Main features: (Navisworks)
- Extensive repertoire of navigation and review tools
- smooth navigation with no performance deterioration even in large projects
- Can combine multiple models into one file, synchronize them easily, and review them against each other
- Good photorealistic output, along with a wide variety of sketch styles for a hand-drawn look
- Availability of an API for customization
- Relatively easy to learn and use

1.6.1. Roamer

Overview: Roamer is the central product of JetStream. It allows opening multiple files from any of the major 3D CAD design formats into a single 3D environment. One can then navigate through the 3D model in real time and use Roamer's extensive tool set to review the design.

Application: Model viewer, design review

Main features:
- Organization:
  - Reference Files - every time the model is opened the latest version of the CAD design is used but past review data is kept.
  - Database Link - DataTools feature allow import of live data from external databases using SQL through ODBC to be displayed with the model.
- Viewing:
  - 3D File Support - Opens all major 3D design and laser scan file formats.
  - Streaming - JetStream technology allows the handling of large models and intelligently streams content from disk, enabling navigation around the design whilst the model is still loading.
  - Merge Models - Models can be combined together, regardless of file format, into a single unified model.
  - Smooth real-time walkthrough with a range of navigation tools

  - Full Screen Mode- with the interface hidden or on a secondary screen.
  - Stereo Viewing - Support for full OpenGL stereoscopic viewing.
- Gravity and Collision Detection
- Review Tools - Review toolkit includes:
  - Measurements - detailed measurement of distance, area and angle.
  - Viewpoints - Store, organize and share camera views of the design.
  - Comments – Notes can be added to viewpoints.
  - Redlines - Mark-up to viewpoints.
  - Section Planes - Cross sections to enable close inspection and focus on details.
  - Animations - animated walkthroughs.
- Object Properties – Allows reading intelligent data from the original design files.
- SwitchBack - Open the current model and viewpoint in the original design software with one click. (Compatible with AutoCAD 2004 and up or Microstation J and v8)
- Collaboration - Multiple users can share a single review session through Windows NetMeeting technology.
- API - Automate tasks or extend functionality using our extensive COM API.

1.6.2. Publisher

Overview: allows publishing model in a single, secure and compact, .nwd file. This .nwd file can be shared freely with all stakeholders who can open it in JetStream or Freedom.

Application: Model publishing

Main features:

- Organization
  - Stores the complete 3D model in a single distributable JetStream model file.
  - Security - Files can be password encrypted, time expired, made readonly, and have authorship and copyright details attached.
- Viewing:
  - Free Viewer - Freedom.
  - Internet and Office support - allows the viewing of an .nwd model from an internet page or inside a Microsoft Office document, such as a PowerPoint presentation.
- Embedded Review Data - JetStream review data from Roamer, Clash Detective and TimeLiner is stored alongside the model.
- Embedded Materials - Presenter data including textures can be embedded inside the file.
- Embedded Properties - Object properties including external databases read through Roamer's DataTools can be embedded or excluded for added security.
- Compact File Size

1.6.3. Freedom

Overview: free viewing software that can be downloaded and used by anyone to open .nwd files created by JetStream Publisher. It allows navigation around the model and viewing of embedded viewpoints, redlining and animations.

Application: Viewer

Main features:

- Completely Free
- Navigation - Includes Roamer's full set of navigation tools.

- Review - Allows the viewing of review data embedded in the model, including viewpoint, redlines and animations.
- Real-time display of materials and lighting added using the Presenter module.
- No Install - Available with or without an installer for users without installation privileges.

1.6.4. Presenter

Overview: JetStream plugin that allows the enhancement of 3D designs with photorealistic materials and lighting. The results can then be exported into render ed images and animations.

Application: Viewer/ presentation tool

Main features:
- Photoreal Images & Animations
- Drag & Drop Interface - Simple but powerful workflow.
- Huge Archive - Over 1000 built-in materials.
- Full Customisation - materials, lights, back grounds, and rendering styles, everything can be configured.
- Various rendering/sketch effects
- Real World Lighting - Support for real world lighting intensity units.

Underlying technology:
- Realtime Shaders - Supports OpenGL 2.0 shader language to provide r ealtime lighting and shadows.
- LWA-enabled - Presenter uses the LightWorks rendering engine, allowing you to add additional materials available from the LightWorks user site.
- RPC - Rich Photorealistic Content allows photographic imagery such as people and trees to be dropped into a scene.
- HDRI Lighting - Powerful rendering technology to provide smooth shadows and natural lighting.

1.6.5. Clash Detector

Overview: enables the identification, inspection and reporting of interferences found in 3D models.

Application: Clash detection, Model checker

Main features:
- Interference Detection - clash tests against specified geometry to find conflicts.
- Time Based Clashing - TimeLiner can be linked with Clash Detective to catch interferences arising over the course of a project's lifetime.
- Point/Line Based Clashing - Check as-built laser scan data against 3D designs.
- SwitchBack - Open the current clash in the original design software. (Compatible with AutoCAD 2004 and up or Microstation J and v8)
- Audit Trail - Track the status of clashes as they are found and resolved.
- Reports - Export results of clash tests including comments and screenshots.
- XML import/export - Share clash scenarios with other JetStream users in XML format.

1.6.6. TimeLiner

Overview: TimeLiner is a project pla nning and review tool that enables 3D model data to be linked with project software for fast 4D visualization of construction schedules.

Application: Planning tool

Main features:

- 4D Simulation - Links model geometry to times and dates, then playback c onstruction or demolition sequences to check buildability.
- Schedule Linking – Allows importing times, dates and other task data from project management software
- Time Based Clashing - TimeLiner with Clash Detective to catch interferences arising over the course of the project lifetime.
- Planned vs Actual - Planned and actual times to visualize deviations from the project schedule.
- AVI Export - Export 4D simulation into a pre-recorded avi animation.
- Customize Output - Task color and transparency, along with ov erlay text can all be customized.

Shortcomings:

- It is a generic, geometry -based solution that works for any industry dealing with 3D design, rather than being a building -specific solution like Solibri Model Checker that represents building entities, unders tands about concepts such as space, wall, door, etc., and can be used to review the building model in a more intelligent fashion by checking for code violations, satisfaction of specified constraints, and so on.
- Lack of IFC support, an issue that is fast becoming critical from an interoperability perspective.

1.7. Digital project (Gehry technologies)

Overview: Fully parametric tool built on CATIA. Here parts are considered as basic objects (User definable tag for BIM object) and products are assembly of multi ple parts.

Applications Type: BIM Design Tools, Fabrication Tools

Main features:

- organization
  - Can store data as either a Part or Product file. A complex assembly can hold enormous amount of parts or products.
  - Existing part and product files can be refer enced from other files to increase the reusability of designed parts.
- Interoperable with Subsystems: DP can produce information for many subsystems and not only preliminary objects from the architectural design. As a BIM application it can produce structure, MEP and other manufacturing documents along with the design.
- Modelling
  - Full parametric definition:
    - User definable parametric geometry
    - User definable parametric objects
  - capability to handle complex and parametric geometry

1.8. Acrobat 3D

Application: Design collaboration tool.

Main features:

- Works with all design software and platforms.
- Can import 3D models saved in common exchange formats such as 3ds, obj, dxf, wrl, iges, and so on.
- Allows embedding 3D models in Word, Excel, Powerpoint, and InDesign d ocuments.

Acrobat 3D is needed to create 3D -enabled PDFs, but anyone with Adobe Reader can view, interact, comment and markup the very same PDF. Complex 3D models can be emailed as PDF files.

1.9. Data Design System (DDS)- mechanical engineering

Application: Modelling and calculation tools

Main features: (STATSBYG 2006)

- Good for modelling sanitation installations
- Has its own functions for calculating pressure drop and heat requirements

1.10. Riuska energy simulation program

Application: Analysis and calculation tools

Main features: (STATSBYG 2006)

- Used to run energy simulations and annual cost calculations.
- Properties for walls and roof and load factors can be entered
- Allows quick and easy simulation of the entire building with correct sun, weather and internal load data.
- Good for energy calculations, very accurate and can run various calculations for the entire building or individual rooms.

1.11. G-PROG Calcus from NOIS

Application: For calculation of projects according to the Building Element Table.

Main features: (STATSBYG 2006)

- Calcus calculates volumes itself based on the model.
- Easy to build up the calculation by extracting priced elements and price lines from the price directory in the software.
- Building up customized directory with prices is straightforward.
- Presentation of the calculation result is very good and flexible.
- Ability to evaluate chapters, sub-projects or the total calculation.
- Can compare the project with a previously calculated project.

Import/export

- Easy to import IFC files to either an empty account list or one containing defined elements.
- IFC file can be saved as a sub-project or everything can be saved under a main project.
- Price lines can be added to the elements as they are imported.
- Importing several IFC files in the same calculation is possible.
- Cannot export IFC information but can export calculations in NS3420 format and to Excel.
- Options to export the whole calculation or parts of it.

Viewing (IFC viewer)

- Marks an element in the calculation, which marks the corresponding element in the model.
- The graphics are too diffused. It is difficult to separate activated elements from those to be evaluated.
- Necessary functions (such as pan, zoom etc) are absent.

Shortcomings:

- Function for *export* of IFC information is missing.
- It should allow product selection directly in the model
- Non-calculated elements should be reported in the model
- Weak graphic reproduction that cannot be used for large models.

1.12. O2c_Interactive!

Application: 3D Presentation, Viewer

Main features: (STATSBYG 2006)
- Built on the highly-compressed, Internet-deliverable o2c format.
- Allows interactive navigation through 3D content online.
- Exploration and presentation of different variations of material finishes for 3D objects on the fly.
- Scope is mostly limited to exploring material alternatives for a design project.
- Generate high-resolution photorealistic renderings of selected.

1.13. Solibri Model Checker

Overview: To detect potential problems, conflicts, interferences, or design code violations, and ensure the integrity of the model to downstream building analysis applications.

Application: Model checker, Clash detection

Main features: (STATSBYG 2006)
- IFC format
- has a good visualization interface, allowing viewing and walk through of the model
- Enables parametric constraints for checking that can be configured to desired standards.
- Requires a little training to make use of its potential.

1.14. QuadriSpace Presenter

Overview: Tool for creating interactive multimedia presentations combining navigable 3D models, animation sequences.

Application: 3D publishing and presentation solution

Main features:
- Ability to record animation sequences in 3D models and include these sequences in the presentation
- Ability to synchronize a 3D model and the corresponding 2D vector drawing so that the position in the floor plan can be monitored during navigation through the 3D model, and collision detection in walkthrough animation.

1.15. Octaga

- **Octaga viewer**
  - Pure viewer able to read IFC files
  - Easy to use and seems to be stable, even with large fi les.
- **Octaga Modeller**
  - Works well with model server, good colour schemes and visualization
  - simple user interface

1.16. Trelligence Affinity

Overview: Is an architectural programming, space planning, and schematic design application that extends BIM to the pre-design phase of building projects.

Application: Preliminary design tool

Main features:

- Customizable questionnaires that can be used to capture
  - Project and client requirements
  - Spaces and their areas
  - Spatial relationships, finish details, and size/cost constraints.
- Can create schematic designs base don requirements
- Data analysis engine allows requirements validation as the design is developed.
- Facilitates bi-directional integration with Autodesk Revit and Graphisoft's ArchiCAD.

Export
Finalized schema tic design can be exported to any CAD or BIM application for further development. Relevant project information can also be exported to cost estimation and project management tools if required.

Add-ons-Plug-ins
Available as a stand -alone application or in t wo other versions that integrate either with ArchiCAD or with Revit.

1.17. ADSearch from Architectural Data Systems

Overview: ADSearch, an attribute-based search engine tool that allows users to find products from the growing ADS library of over 1000 manufacturers' catalogs.

Application: Product library

Main features:

- Provides multiple product results in one search, and thus eliminates the hassle of browsing several sites.
- ADSearch-Green feature is dedicated to finding building products that are eligible for LEED credits.

Add on/ Plug in:

ADSearch can be integrated within Revit, AutoCAD Architecture, and AutoCAD, in addition to being available online. Free plug -in available from the ADS website. Once this is installed, it allows ADSearch to be activated from within the Autodesk applications listed above.

1.18. Tectonic BIM Library Manager and Quantity TakeOff

1.18.1. BIM Library Manager

Overview: Specifically designed for the organization, management, naming and selection of Revit object families used in the creation of Revit building models.

Application: Product library

Main features:

- Comes with an extensive collection of parametric families of 2D and 3D objects such as doors, windows, cabinets, plumbing, lighting, etc., which Revit users can include in their models.
- Simple interface for collecting, organizing, and presenting content in families.
- Supports drag and drop from the interface to Revit.
- BIM Library Manager can reside on individual computers or on a firm's network. Plans of making them available to customers through a link on their website.

Add-on/Plug-ins: Tectonic QTO

1.18.2. Family Content Publisher

Overview: Works as a companion product to BIM Library Manager. Plugs into Revit Architecture 2008 to automate the process of adding the Revit family files that come w ith the application, or are obtained from other sources, into the BIM Library Manager content management system.

1.18.3. Tectonic QTO

Main application: Quantity Take Off application

Overview: Works by segregating those Revit families that are used in a project an d associating unit line items from line item databases to the Revit elements. Includes an assembly editor and unit line item calculator to describe constituent products of Revit families that aren't represented explicitly in Revit and rules to calculate th eir quantities.

1.19. BIMWorld

1.19.1. BIMLibrary

Overview: Focused on developing building product manufacturer -specific BIM content as well as generic 3D product models in its BIMLibrary resource.

Application: Product library

Main features:

- Over 18000 objects including 2D drawing files, image texture files, and 3D models.
- These objects can be used in Google Sketchup, Autodesk Revit, Graphisoft ArchiCAD, Bentley Architecture, AutoCAD, and other applications.
- Free for users.

1.19.2. BIMContentManager

Overview: intended to s erve as a content management solution for Autodesk Revit and AutoCAD DWG files.

Application:

Main features:

- Allows managing Revit family (RFA, RVG) files on local computer, company network and optionally publish them to the Web for sharing and collaborat ion.
- Features an interface where content can be viewed as thumbnails in a grid display with the ability to dynamically resize thumbnails using a slider
- Provides the ability to sort families by any number of fields, including Supplier, Uniformat, Masterformat, Path, Filename, Cost, etc
- Ability to associate custom images and multiple URLs to families.
- Users can manage products specified inside of each Revit project —allows content to be managed at a project-by-project lev el with the creation of custom projec t libraries.

1.20. Form Fonts

Overview: Web-based subscription service that provides professionally -created, low polygon count 3D models and textures for a low monthly fee.

Application: Product library

Main features:

- Over 26,000 objects in various file formats, including GDL (ArchiCAD).

- For corporate subscribers an enterprise -level content management solution, the EdgeServer is provided, which is installed on-site and
    - Provides exclusive access to a sharing and collaboration platform that Form Fonts has established called SharedNet
    - Allows exchanging virtual building objects and other digital assets either on a one-to-one or one -to-many basis. The content is exchanged server -to-server, so that each firm has a local copy of the shared content on their respective s erver.
- Allows firms to meet their content demand in three ways:
    - Accessing the Form Fonts content library
    - Sharing their own content on a peer-to-peer basis
    - Contracting Form Fonts to develop custom content on demand.

2. BIM model servers

This review is based on product demonstrations, white papers and product brochures. Though this report discusses only two of the model servers there are a few more available in the market.

2.1.ActiveFacility

Overview: A web based model server to support hosting of a unified buil ding 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 natural language interpreter for making queries to the database.
- Site specific glossary can be developed as per the customer requirement.
- Organization:
    - There is a separate website for each customer and each project. Thus, the access is provided through a web application.
    - Active facility team builds the Unified Building Model once the data is provided by the client. The object relationships are identified and references are made.
    - It is like any other DBMS where information is manually loaded.
    - The database is hierarchically organized based on the IFC specifications.
    - 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.

- Active Facility is a service provider that manages the project data for the client.
    - Supports import and export of data
    - Supports viewing of data in both graphical and non-graphical form
    - 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:
    - GUI is customized to meet the client requirements.
    - On the client side SVG viewer needs to be loaded for graphic support.

Underlying technology:

- Built around Oracle relational database technology, which

    - Supports XML messaging as native datatypes within the database.
    - Provides an object layer as part of its relational technology.
    - Provides a spatial module that allows geometry to be stores directly.
- Microsofts.NET architecture allows high level of development and integration possibitites, 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 better organize and manage their building data.

2.2. 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, visualisation etc.

Application:

Underlying technology:

- EPM is based on a native IFC database.
- Model driven architecture. Models are instances of IFC specifications.

Main features: (Bengtsson, K: 2005, EPM Technology 2004)

- The database has a hierarchical structure, where project is at the top, which is the model.
- Supports t he 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 (2) back/ inverse relationships.
- The model server has checks before drawings can be merged. Synchronization of the models from different disciplines is what is checked.
- Model server has a global administrator who is basically the database manager.
- Model server has multiple ways of data in and out.
- Check-in and check-out allows for version management.

2.2.1. 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 tha t 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 IFC and STEP (Standard for The Exchange of Product Model Data)
- 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.

2.2.2. EDMmodelMigrator™

Overview: Supports migrating data from a legacy data system to a different product data support environment, such as a PLM and BIM systems.

Application: Web-enabled client-server solution

Main features:
- Enables multi-user operation
- Addresses the need for a gap analysis between the legacy data model and the target data model.
- Mapping Analysis Tool assists the user in the production, management, and follow-up of this gap analysis.
- Internet browsers serve as graphical user interface.
- All data is managed by an EXPRESS database management system on the server.

2.2.3. EDMdeveloperSeat™

Overview: A comprehensive package of tools for users of the EXPRESS data modelling language who are working to develop, implement or maintain applications or systems supporting the international standards for product data representation and exchange.

Application: Application development toolkit

Main features:
- Includes a database designed specifically for storing and manipulating data modelled and described in EXPRESS.
- Fully supports and significantly expands the scope of the Standard Data Access Interface (SDAI).
- Includes powerful functions for database supervision and management, data queries, and user convenience.
- Multi-user access for data sharing. Allows several processes or applications to have controlled access to the same data at the same time.
- EDMI can be used as a linkable library providing access to the EDM database and all EDMdeveloperSeat™ functions except those specific to EDM's own graphical interface.
- Application data can be isolated from the application for long-term archiving.
- An EXPRESS schema and data can be presented in HTML format, automatically creating links that make it easy to examine the source in a Web browser and correct errors.
- Has an in-depth help system includes complete, clear documentation.

Underlying technology:
- EDM's EXPRESS compiler makes it possible to validate any EXPRESS schema with respect to syntax and consistency, regardless of the source or system.
- It is also possible to store the results as a dictionary model in the SDAI without any loss of information and begin populating it immediately.

2.2.4. EDMvisualExpress™

Overview: For creating and visualizing data models based on the graphical notation EXPRESS-G.

Application: Visualization tool

Main features:

- Fully supports EXPRESS-G
- Makes it possible to visualize the objects in a data model that are not possible to display using only EXPRESS-G. These objects are basic to all data models and are essential for accomplishing any serious tasks in EXPRESS:
  - Global rules
  - Where rules
  - Uniqueness rules
  - Derived attributes
  - Functions Procedures
- Includes a documentation feature allow displaying comments as part of the graphic data model or print them as independent text, as well as publish the data model on the web.
- Facilitates moving quickly and easily between the representation of the model in the graphic view, the structure of the model in the object navigator, and the actual EXPRESS source code.
- Gives immediate feedback as a data model is created or modified, giving notification.

2.2.5. EDMmodelConverter™

Overview: Uses EXPRESS-X to convert data from one EXPRESS schema to another.

Application: Data conversion

Main features:

- Facilitates developing translators to any database system as well as any advanced data-warehouse application.
- Makes it easy to maintain translators
- Allows defining the mapping for data exchange
- Provides a fast, reliable path for any bulk conversion that may be required.
- Enables easy handling of data described by multiple schemata.

Underlying technology:

- Includes an EXPRESS-X compiler to validate the mapping schema and set up a dictionary model which is the definition for the actual conversion process.
- The data model that results from the conversion is saved automatically in the EDM database. It can be exported as a STEP physical file and, thus, used by virtually any system.

2.2.6. EDMmodelChecker™

Overview: Validates a data set and ensures that it conforms to all rules and constraints defined in one or more EXPRESS schemata.

Application: Model checker.

Main features:

- Errors can be quickly and easily identified before importing any data to the database.
- Validation possible all at levels.
  - Complete model in one call.
  - Check all entity instances of a particular type for all applicable rules and constraints.
  - Entity instance can be checked against one specific rule or constraint.
- Continues the validation process until everything is checked according to specifications.

- A detailed error report is generated as a text file. EDM allows examining the STEP physical file of the model in HTML format and use a Web browser to easily examine the violations.
- Provides the high standard of quality assurance and active control.

EPM's BIM and business Approach:

- A range of products supporting building information integration.