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DESIGNING A FRAMEWORK FOR EXCHANGING PARTIAL SETS OF BIM INFORMATION ON A CLOUD-BASED SERVICE

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Thesis submitted to Dublin Institute of Technology,
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15 November 2012

DECLARATION

I certify that this thesis which I now submit for examination for the award of _____________________, is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any Institute.

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ABSTRACT

The rationale behind this research study was based on the recognised difficulty of exchanging data at element or object level due to the inefficiencies of compatible hardware and software. Interoperability depicts the need to pass data between applications, allowing multiple types of experts and applications to contribute to the work at hand. The only way that software file exchanges between two applications can produce consistent data and change management results for large projects is through a building model repository. The overall aim of this thesis was to design and develop an integrated process that would advance key decisions at an early design stage through faster information exchanges during collaborative work. In the construction industry, Building Information Modeling is the most integrated shared model between all disciplines. It is based on a manufacturing-like process where standardised deliverables are used throughout the life cycle with effective collaboration as its main driving force. However, the dilemma is how to share these properties of BIM applications on one single platform *asynchronously*. Cloud Computing is a centralized heterogeneous network that enables different applications to be connected to each other. The methodology used in the research was based on triangulation of data which incorporated many techniques featuring a mixture of both quantitative and qualitative analysis. The results identified the need to re-engineer Simplified Markup Language, in order to exchange partial data sets of intelligent object architecture on an integrated platform. The designed and tested prototype produced findings that enhanced project decisions at a relatively early design stage, improved communication and collaboration techniques and cross disciple co-ordination.

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The term **innovation** derives from the Latin word *innovatus,* which is the noun form of *innovare* "to renew or change," stemming from *in*-"into" + *novus*-"new". Although the term is broadly used, innovation generally refers to the creation of better or more effective products, processes, technologies, or ideas that affect markets, governments, and society. Innovation differs from invention or renovation in that innovation generally signifies a substantial change compared to entirely new or incremental changes.

From Wikipedia, the free encyclopedia

‘The reasonable man adapts himself to the world: the unreasonable one persists in trying to adapt the world to himself. Therefore all progress depends on the unreasonable man.’

George Bernard Shaw, *Maxims for Revolutionists*

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Glossary of Acronyms

ACID	Atomicity, Consistency, Isolation and Durability
AEC	Architect, Engineering and Construction
AECOO-1	Architect, Engineering, Construction, Owner Operator Phase 1
AEX	Automating Equipment Information Exchange
agcXML	Associated General Contracting XML
APIs	Application Performance Interfaces
BAS	Building Automated Systems
BCIS	Building Cost Information Services
B2B	Business to Business
BIM	Building Information Modeling
BMS	Building Management Systems
BPEL	Business Process Execution Language
BPEL4WS	Business Process Execution Language 4 Web Services
BPD	Business process Diagram
BPEA	Building performance Energy Analysis
BPMI	Business Process Modeling Initiative
BPMN	Business Process Modeling Notation
BPR	Business Process Re-engineering
bSa	buildingSMART Alliance
CAD	Computer Aided Design
CAPEX	Capital Expenditure
CityGML	City Geography Markup Language
CEO	Chief Executive Officer
CCC	California Community Colleges
CITA	Construction IT Alliance
COBie	Construction Operation Building Information eXchange
CPU	Computer Processing Unit
CRM	Customer Resource Management
CSA	Cloud Security Alliance
CURL	Command line for getting files using Syntax
DDS	Data Design System
DM	Decision Makers
DTD	Document Type Definition
DWF	Drawing Web Features
EIDG	Enterprise and Industry Directorate General
EPSRC	Engineering and Physical Sciences Research Council
ERP	Enterprise Resource Planning
ESB	Enterprise Service Bus
EU	European Union
FCI	Facility Condition Index
FAST	Function Analysis System Technique
FIATECH	Fully Integrated Automated Technology
FM	Facility Management
gbXML	Green Building XML
GIA	Gross Internal Area
GIS	Geographic Information System
GML	Geography Markup Language
GPU	Graphic Processing Unit
GUI	Graphical User Interface

HCC	Hosted Client Computing
HIaaS	Hardware Infrastructure as a Service
HPGWs	High Performance Graphical Workstations
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
HVAC	Heating, Ventilation and Air Conditioning
H&S	Health and Safety
IAI	International Alliance for Interoperability
IaaS	Infrastructure as a Service
IBM	International Business Machines
ICT	Information Communication Technology
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IIA	Irish Internet Association
IP	Internet Protocol
IS	Information Systems
ISACA	Information Systems Audit and Control Association
ISO	International Standard Organization
JCT	Joint Contracts Tribunal
KB	Kilo Bytes
KML	Keyhole Markup Language
KMZ	Keyhole Markup Language Zipped
LAN	Local Area Network
LCCA	Life Cycle Costing Analysis
MAD	Multi-Attribute Decision Model
MB	Megabytes
KB	Kilobytes
MDX	Multi Dimensional eXpressions
MVD	Model View Definition
NBIM	National Building Information Modeling
nD	All Information in a BIM Life Cycle
NEC	New Engineering Contract
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NoSQL	Not Only SQL
OGC	Open Geospatial Consortium
OMG	Object Management Group
OLAP	Online Analytical Processing
OS	Operating System
OSS	Open Source Software
OWS	Open Geospatial Web Services
PaaS	Platform as a Service
PDA	Portable Device Assistant
PwC	Price Water House Cooper
R&D	Research and Development
REST	Representational State Transfer
RFI	Request for Information
RIA	Rich Internet Application
ROI	Return on Investment
SaaS	Software as a Service
SCM	Supply Chain Management

SIaaS	Software Infrastructure as a Service
SIIA	Software and Industry Information Association
SLA	Service Level Agreements
SMEs	Small to Medium Size Enterprises
SML	Simplified Markup Language
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
STEP	Standard Transfer eXchange for Product model
SWE	Sensor Web Enablement
UDDI	Universal Description Discovery and Integration
UI	User Interface
UK	United Kingdom
UML	Universal Modeling Language
URL	Uniform Resource Locator
USA	United States of America
VA	Value Analysis
VE	Value Engineering
VDM	V. Device Manager
VM	Virtual Machines
VPN	Virtual Private Network
VRML	Virtual Reality Modelling Language
W3C	World Wide Web Consortium
WFS	Web Features Services
WSDL	Web Service Description Language
XSLT	Extensible Stylesheet Language Transformation
XMI	XML Metadata Interchange
XML	eXtensible Markup Language
XSD	XML Schema Definition

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In the mid-1990s the Internet-enabled Computer Aided Design (CAD) environment promised to integrate activities across projects and throughout product life cycles. Developing an open system of network accessibility, software solutions and platform independence, allowed many organisations to engage in collaborative work. The capacity of manufactures; to increase value-added elements of their products by making their products more visible and amenable via the Internet incited the construction industry to issue completed electronic drawings that would be accommodated instantaneously in a designer's drawing (Finch, 2000). However, limitations of 2D CAD packages were often highlighted as not being able to contribute to key decisions at the early design stage. The drafting system itself was viewed as a drawing tool that did not improve the actual design process (Sun and Howard, 2004). In contrast, the use of Building Information Modeling (BIM) utilised the characteristics of intelligent objects created by users representing real-world components of actual buildings, such as doors, windows, walls and roofs (Smith and Tardiff, 2009).

The difficulty of exchanging data at element or object level relates to the information requiring compatible hardware and software, in order for the data to be read and transferred freely between applications (Alshawi and Ingirige 2003, and Alshawi 2007). The concept of interoperability allows seamless data exchange, at the software level, among diverse applications with their own internal data structures. The process involves mapping parts of each participating application's internal data structure to a universal data model and vice versa. The concept is to employ a universal open data structure enabling other applications to become interoperable via mapping and eliminate the costly practice of manually integrating particular applications (National Building Information Modelling Standard NBIMS, 2007). Sebastian (2010) acknowledges that BIM has become one of the most important innovations in managing building projects, with an array of technological developments, such as, IFC (public product data model exchange formats) to enable an open standard exchange of data.

The IFC model standard is based on modularity, reusability, and upward compatibility derived from the Building Construction Core Model developed within the ISO 10303 framework, known informally as Standard Transfer eXchange for Product Model data (STEP). In the 1980s STEP was the first major data exchange standard. However, the information models were provided using schemas represented in EXPRESS which was developed to be a general-purpose information model language but the encoding rules were complicated. The fifth and sixth release of IFC included an eXtensible Markup Language (XML) based on having Web characteristics such as, easy to write, interpret, and implement. However, ifcXML retained the EXPRESS schema, which create XML documents that were more intricate and voluminous in comparison to an information model optimized for XML (Begley et al. 2005). The proposed interoperable solution is to create a repository for exchanging and facilitating partial-model exchanges through Web Services.

The author's main objective is to re-engineer and test the capabilities of Simplified Markup Language (SML) for exchanging partial sets of BIM information on a cloud platform. This will lead to a new process being developed whereby exchanging information between applications is possible in real-time. BIM users working across the internet with a wide range of software solutions that can implement SML to decisively make key decisions that can contribute to the building's life cycle and significantly reduce cost (Redmond and Smith, 2011).

1.2 THESIS OBJECTIVES

The overall aim of this thesis is to design and test a prototype for exchanging partial sets of BIM information on a cloud-based service. This integrated process will advance key decisions at an early design stage through faster information exchanges and improve best practices during collaborative work that can readily be transferred to project teams using Cloud-BIM software.

In order to achieve this aim, the following objectives will be realised:

1. To describe the importance of design interoperability and the potential to develop a more simplified data exchange service in supporting of more efficient cloud-based BIM data exchanges.
2. To discuss how cloud computing and BIM can support the future development of an interoperable software that will utilise the data interchange benefits of Web services in the construction industry.
3. To investigate the potential of cloud computing and BIM in re-engineering early design processes.
4. To establish expert opinion on advancing interoperability of data exchange through the use of Cloud BIM.
5. To identify the need for an agreed information architecture framework that will create an interoperable layer of business processes in a software form common to a building project that will require information exchanges between specialised software packages.

6. To measure the ability of advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform.
7. To develop and validate a prototypes ability to exchange partial sets of BIM data by use of simplified XML between differing applications on a cloud platform, to optimize productivity and performance at the early design stage of a construction project.

1.3 METHODOLOGY

The methodology involves developing a full hybrid research model based on mixed methods, 'quantitative and qualitative', interlaced into two main phases. The initial phase was derived from a series of survey techniques; a main survey questionnaire, focus groups, two Delphi questionnaires, semi-structured interviews and a case study. The case study involved a research technique, 'Function Analysis System Technique' (FAST), used for displaying functions in a logical sequence to prioritise them and test their dependencies. The final phase, 'product design and testing' used semantic methods and tools, such as, Business Process Model's Notation (BPMN) to support a Multi-Attribute Decision (MAD) Model based on benchmarking the productivity of the prototype.

The overall order of sequence is established in the five key areas of Business Process Re-engineering (BPR) namely; (i) developing a business vision, (ii) identifying a process to be designed, (iii) understanding and measuring an existing process, (iv) identifying IT levers, and (v) design and build a prototype of the new process (Avison and Fitzgerald, 2003).

The first initial phases of the methodology feature an extensive literature review investigating the challenges of interoperability for BIM software in relation to data exchange formats and how cloud computing may revolutionise the construction industry by exchanging information between different applications through openly collaborating on an internet platform. The literature review stage identified the questions for the mains survey. The mains survey targeted 90 respondents representing a mixture of non-random (40 international vendors) and probability sampling (50 Irish construction firms). The main themes of the research survey included investigating drivers, barriers and benefits of 'Cloud Computing.'

The results of the main survey contributed to the discussion topics undertaken in the Focus Group sessions. The Focus Group comprised of 10 vendors in the Irish construction-marketplace. The group analysed various issues such as, security concerns relating to data being stored outside of Europe and the potential of developing a hybrid cloud (mixture of both public and private) for the group.

The 'Delphi technique' which followed, comprised of two consecutive survey questionnaires. The initial questionnaire concentrated on information extracted from the main survey and focus group. The questionnaire's ultimate aim was to analyse the potential for developing a cloud service based on combining three individual applications; originally identified as; BIM, project management and accountancy. The subsequent questionnaire compiled the results of the initial questionnaire and formatted new questions based on these results. This questionnaire's main objective was to investigate how to develop a BIM service prototype.

The methodology was based on a heuristic approach (longitudinal study) and had been constantly evolving depending on the results of each stage. The structured interviews, in parallel with measuring an existing process, were the final stages of the initial phase of research relating to the first three key areas of BPR.

The purpose of the semi-structured interviews was to map a business process and identify the mechanics of developing a product. The case study involved a virtual project to be tested, which comprised analysing 'BIM XML,' an SML using import and export plug-ins which exchange data between different applications on a cloud platform in real-time. By undertaking this test, it highlighted the capabilities of BIM XML and identified how this process could be integrated with the concept of exchanging data simultaneously between three independent applications on a cloud platform using Web services similar to Geography Markup Language (GML).

The aim of the final stage was to initially test the Information and Communication technology (ICT) capabilities of the prototype 'Cloud BIM' using a robust XML Schema Definition (XSD) feature of BIM XML. The analysis involved testing the service from an end-user's perspective, in order to establish if the main aim of the research 'to develop an integrated process that would advance key decisions at an earlier stage through faster information exchanges that can readily be transferred to project teams using Cloud-BIM software' had been achieved.

1.4 OUTLINE OF THE CHAPTERS

This thesis commences with a dual literature review; Chapters 2 and 3. In Chapter 2 the challenges facing the construction industry and objectives of designing an interoperable solution based on a cloud platform are discussed. Chapter 3 deals with the current issues associated with BIM data exchange formats are together with the opportunities to explore and enhance the latest data exchange mechanisms. The ability to provide interoperability across the Internet and the need for simplified subsets in comparison to traditional standard information exchanges are also discussed at length in this Chapter. Examples of successful case studies are presented in both Chapters to highlight the cost saving benefits of using cloud computing in Chapter 2 and BIM in the construction industry in Chapter 3.

Chapter 4 focuses on the research process and how it evolved into various techniques to meet the research objectives.

Chapter 5 concentrates on the primary research questionnaire, within an Irish context for the end users and an international perspective from the vendors. The drivers, barriers, of cloud computing are mapped together allowing a comparison of the results.

Chapter 6 consists of two questionnaires utilizing the 'Delphi technique,' in order, to fully investigate the potential of developing a cloud integrated model through BIM. The survey focused on international experts with a mixture of either or both epistemic and performative knowledge.

Chapter 7 highlights the interview results of 11 industry-related experts' views on achieving improvements in cost, value and carbon performance by adopting such an integrated information exchange processes between all members of a project team using 'Cloud BIM.'

Chapter 8 evaluates and compares existing methods for exchanging data information through a relational database, such as, simple flat files. This approach assisted in appraising 'Cloud-BIM' design capabilities. The use of the FAST technique as a product development method identified the most dependent function to be designed or improved. After fully understanding the process to be measured, 'BIM XML' was tested in a controlled industry environment at the 'BIMStorm 2010' event in the United States.

Chapter 9 involved designing a participant observation case study using semantic methods and tools to define its capabilities/boundaries. This chapter evaluated the process involved in 'testing' the benefits of transferring nD information through BIM XML for Web services and plug-ins exchange, thereby validating the main aim of the thesis; to advance key decisions at an earlier stage through faster information exchanges and best practices during collaborative work.

The thesis concludes with a brief description of the research undertaken, the principal conclusions and an evaluation of whether or not the research objectives have been achieved. A series of recommendations are made for further work in this area of growing significance. Figure 1.1 illustrates the 'thesis roadmap.'

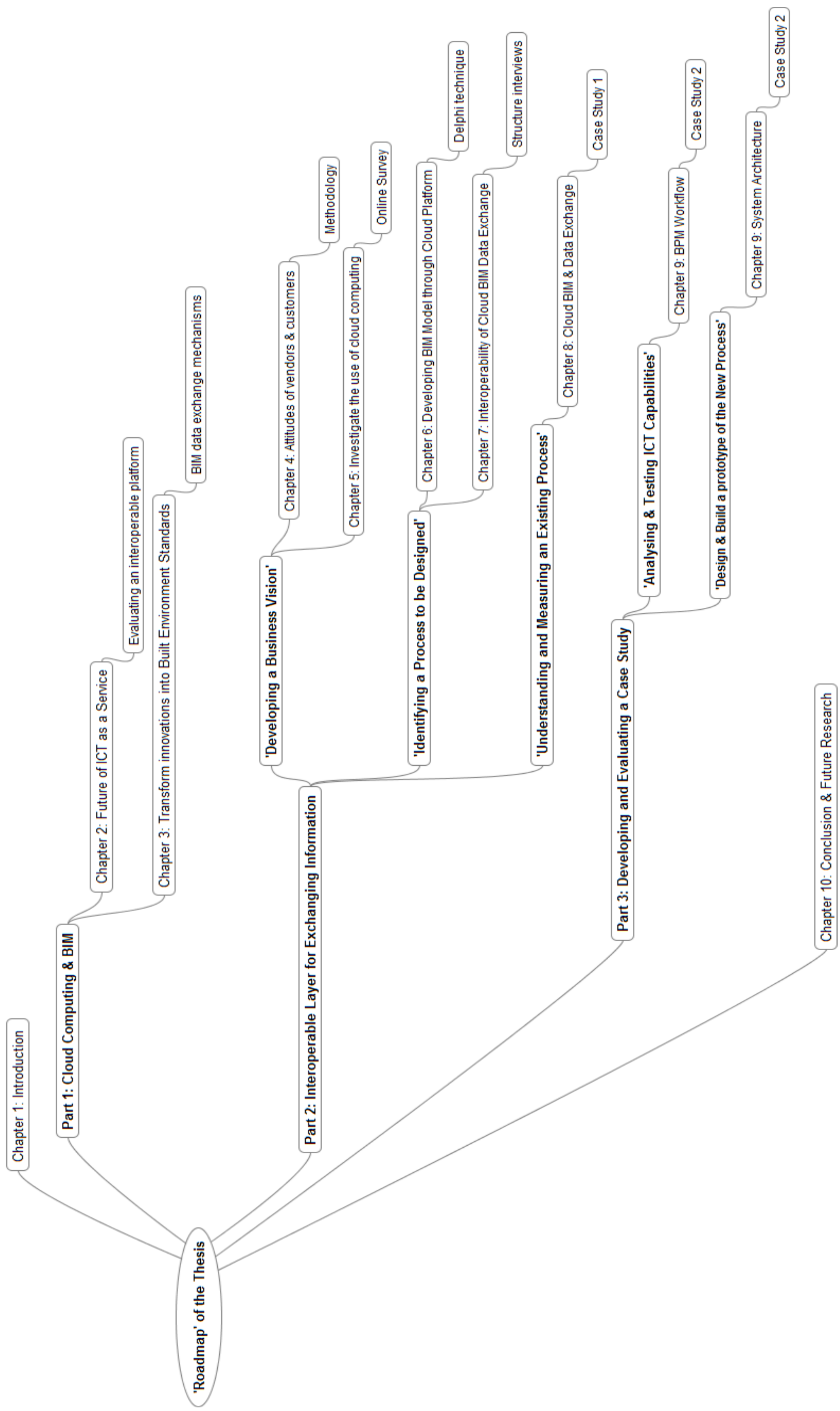


Figure 1.1. 'Thesis Roadmap'

PART 1:

THE POTENTIAL OF CLOUD COMPUTING AND BUILDING INFORMATION MODELING IN SECURING MORE EFFICIENT CONSTRUCTION DATA INFORMATION EXCHANGE

CHAPTER 2

A REVIEW OF ICT SYSTEMS AS A SERVICE DEPLOYED FROM A CENTRALISED DATA CENTRE

2.1 INTRODUCTION

The use of ICT has proven to be instrumental in creating productivity gains within global markets, through reduced transaction costs, scalability, fast and reliable information flows, enhanced online collaboration tools and new ways to market goods and services (Pepper et al. 2009). Hecht (2008) attributes much of the waste that is generated throughout the life-cycle of a building to people not having access to information that others have created. He emphasises that insufficient information results in waste and waste costs money, whether the waste comes from change order requests during construction, engineering errors, manual re-entry of data, redundant data collection, unnecessary meetings, mistakes in component dimensions or quantities, or over design to allow for uncertainty. All such waste translates into wasted natural resources.

In Becerik (2004), Internet connectivity and the general use of email and the World Wide Web are viewed as being high adopters in the construction industry. However, she accepts that many other studies demonstrate that new technologies are adopted slowly and ineffectively in the Architect, Engineering and Construction (AEC) industry. For example; 2D Computer-Aided-Design (CAD) was in the market for almost four decades before it became pervasive. 3D is a well-established technology that is only now beginning to enter the main stream. 4D CAD, an incorporation of 3D CAD and time, has started to be used by the innovators in the industry. It appears that larger manufacturing firms are more innovative towards the adoption of new technology than AEC firms, possibly by 3 to 5 years. Becerik acknowledges that there may be many reasons why this is the case. Identifying the need for a rapid shift in terms of new technology adoption in the AEC industry would certainly be a positive contributor to this adoption process.

Software is very widely used today, yet its instrumental role in the modern digital economy is often overlooked. With market revenues of over €200 billion in Europe and growth rates of between 6 and 8%, software is the largest and the fastest growing segment of the ICT market. However, European companies rarely become global leaders, as it is difficult to grow fast enough in an increasingly globalised market (European Commission, 2009). Alvarez (2008) identified that today’s buyers desire Web sites to be accessible and successfully speed up the process of finding a product, enable comparisons of products, provide tools to help buyers understand the product and have community-based information to assist them in making the final buying decision.

Cyon Research White Paper (2006) questioned Harvard Business School Professor Clayton Christensen's theory on disruptive innovation. Disruptive innovation identifies that a technological innovation, product, or service will eventually overturn the dominant technology in the market by either filling a role in a new market or moving up the market through performance improvement.

This chapter will review similar research that has adopted an Internet collaboration process to enhance communication within the construction industry, thus leading to efficient key decisions being made through the use of Web technology. The author will use the knowledge gained from previous research to identify the main incentives, problems, and potential benefits of cloud computing; a network platform that will enhance the delivery of information flows. The chapter will review international research study into using such a vehicle for analysing the requirements of using ICT to transform construction practices in to standard manufacturing deliverables. The final part of this chapter will demonstrate how the benefits of cloud computing transformed a construction company's traditional vertical ICT in to an integrated horizontal infrastructure.

The author envisions that cloud computing will contribute to developing innovative solutions and improve operation flows for construction disciplines using this alternative technology. The ability to streamline information exchanges through the Internet has not yet been fully embraced by the construction industry, with security and infrastructure being major barriers. However, the author concludes that the infrastructure exists to expand the use of Web technology for achieving financial gains with applications that can assist construction methods to become more efficient and effective in a global economy.

2.2 ADOPTION OF ICT IN CONSTRUCTION

The Enterprise & Industry Directorate General (EIDG, 2006) survey data suggested that large construction enterprises are increasing their focus on ICT issues, such as eProcurement systems, collaborative design systems and collaborative document sharing. However, it also stated that there was a low percentage of firms employing ICT, as well as, a low adoption of Enterprise Resource Planning (ERP) software and advanced eProcurement solutions. The survey also mentioned that the construction industry was a sector where ICT and eBusiness are used to a lesser extent than in most other sectors. The two reasons identified for low ICT uptake were; (i) The high concentration of Small to Medium Size Enterprises (SMEs) in the construction industry, and (ii) The typical nature of the service provided in construction, being an on-site and often highly customised service. There are approximately 2.4 million construction enterprises in the European Union, of which 97% are small enterprises with fewer than 20 employees. The industry employs about 14 million people, corresponding to about 7% of the European work force and 28.5% of industrial employment.

As the use of computers and telecommunications have changed over time, the portfolios of information systems suitable to an era of supply chain activities are unlikely to be suited to an age which focuses on information to support key decision making, connecting the organisation to another organisation in the business environment (Razali et al. 2005).

Hore and West (2005a) reported that building materials account for up to 50% of all construction costs and in the field of business to business (B2B) interactions there is a huge untapped potential for productivity gains. Technologies, such as, Automatic Identification (Auto-I) and bar coding have become widespread within manufacturing, medicine and retail industries but, in comparison, within the construction industry; adoption worldwide is relatively slow. Hore and West carried out a survey of over 100 Irish construction companies. The survey analysed the current level of technology uptake in B2B purchasing transactions between building contractors and material suppliers; the driving forces which attract firms to adopt electronic purchasing; the barriers of such adoption and the future development in adopting technology within the Irish supply chain. The key results illustrated a low level of awareness of appropriate technologies and the absence of appropriate industry standards. The need for an increase in the ICT literacy skills of purchasing staff and familiarity with electronic purchasing was also identified.

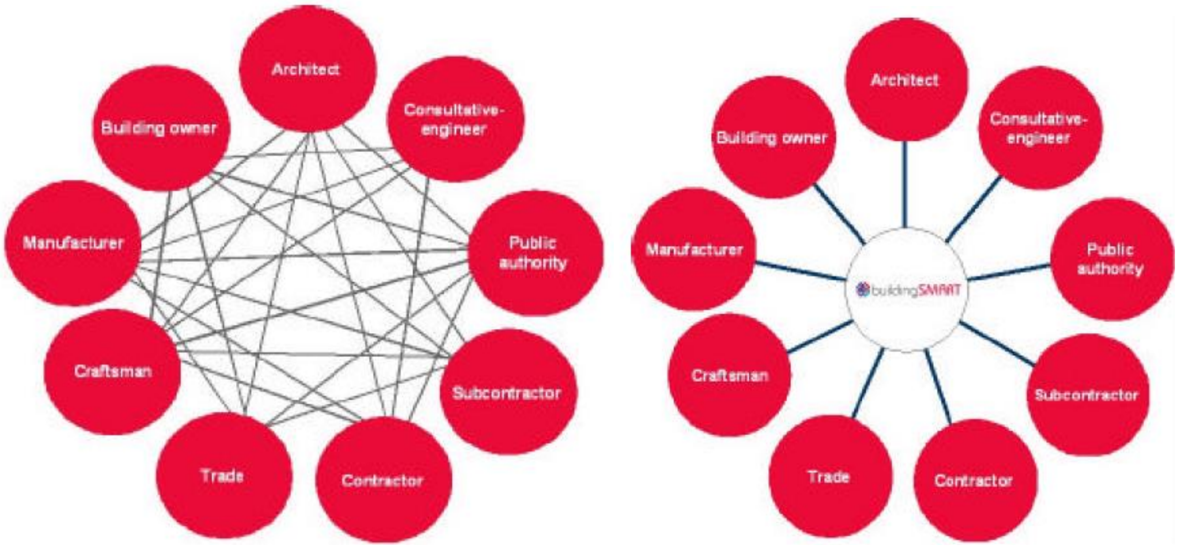
2.3 ICT AND COLLABORATION

In the current age of a global and digital economy and virtual teams, there has been an increasing interest in trust (Stair et al. 2008). In order for the supply chain to collaborate, software vendors will need to produce products that are interoperable with other environments to produce integrated packages.

According to Teicholz (2004), there has been a significant adoption of ICT by the construction industry over the past 35 years. However, Teicholz acknowledges that these applications are stand-alone and do not permit significant, if any, collaboration.

Hjelseth (2008) identifies that within the same professional areas there is a considerable communication deficiency and loss of project information. Hjelseth cites

Sjorgen's (2007) where 25-30% of construction costs were reported to be related to fragmentation and bad communication. The same information was reported to be inserted at least 7 times in different software systems. Figure 2.1 illustrates today's document centric process in contrast to tomorrow's centric model based on all disciplines involved with the project having access rights to information when needed. In this context information between various disciplines in the built environment can be exchanged seamlessly through a cloud platform. Cloud computing is a centralized platform that enables applications to be accessed and used/inter communicated through the Internet.



Today's Document Centric Situation | Tomorrow's Information Centric Model

Figure 2.1. New ways of information diffusion (Sjorgen, 2007 cited by Hjelseth, 2008)

Ragsdale (2009) highlighted the problem of an increasingly distributed workforce. The tool identified for partially eradicating this problem was Web collaboration technology. In identifying development options, the report stated that cloud computing was a significant collaboration tool. The additional benefits of cloud Web collaboration applications include the ability to transfer security concerns to the provider, eliminating scalability concerns and allowing remote employees to easily access technology from any Internet-ready computer. The introduction of Web collaboration tools for customers means adding a new layer of interoperability that cannot be captured on existing standalone systems.

According to Alshawi and Ingirige (2003), the industry should work towards minimum common standards to facilitate the flow of information across the supply chain. These standards will enable exchanged information to be fully integrated with the business, thus giving people the necessary skills and environment to harness the benefits of the internet. Alshawi and Ingirige recommended that the industry should fully address the management of change by considering the implementation of Web-enabled tools to work towards minimum common standards to facilitate the flow of information across the supply chain.

The benefit of using collaboration techniques have already been established in the construction industry. In 2001 a Waste Water Treatment Works Project in the United Kingdom (UK) supported a partnering approach to construction by using an integrated application known as the Gallicon system. This system produced cost savings by implementing a central shared project data model supported by communications technologies. The application system provided the ability to improve communications and information exchange between designs, cost estimating and project planning, resulting in a 80% saving at the conceptual and outline design phases of the project (Gallicon, 2001).

2.4 CLOUD COMPUTING

The future of ICT lies in a service deployed from a centralised data centre across a network providing access to the software applications from a central provider. This solution offers the opportunity for companies to select their ICT priorities and then choose from the growing menu of applications being offered through service providers. With access to a service platform, customers can use the latest technology tools integrated within a cloud infrastructure. The concept of renting rather than buying software and hardware provides lower initial costs through incurring licenses only for the amount of usage that is needed Software and Information Industry Association (SIIA, 2001). For the vendors of cloud computing it makes good sense because the vendor can achieve economies of scale. The cloud computing vendor has a high degree of control over its application and is, thus, a prime candidate for the adoption of a cloud integration platform (Foster and Tuecke, 2005).

Cloud computing is simply software which is delivered from a server in a remote location to a local desktop. Many observers of the past would claim that there is nothing new about this idea. In the seventies, this was called time-shared computing. It was expensive and not very flexible because in the pre-internet era, accessing a remote server meant implementing a private network (Wohl, 2008). Sosinsky (2011) recognised what “productivity software” is; ‘anything one does on a computer that is faster and more productive than one could do any other way.' The following list highlights the characteristics of cloud productivity software as; 1) *static features* – the interface and commands are roughly the same regardless of where and when the applications are used, 2) *standards for data interchange* – options for saving data or for importing data are standardized, 3) *modular interactivity* - the ability to allow one application to interact with another, 4) *inter applications communications* – the ability of an application to use the service features of another.

Ramanujam (2007) outlines some key points as to why cloud computing on-demand would be a major driver for companies;

- No facilities – cloud computing allows you to get out of the business of managing a premise-based facility, so attention can be redirected towards the customer.
- Pay As You Go – pay for usage rather than for software licenses and hardware infrastructure.
- Easy Roll-out and Maintenance – make Internet Protocol (IP)-based adoption easier by avoiding on-site installation and maintenance.
- Spread Out Cost – avoid large capital expenses and installation fees, as subscription costs are spread out across time.
- Frequent Updates – gives one access to "Best of Breed" technology that will allow a company to stay ahead of one's competition.
- Focus on Growth – pass the onus of supporting growth on to the cloud vendor.
- No Day-to-Day maintenance – pass the responsibility of system performance, uptime disaster recovery and backup on to the cloud vendor.

According to Saugatuck Technology (2008), companies should consider cloud computing, especially if the company has a limited capital budget, limited ICT support, and a distributed workforce in a sales or service oriented business. The benefits for SMEs include managed growth and regulatory compliance and competition without also dealing with a variety of challenges relating to ICT, such as, maintenance and future growth. It is more easily affordable due to its licensing options, immediate in its impact, and provides modular interactivity, and is easy to integrate with other systems.

The Irish Internet Association (IIA, 2010) investigated the obstacles facing Irish businesses in adopting cloud computing. The results of a market research survey of Ireland's top businesses identified that certain applications are inherently more suited to the cloud (collaboration applications) whilst others (stand-alone applications) will have many barriers before they gain widespread maturity and adoption in the cloud. The survey concluded that cloud adoption levels in Ireland are higher among SMEs when compared to medium to large enterprises. This suggests that cloud computing represents a good proposition for SMEs. The survey also acknowledged that in these very challenging times, the availability of pay-as-you-go cloud computing services will enable SMEs to increase their business productivity, continue to grow their ICT capabilities and to remain competitive.

Armbrust et al. (2009) identified ten major obstacles to cloud computing;

1. Availability of service – the issues surrounding whether utility computing services will have adequate availability.
2. Data lock-in – customers are concerned about extracting their data from one site to run on another, as data lock-in leaves the customers vulnerable to price increases.
3. Data confidentiality and auditability – current cloud offerings are mainly public rather than private networks, meaning the system is exposed to attacks.
4. Data transfer bottleneck – applications may be "pulled apart" across boundaries of cloud which may complicate data placement and transport.
5. Performance unpredictability – this problematic area relates to the capability of bandwidth and the difficulty with smoothly running parallel computing.
6. Scalable storage – is beneficial when applied to computation (when resources are no longer needed to scale down) but difficult when applying to persistent storage and meeting programmers expectations.
7. Bugs in large-scale distributed systems – the difficult challenge of removing errors in very large scale distributed services.
8. Scaling quickly – the ability to scale in response to load increase and decrease, conserve resources, as well as money.
9. Reputation fate sharing – one customer's bad behaviour can affect the reputation of the cloud as a whole.
10. Software licensing – originally cloud providers relied on open source as the licensing model, as commercial software does match with utility computing.

According to Reeves (2009) building an ICT organisation's confidence in providing ICT solution requires a combination of consistent performance, verifiable results, service guarantees, transparency and plans for contingencies. However, Reeves acknowledges that cloud computing at present does not have many of these attributes. The reasons noted for this lack of confidence include inadequate risk management, poor or nonexistent service level agreements and cost issues.

Figure 2.2 defines the taxonomy for cloud computing, that is it illustrates how the service consumers use the services provided through the cloud. Service providers manage the infrastructure while service developers create the services on a platform 'Platform as a Service' (PaaS) to be accessed by the end user 'Software as a Service' (SaaS).

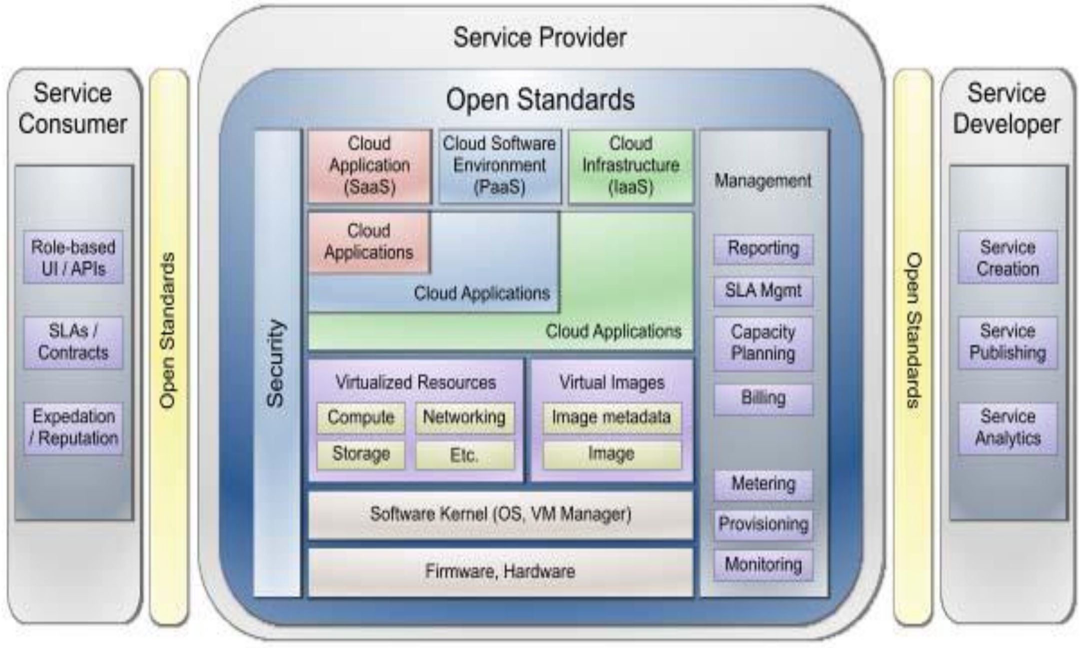


Figure 2.2. Taxonomy for cloud computing (Cloud Computing Use Case Discussion Group, 2009 pp10) [legend: Application Performance Interface (API), Infrastructure as a service (IaaS), Operating System (OS), PaaS, Service Level Agreements (SLA), User Interface (UI), and Virtual Machine (VM)]

The National Institute of Standards and Technology (NIST) and the Cloud Security Alliance (CSA) both defined cloud computing, as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly supplied and released with minimal management effort or service provider interaction. The report summarises this definition by comparing it to enterprises paying for the electricity, gas and water they use and now having the option of paying for ICT services on a consumption basis (ISACA, 2009). Armbrust et al. (2009) referred to cloud computing as applications delivered as a service over the Internet and the hardware and system software in data centres that provide those services. The Cloud Computing Use Case Discussion Group (2009) identifies four deployment models; (i) public cloud – services are provided to clients from a third party via the Internet, (ii) private cloud – cloud-based service, data and processes are managed within one's organisation, (iii) community cloud – controlled and used by a group of organisations, and (iv) hybrid cloud – combination of a public and private cloud that interoperates.

2.5 RE-ENGINEERING IN THE CONSTRUCTION INDUSTRY

The benefit of ICT and its contribution in re-engineering the construction industry has been well documented. Kagioglou et al. (1999) identified that traditionally ICT had been seen as a driver behind changes in the design and construction processes and indeed in many BPR initiatives. Kagioglou et al. identified that the term BPR was first introduced in a 1990 article of the Harvard Business Review by Michael Hammer, suggesting that re-engineering is "the fundamental rethinking and radical redesign of business processes to bring about dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed."

In conjunction with these benefits, Kagioglou et al. list the main process findings of the Engineering and Physical Sciences Research Council (EPSRC) funded project 'Construction as a Manufacturing Process' initiative. This project brought together a number of companies, representing the construction supply chain, and the University of Salford's research expertise to produce the Generic Design and Construction Process Protocol.

	Construction Process Protocol Attributes
1	The required model should be capable of representing the diverse interest of all parties involved in the construction process.
2	There should be a generic and adaptable set of principles that can be carefully applied and used universally.
3	A need for a coherent and explicit set of process related principles; the new process should be able to be managed and reviewed by all partners to the contract with the intention of changing and arranging accordingly to the strategic management of the process.
4	The need for construction operations that form part of a common process controlled by an integrated system.
5	A need for a process protocol (design set of processes and procedures) that can be interchangeable allowing interfaces between existing practices and practice support tools to be operated.
6	Standardised deliverables and roles associated with achieving, managing and reviewing the process.
7	Key emphasis on designing and planning to minimise error and networking during construction.
8	Construction industry involvement to be extended beyond completion – a post completion phase.

Table 2.1. Construction process protocol attributes (adapted from Kagioglou et al. 1999)

The main aims of the project were as follows: a) to analyse the current practices in the construction industry and compare them to similar practices in the manufacturing industry and b) to identify the ICT requirements needed to support the process protocol that would be developed from the previous objective and develop demonstrator models. Table 2.1 outlines the concept on which the Process Protocol was based.

2.6 TRANSFORMING ICT SYSTEMS BASED ON CLOUD COMPUTING

A desktop case study was chosen to highlight the cost saving benefit of using cloud computing infrastructure in the construction industry. This case study examined the contribution of cloud computing in reducing infrastructure costs by adopting an architecture that creates a legacy-free infrastructure (moving from traditional vertical server infrastructure to a virtual infrastructure) through enabling virtualization and horizontal connections to other operating systems (see Figure 2.3).

In 2009, PriceWaterHouseCoopers, (PwC) summer quarterly journal was based on the real promise of cloud computing. Within this report, PwC analysed Bechtel, a construction company with a workforce of 44,000 employees and revenue of $31.4 billion in 2008. Bechtel had made a progression towards cloud computing after identifying the problems associated with traditional ICT vertical stacks (standalone middleware). The three principal layers of a typical traditional stack are: infrastructure, including computing, storage, and networking assets; application workloads that enable business processes; and end-user devices, which provide the interfaces to access applications. This vertical technology delivered a solution with an acceptable performance; hardware, application software, and middleware tools were built to order for the application requirements. However, this system creates an instant legacy problem of interdependencies among process logic, data logic, integration logic, computing capacity, storage capacity and networking functionality. The problems associated with creating interdependencies with standalone stacks become evident from the complexity of making changes to individual layers to the increased cost of support and maintenance because they rely solely on the function of the parts within their stack. The typical ICT environment is a collection of hundreds or even thousands of tightly coupled vertical stacks integrated with each other (for example refer to Figure 2.3).

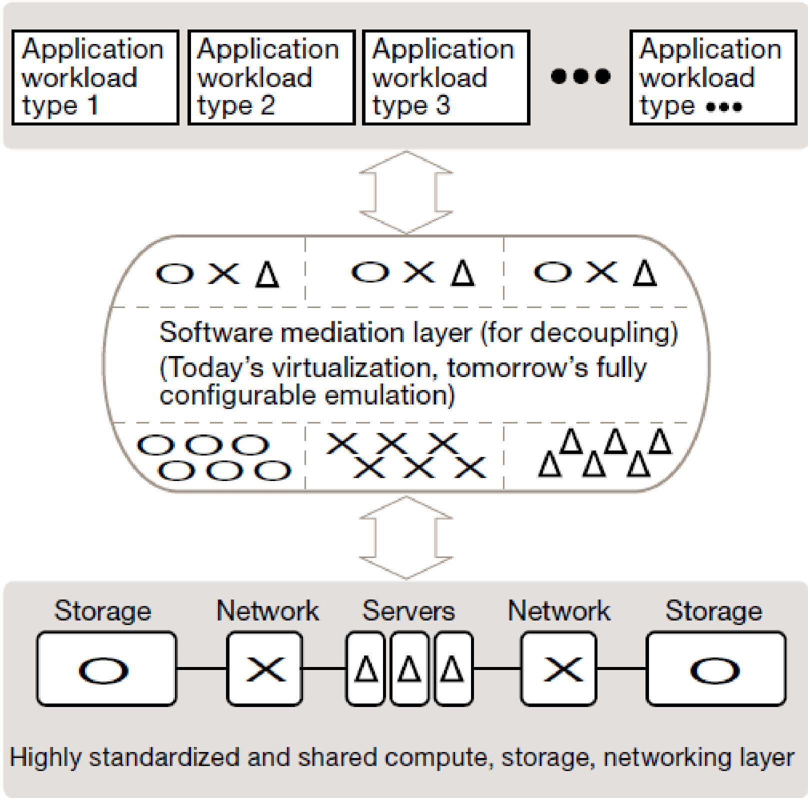


Figure 2.3. Decoupling of the middleware that enables virtualisation and horizontal connections to other operating systems (Sourced from PwC, 2009)

Bechtel transformed its ICT systems and processes based on the best practices of cloud computing providers and in doing so moved towards a more cost efficient, high performance computing. PwC describes this move as Evergreen ICT. Evergreen ICT is an infrastructure architecture designed to deliver loose coupling (decoupling of middleware) between distinct layers of ICT stacks, and transition of ICT operations from manual to automatic through machine readable software. The critical ingredient for Evergreen ICT architecture is the loose coupling between hardware or middleware and application workloads.

The software sits between the raw computation, storage, network environment and the applications known as the software mediation layer (virtualisation). Figure 2.3 illustrates the software mediation layer that decouples the infrastructure and supports the automation of the ICT processes of provisioning, management, and orchestration.

In practice, this means that the mediation layer should be designed to emulate whatever application programming interfaces for which the application were written; for example, Windows and various versions of UNIX OS can be interoperable through virtualisation.

In conclusion, the history of ICT has been dominated by build-to-order systems, resulting in legacy environments. However, the adoption of architecture that can create loose coupling between infrastructure and applications will create legacy-free infrastructures. As Bechtel has indicated, it does not have to happen in one big move, but rather, a process that begins with creating standardised infrastructure, onto which compliant workloads can be moved and over time organisations can move more complex application workloads to this infrastructure' as software mediation (virtualisation) technology matures (PriceWaterHouseCoopers, 2009). Figure 2.4 shows the comparison between Bechtel's traditional legacy IT and Bechtel's private cloud 'Evergreen IT.'

Legacy IT resulting from build-to-order culture	Delta	Evergreen IT leveraging configure-to-order culture
$3.75/GB/mo at Bechtel	Storage benchmark	$0.15/G/mo at Amazon.com
$0.55/server/hour at Bechtel	Computer benchmark	$0.10/virtual machine/hr at Amazon.com
1 admin/100 servers at Bechtel	Server admin benchmark	1 admin/20,000 servers at Google
$500/Mb at Bechtel	Network benchmark	$10-15/Mb at YouTube
230 apps x 5 versions x many upgrades at Bechtel	Application benchmark	1 application image x 4 upgrades/year at salesforce.com

Table 2.2. Bechtel's cost savings approach to transformation (Sourced from PwC, 2009)

In summary the desktop case study of Bechtel's private cloud 'Evergreen IT' highlighted the interoperable advantages of a virtualised infrastructure for connecting OSs. The configure-to-order culture of cloud computing enabled Bechtel to have a more competitive storage and server rates in contrast to using their existing legacy infrastructure. In reference to Ramanujam's benefits, no facilities, frequent updates, focus on growth and no day-to-day maintenance. Evergreen IT only needed one administration (Google) to manage 20,000 servers, whereas Bechtel in-house administration could only cope with 100. Traditionally Bechtel's 230 applications have 5 versions and many upgrades, whereas Saleforce (a SaaS vendor) provides one application image and four upgrades per year.

2.7 CONCLUSION

It is clearly evident that there has been a slow up-take of ICT by the construction industry. Key indicators are a low level of awareness of appropriate technologies and the absence of appropriate industry standards. The industry does acknowledge the productivity growth aspects of using ICT for enabling organisations to be connected in order to make key decisions. However, distributed workforces, splitting up construction processes and bad communications have all contributed to construction waste and in general a fragmented industry. Web collaboration technology has been identified as the solution for eradicating these problems. The vehicle most likely to surge its growth is 'cloud computing.' Cloud computing has been defined as a network platform capable of reducing transaction costs, for creating reliable information flows for enhanced online collaboration tools. However, problems with using cloud computing within the construction industry include a lack of confidence in relation to SLAs and security issues. ICT has always been seen as a driver and a catalyst for developing construction into a standard deliverable process. The Bechtel desktop case study summarised the benefits of transforming a traditional process in to a legacy free 'private cloud.'

Author's key findings in relation to the thesis objectives:

Objective 1: To describe the importance of design interoperability for BIM software through a Cloud BIM – Figure 2.1 illustrated the existing fragmentation of ICT in the construction industry in comparison to tomorrow's information centric model. This concept of all disciplines having access to the same software relates to Sosinsky (2001) characteristics of cloud computing productivity software, such as, inter applications communications.

Objective 2: To discuss how cloud computing and BIM can support the future development of interoperable software – The desktop case study of Bechtel's private cloud 'Evergreen IT' demonstrated the productivity benefits of cloud computing through the interoperable advantages of a virtualised infrastructure for connecting Operating Systems (OS); more competitive storage and server rates, no facilities, frequent updates and no-day to day maintenance.

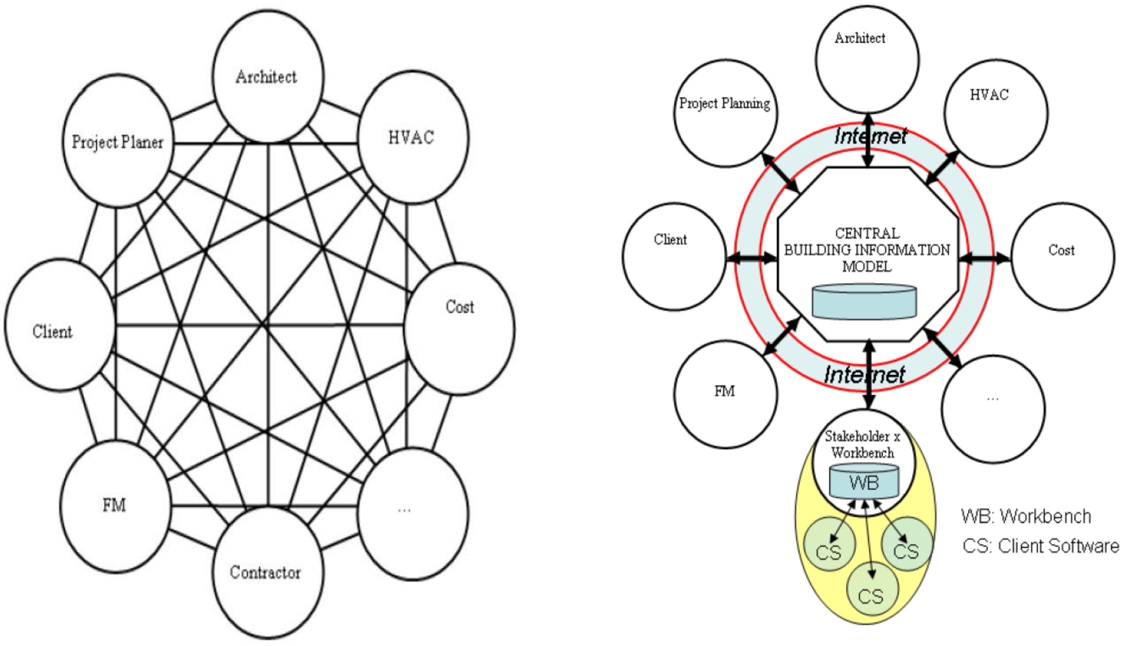
Objective 5: To identify the need for an agreed information architecture framework that will create an interoperable layer of business processes – In this chapter elements of contractual issues for cloud computing were identified in Armbrust et al. (2009) and Ramanujam (2007).

CHAPTER 3

INTEROPERABILITY THROUGH BIM AND OPEN STANDARDS

3.1 INTRODUCTION AND PROBLEM STATEMENT

Each year in the U.S. there are approximately 5 billion square feet of new construction, 5 billion square feet of renovation, and 1.75 billion square feet of demolition. It has also been predicted that $400 billion will be wasted in design and construction effort before BIM is universally adopted (iwmsnews, 2009). Much of this cost involves data management failures to adapt coherent information strategic practices. Hecht (2008) acknowledges that the "I" in BIM is not about automating paper-based processes but about synchronizing information across applications to speed up workflows and enable decision support, databases and purpose-driven content sharing. Industry can embrace interoperability through the use of 'eXtensible Markup Language', an open standard of the World Wide Web Consortium (W3C), which can effectively facilitate the structured exchange of information (Smith and Tardif, 2009). Figure 3.1 compares traditional and Internet-based BIM exchange.



'The traditional proprietary file-based exchange' 'Internet-based BIM exchange'

Figure 3.1. Contrasting exchange without and with Internet-based BIM (cited by Nour, 2009)

This chapter will seek to build upon the interoperable infrastructure vehicle identified in the previous chapter in order to describe models that can obtain building object data and exchange this information freely on an internet platform. The author will define the various technologies and tools currently available to support data exchanges, research work in this area and the importance of data information standards in achieving interoperability of the many facility life-cycle relationships (building components assigned to facility life-cycle applications).

The author will seek to establish the cost saving capabilities of implementing a subset of XML 'SML' to exchange partial BIM data on a cloud platform (to discuss how cloud computing and BIM can utilise the exchanging benefits of Web services in the construction industry). The construction industry's waste deficiency has been linked to its incompetency in not being able to synchronise information flows between various disciplines. The outcome of this chapter is a review of BIMs and open standards; contribution in minimizing the 'bottleneck' (a single system resource that effects the performance of the entire system) in this process.

3.2 BIM AND OPEN STANDARDS

Smith and Tardif (2009) viewed interoperability as an introductory technology for greater efficiency and productivity in the building industry, similar to the Universal Product Code system, which is used for greater efficiency and productivity in the consumer product industry. However, they also acknowledge that although interoperability is important, it is only one of the many challenges facing the industry. They referenced buildingSMART Alliance, formally International Alliance for Interoperability (IAI), a council for the National Institute of Building Sciences (NIBS) in the USA, as a major industry standard body whose early project 'open-standard data format;' otherwise known as IFC, was designed to facilitate interoperability by fostering the use of standardisation that is useable by and accessible to all disciplines. Bew and Underwood (2009) credited BIM's evolution to early product modelling, such as STEP. They acknowledged that, in 1983, IFC-STEP emerged to define product modelling as the long-term ambition to improve the communication of engineering information (including manufacturing, ship building and construction) and to enable integration through the co-ordination of open standards for data exchange and sharing.

Smith (2007) emphasised that the concept of BIM is to build a building virtually, prior to building it physically, in order to simulate potential problems, and analyse potential impacts. Smith stressed that in reality all the information for a building already exists electronically and that this is the catalyst which makes implementing BIM a possibility. The bi-directional virtualisation capability of identifying virtual problems will minimise waste on-site, as products will be delivered when needed (known as 4D programming), more components will be built and pre-assembled off site in controlled environments. The completed model will be the main source for planning and executing changes throughout the life of the facility; it will be tested and updated to validate compliance with the original design intent, such as energy usage for analysing the most cost effective amount of glazing required. In Figure 3.2 the many facility life-cycle relationships are displayed, such as, systems, space and overlays. Each system can operate dependently or independently from the other by exchanging data using ontologies, such as the International Framework for Dictionaries (IFD) to create user-facing requirements that are mapped to IFC objects for implementation in software.

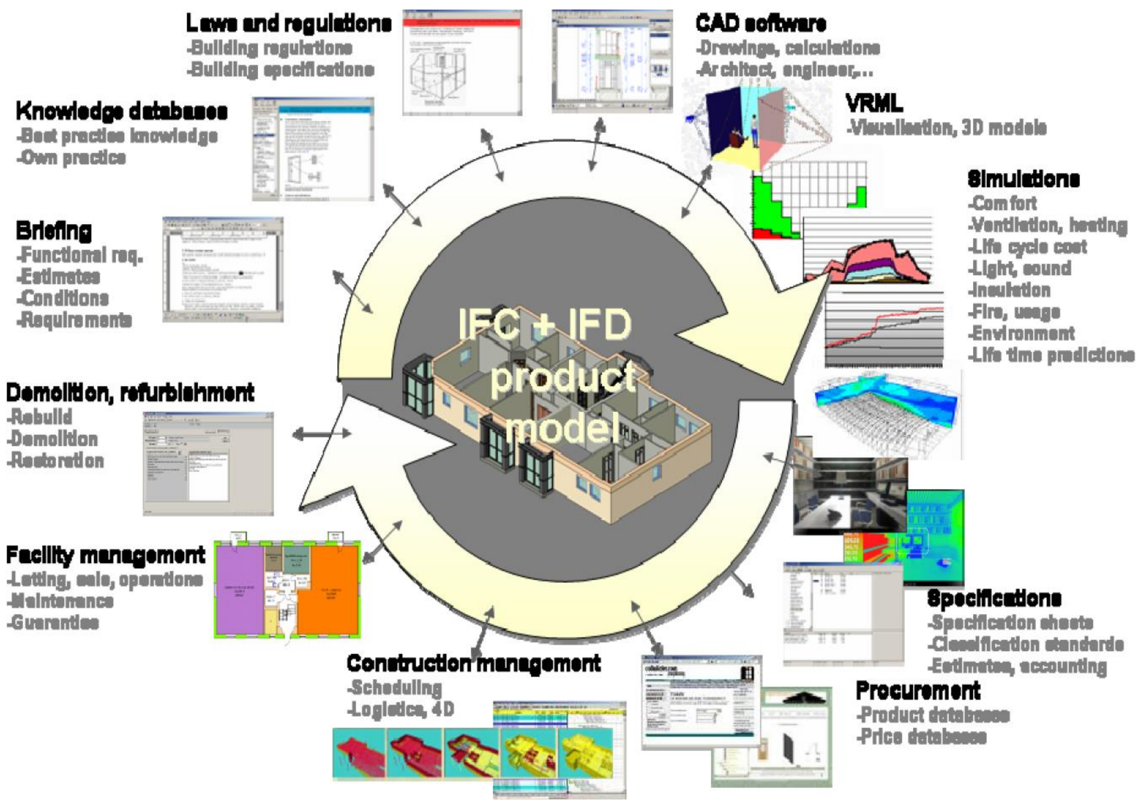


Figure 3.2. BIM relationships (NIBS, 2007 pp53) [legend: Virtual Reality Modelling Language (VRML)]

3.3 CLOUD COMPUTING AND BIM

The use of Application Performance Interfaces (APIs) for binding heterogeneous applications through a central repository platform, such as, "cloud computing" has created a way for different applications to openly interoperate and exchange information. Cloud computing is both the applications delivered as a service, over the Internet, and the hardware and systems software in data centers that provide those services (Ambrust et al. 2009). Onuma (2010) recognises that the Internet is viewed in real-time and that computer device, coupled with cloud-based tools, should make information more accessible to users. In a BIM context, Onuma acknowledges that traditionally exporting a file from application A and then importing that file into application B, was the industry norm for sharing data between applications. However, it resulted in creating multiple copies of data. The identified solution is Service Oriented Architecture (SOA), where data can remain on application A and be used or modified by application B (or other applications). For Onuma this approach allows the user to access pertinent data enabling BIM model views to be shared in small data chunks. Kurtalj (2011) defined mashups, as a way to integrate into a common system various products and services. For example, using GML to define both the geometry and properties of objects that comprise geographic information; for example, adding Google Maps with buildings scattered around the world, it is possible, when clicking on the building, for a pop-up with a Building Management Systems (BMS) of that particular building to be accessed. The mashup concept is highlighted by Kurtalj in relation to Building Automated Systems (BAS) for integrating data points and services from various networks into the same classes/objects infrastructure (as a programming language, such as, a value, variable, function or data structure), usable through the cloud model. Instead of translating the data from one protocol to another, they can all be processed in the same script, as well as, returning the data results back to the very network in its native language so called 'plug-ins.' BAS and BMS can greatly improve the energy conservation within building operating and maintenance; especially by implementing a centralised heterogeneous network 'cloud.' By exchanging data from interoperable energy consumption analysis applications with so called 5D costing, via the Internet, in order to calculate the actual costs of running the building, the potential exists for predicting early building performance costs which would produce alternative economical designs.

3.3.1 Model repository

The standard of IFC was approved by ISO/PAS 16739 referring to a computer system with a data base. Its concept was to feature data about how a building is presented for example; surface colours, line weight and line colours. This standard also specified how the data would be represented in data files, in order for software vendors to develop interfaces, which would read and write files. The initial IFC file format originated from the International Standards Organisation (ISO) 10303 Part 21 file. The challenges of using IFC are associated with having building models available for corresponding model servers to store all kinds of data being extracted from the exchanging mechanism. This relates to the specifics of how each individual software tools do not perform the exact same transformations (Jorgensen et al. 2008). In recent issues, the XML specifications defined by Document Type Definitions (DTD) in Part 28 (ifcXML) are not an open-ended data model like XML Schema (XSD), which extends custom markup languages and establishes complex relationships between elements without validating documents (Morrison, 2006).

Van Berlo (2012) highlights how BIMserver (an open source Building Information Model server) created a plugin for the open BIM Query Language (BIMQL.org - a query language intended for selecting and updating data stored in FIC models) for streamlining the selection and transformation of partial data in the design and construction process. Van Berlo highlights that it is BIMserver's intention to focus on positioning itself as an open and stable platform and less of a product ready for end-users.

3.4 INTEROPERABILITY

Gallaher et al. (2004) identified that interoperability issues occur creating a fragmented business process and organisational structure. It is estimated that the cost of inadequate interoperability in the U.S capital facilities industry is $15.8 billion per year. In 2002, the value of capital facilities in the U.S. was $374 billion. The magnitude of this figure suggests that even small improvements in efficiency potentially represent significant economic benefits. In recognising that ICT has the potential to revolutionise the construction industry and streamline historically fragmented operations, Gallaher et al. state that tools, such as computer-aided drafting technologies, 3-D modelling technologies and a host of Internet and standards-based design and project collaboration technologies can reduce the fragmented nature of the industry (see Figure 3.1). However, the problems associated with not being able to manage and communicate electronic products and project data between collaborating firms and within individual companies are compounded by the fact that a large number of small companies have not adopted advanced ICT.

Eastman et al. (2008) recognised that no single computer application can support all of the tasks associated with building design and production. Interoperability was highlighted by Eastman et al. because it depicts the need to pass data between applications, allowing multiple types of experts and applications to contribute to the work at hand. McGraw Hill Construction (2007) defined interoperability, in a generic sense, as the ability to manage and communicate electronic product and project data among collaborating firms. Beyond the technological aspect, it is the ability to implement and manage collaborative relationships among members of cross-disciplinary build teams that enables integrated project execution. In relation to project life-cycle, McGraw Hill identifies that the traditional method generally focuses its greatest amount of effort during the construction documentation phase, in contrast to the integrated approach, where the team members work closely together during the design phase, resulting in a greater ability to save costs before the construction process commences.

Figure 3.3 shows BIM's ability to control costs by improving the cost of design from construction documents to the early design stage.

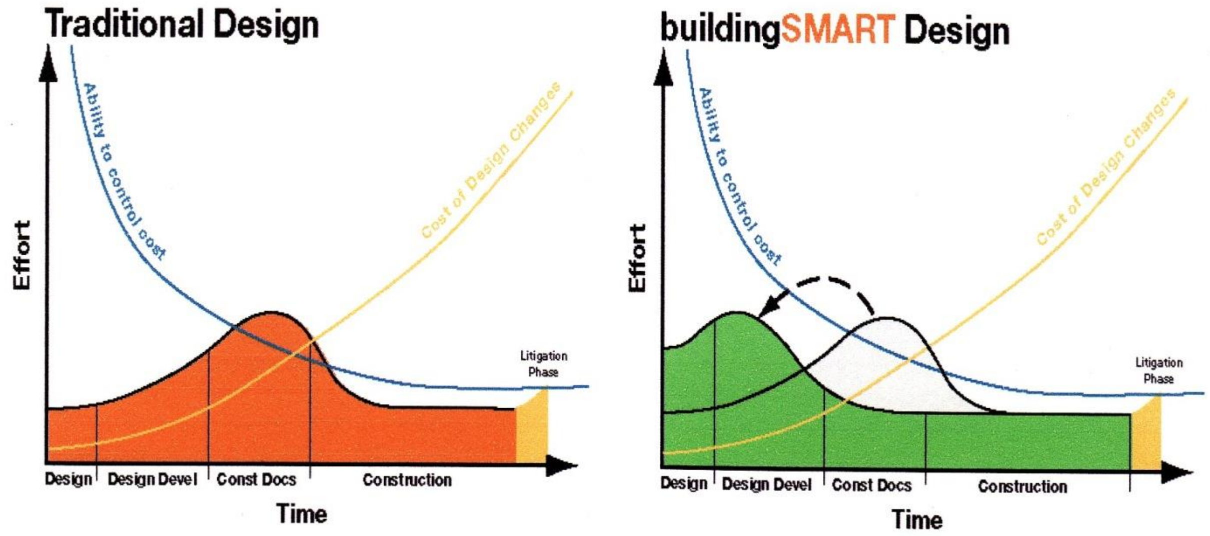


Figure 3.3. Earlier decision making with BIM improves ability to control costs (Sourced from McGraw Hill, 2007)

In reference to this idea, McGraw Hill acknowledges that, in order to reap the full benefits of BIM's ability to more than promote integrated project delivery, build team members will increasingly need to have interoperable systems.

3.4.1 Interoperability across the internet

However, as attractive as this Hub or Cloud BIM strategy appears, a heavy reliance exists on an IFC object model that creates speed and accuracy difficulties, such as exchanging pertinent data. Conventional thinking requires processing a complete project data model, so innovators began searching for alternatives, such as simplifying the full model into subsets or through the novel use of XML. Frequently trade associations test innovations with Testbeds before recommending new practices to their paying members. The Architect, Engineering, Construction, Owner Operator, Phase 1

(AECOO-1) Testbed commenced in 2008 with the objective to create standards that would allow software (such as energy analysis and quantity take-off) providers to streamline communications and information exchanges between project participants during the design phase of capital projects. The process involved creating an Information Delivery Manual (IDM), which articulates what building information is required and a Model View Definition (MVD), which is the smallest set of IFCs that are needed to, express the information requirements of a particular IDM (Hecht and Singh, 2010). IBM (2008) emphasised that a relatively smaller subset of IFC data is sufficient to enable business procedures to take place.

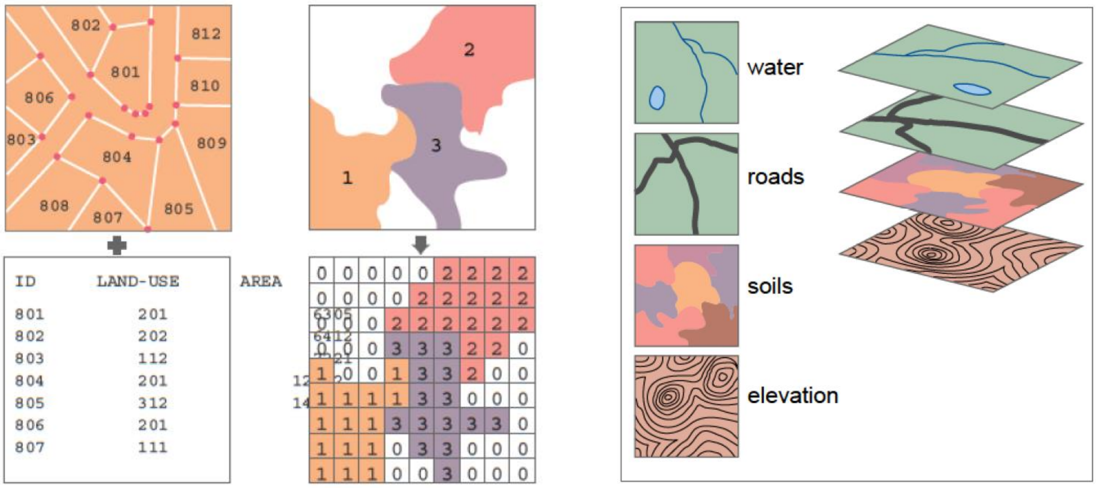
Turk (2004) identified the challenges facing large engineering industries in orchestrating the work of numerous organisations and professionals towards a common goal. He highlighted how Inteligrid a world-leading EU FP6 grid project in the AEC context harnessed a grid technology and semantic (where the infrastructure manages the meaning of the data) interoperability through virtual organisations. The use IDM was implemented as a key technology to make structured information exchanges work on semantic collaboration among business.

3.4.2 GIS and Mapping

Geospatial Information Services (GIS – a computer-assisted system for the acquisition, storage, analysis and display of graphic data) use a simple database (input, manage and analyze data) query to examine requested results as maps. Eastman (2006) identifies that with spatial databases (data based on its location) there are two types of questions that are usually asked "What locations have this attribute (tabular information and statistics)?" and "What is the attribute at this location?" The former is referred to as query by attribute, while the latter is known as query by location.

Query by attributes operations generally depend on the geography layer being implemented for example; single geography (farm fields, provinces) are defined by vector files ("the boundaries of the features are defined by a series of points (encoded with a pair of numbers giving the X and Y coordinates in systems such as latitude/longitude) that, when joined with straight lines, form the graphic representation of that feature") that relate to multiple of attributes in a database. In order, to accomplish a database query a Structured Query Language (SQL) (a database programming language for querying and editing information) filter may be used in a database workshop linking the results to a vector file or assigned to a raster (investigate an area by subdividing it into a fine mesh of grid cells that record the condition or attribute of the earth's surface at that point) feature definition image.

Query by attribute is successful in mapping countries databases with multiple of attributes to find the answers to such queries as, “find all the countries where the median per capita annual income is less than $5000, but the literacy rate is higher than 60%.” Query by location involves creating raster image groups file (.rgf – used by IDRISI software) that contain all files connected to a certain organization. The query associated to these groups will bring up information about a pixel value at the location referenced to all the images in that cluster.



Vector Raster Unitary Layer

Figure 3.4. Map data representation (Sourced from Eastman, 2006)

Figure 3.4 demonstrates the boundaries storage features of map data used by vector images in contrast to raster systems analysis orientation. This figure also shows how raster systems use map-like logic, with data divided into sets known as unitary layers (a layer can contain single attributes such as a soil layer, a road layer etc.).

Van Berlo and de Laat (2010) identified that there is an enormous interest in the integration of BIM and GIS however, at present polarization exist between both worlds for example; different technologies, standards and syntax descriptions. They also recognized that each sector does have attributes that can be of value to the other such as, the strong relationships between objects in open BIM models and GIS worlds’ server-focused approach concentrating on data referencing geolocation (using real world coordinates) and the relationship between geospatial objects based on these coordinates. For example; the “sniper illustration” used by the Department of Homeland Security to investigate where a sniper can hide with regards to buildings and their windows and instead of using a virtual model for all buildings the analysis focuses on all corresponding windows, rooms, and buildings. The problem is that CityGML (an open data model and XML-based format for the storage and exchange of virtual 3D city models) does not store window width and height due to complex calculations. However, these attributes can be stored semantically in IFC and referenced to the development of a GeoBIM CityGML extension.

3.5 DATA INFORMATION EXCHANGE

Data exchanges are generally classified in one of three formats; (i) direct links, (ii) proprietary file exchange and (iii) public product data model exchange.

- Direct links are languages which incorporate APIs to extract data from one application and rewrite the data in a format using another receiving application; for example, a Geometric Description Language (ArchiCAD).
- A proprietary exchange format primarily involves geometry, such as a Drawing Exchange Format (by Autodesk). It is a file or interface developed by an organisation solely for interfacing with that company's application. The majority of software vendors prefer to provide direct or proprietary file exchanges.
- Public product data model exchange formats are open and publicly managed schema and languages (the code can be manipulated by the public), such as XML, text file and IFC (Eastman et al. 2011a).

The IAI developed the interoperable open standard 'IFC,' which was derived from the Building Construction Core Model and developed within the ISO 10303 framework, known formally as STEP. IFC information models use schemas sourced from EXPRESS (a data modelling language). However, the issue with EXPRESS general purpose information modelling language and encoding rules is its complex and difficult to compile, without using STEP technology (Begeley et al. 2005).

In 2010 a new version of the IFC was released, Version 2x4. This release of IFC has about 800 entities (data objects such as ifcMaterial), 358 property sets; container class that holds properties within a property tree (property sets are assigned to objects (*IfcObject*) through an objectified relationship - *IfcRelDefinedByProperties*), and 121 data types (ifcActor such as clients linking with ifcElements) these numbers reflect the complex yet schematic richness of building information models.

Figure 3.4 illustrates the structural layers involved with IFC system architecture. The architecture comprises of the following:

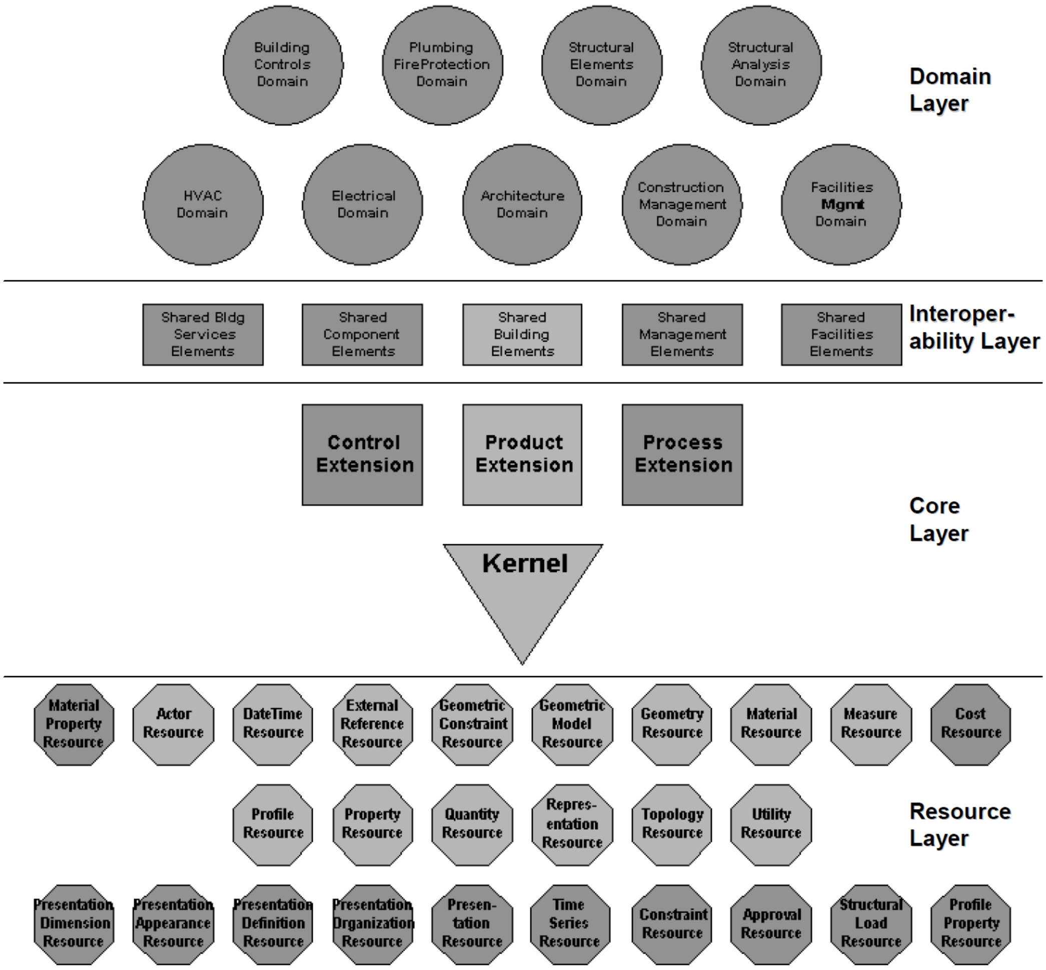


Figure 3.5. IFC model architecture (Sourced from Begley et al. 2005)

- At the bottom 26 sets of base EXPRESS definitions, defining the base reusable constructs, such as Geometry, Topology, Materials, Measurements, Actors, Roles, Presentations, and Properties.
- The base entities are then composed to define commonly used objects in AEC, termed Shared objects in IFC. These include building elements, such as generic walls, floors and structural elements. IFC is an extensible data model and is object-oriented meaning the base entities could be specialized by sub typing.

- The top level of the IFC data model are the domain-specific extensions that deal with different specific entities needed for a particular use for example; there are structural elements (columns) and structural analysis extensions (individual parts such as bolts).

The levels associated with IFC hierarchical tree, introduce different attributes and relations (relations are typed and link one object with another) to the wall entity. The following is a breakdown of the levels connected to the various attributes and relations of IFC schema:

- IfcRoot assigns a Global ID and other information for managing the object, such as who created it and when,
- IfcObjectDefinition places the wall into the aggregate building story assembly; identifying the components of the wall, including windows and doors,
- IfcObject level provides links to properties of the wall, based on its type,
- IfcProduct defines the location of the wall and its shape,
- IfcElement carries the relationship of this element with others, such as wall bounding relationships, and also the spaces that the wall separates (Eastman et al. 2011b).

The encoding data in XML produces IFC files that are bigger than traditional American Standard Code for Information, encoded IFC files. However, the schematic approach of XML enables users to submit a query and receive the required information without having to download a big batch of data files to extract an answer (Hecht, 2010). Unfortunately the XML schema has also been reviewed as too complicated and hard to use by non-experts, as many non-experts need to be able to read schemas to write valid documents. On the other hand, Web services; which are developed from XML data representation format and Hypertext Transfer Protocol (HTTP) communication protocol, are platform neutral, widely accepted and utilised and come with a wide range of useful technologies and they support SOA (Moller and Schwartzbach, 2006). In 2008 the Open Geospatial Consortium developed new standards to extend to the integration of CAD and GIS technologies on the Web. One such Web standard was based on exchanging proprietary BIM data through Web Feature Services (WFS) derived from the GML. CityGML is a champion of the major technical advantage of Web services with IFCs for the geospatial environment, as it enables 3D buildings to be displayed and exchanged through Web services (Rees, 2008). APIs have allowed developers to connect applications together by extracting rivulets (streamlined) of information from various Web 2.0 sources (read and write data). This process is known as 'mash-ups' where the concept is to open up content production to all users and expose data for re-use (Anderson, 2007).

Josuttis (2007) recognises that SOA is a simple and fast way to provide access to data or resources provided by Web servers. In analysing SOA, Josuttis identifies Enterprise Service Bus (ESB – enables asynchronous oriented design for communication and interaction between applications) as the backbone to the architecture and highlights its heterogeneous ability through two approaches; protocol driven, and APIs. The issue with the API-driven approach relates to the tools and/or libraries (set of rules) for mapping the APIs. In order to provide for service calls (communication between two electronic devices over the Web) and implementations, the messages to be sent over the ESB have to be defined, which means XML with XSD must be proven. In contrast, the protocol-driven approach allows the participants to choose their specified tools to send service calls and provide service implementations (connections). Stair et al (2008) emphasises that the main contribution of APIs is their ability to link application software to the operating system. Oracle (2008) refers to Web APIs as Web 2.0 and highlights that its emergence has vastly improved and enriched the user's Web experience. Anderson (2007) recognises that APIs have helped Web 2.0 services expand and have facilitated the creation of mash-ups of data from various sources by providing mechanisms for programmers to make use of the functionality of a set of data without having access to the source code.

3.5.1 Orientated information exchanges

Eastman et al. (2011b) highlighted that until 2008, there were two separate development teams concentrating on IDM and MVD. Originally IDM developers mapped functional specifications directly to the IFC schema whereas MVD developers began their process by developing a generic MVD. However, in late 2007 a primarily agreement was established to integrate both teams. This meant that IDM would focus on the end-user requirements definition and MVD on the translation of those requirements into exchange representations and implemented into software products. Eastman et al. identified that different areas of the building industry have different information needs (i.e. an architect's needs are different than an engineer's) and in order to examine the needs of various professionals the NBIMS project committee workgroup documented exchanges through use Cases based on BPMN. Figure 3.6 is an example of a process map for structural precast the overall structure is referred to as "swim lanes". The components of the swim lanes are divided into horizontal lanes identifying actors such as activities of the progression through the lifecycle of a business process and vertical defining the stage stages of the process.

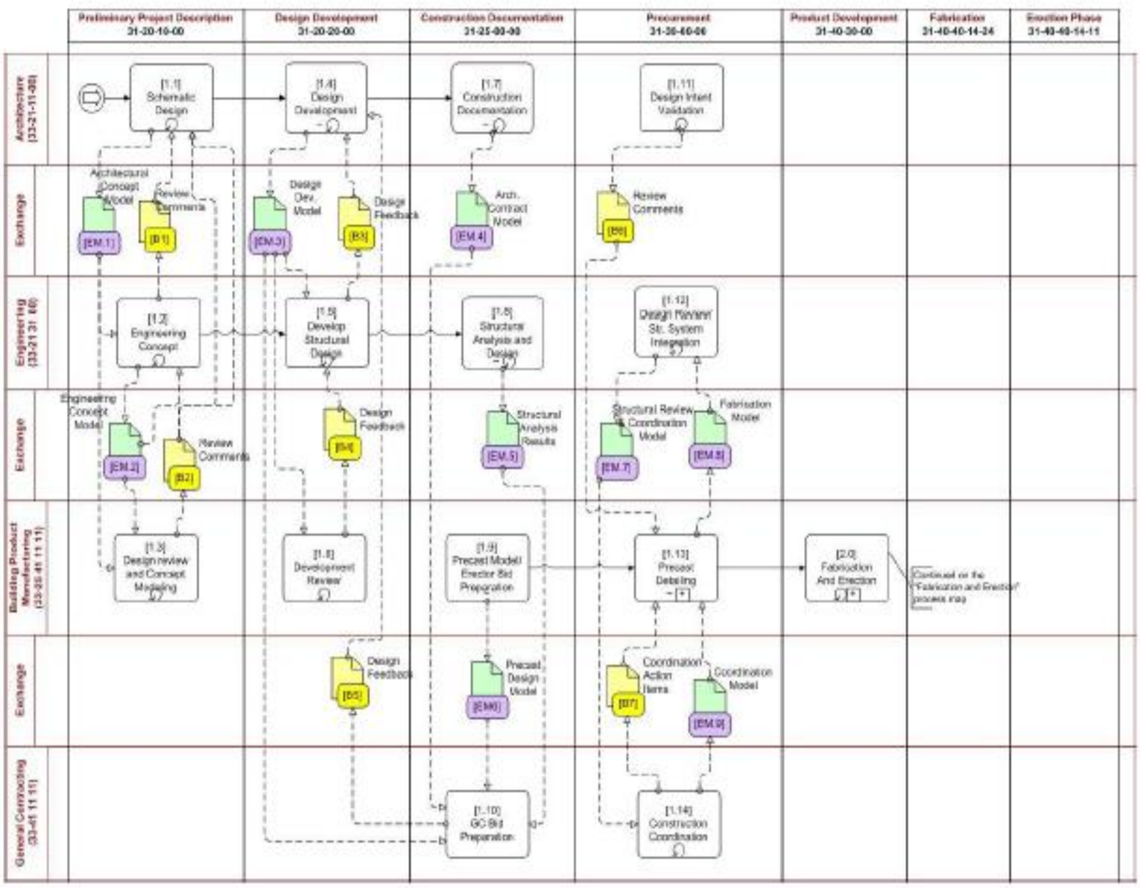


Figure 3.6. Example processes model for Structural Precast (Sourced from Eastman et al. 2011b)

Katranuschkov et al. (2011) recognised within the context of developing an energy-efficient BIM framework the value of IDMs in capturing data exchange requirements. They emphasised that in order to identify the IFC capabilities each functional part needed to be supported in terms of their entities (data objects), attributes (element of information), property sets (container class) and properties (objects) required. The concepts of IDMs were orchestrated into four main parts: i) process maps - describe the flow activities for a particular business process, ii) exchange requirement - characterising a set of information that needs to be exchanged, iii) functional part – unit of information used by solution providers to support exchange requirement, and iv) business rules – these are the constraints that may be applied to a set of data used within a particular process. From this structure Katranuschkov et al. designed their methodology for a life cycle energy management, adaption and extension of IDM.

Figure 3.7 illustrates the life cycle representing a typical subset of the full business process.

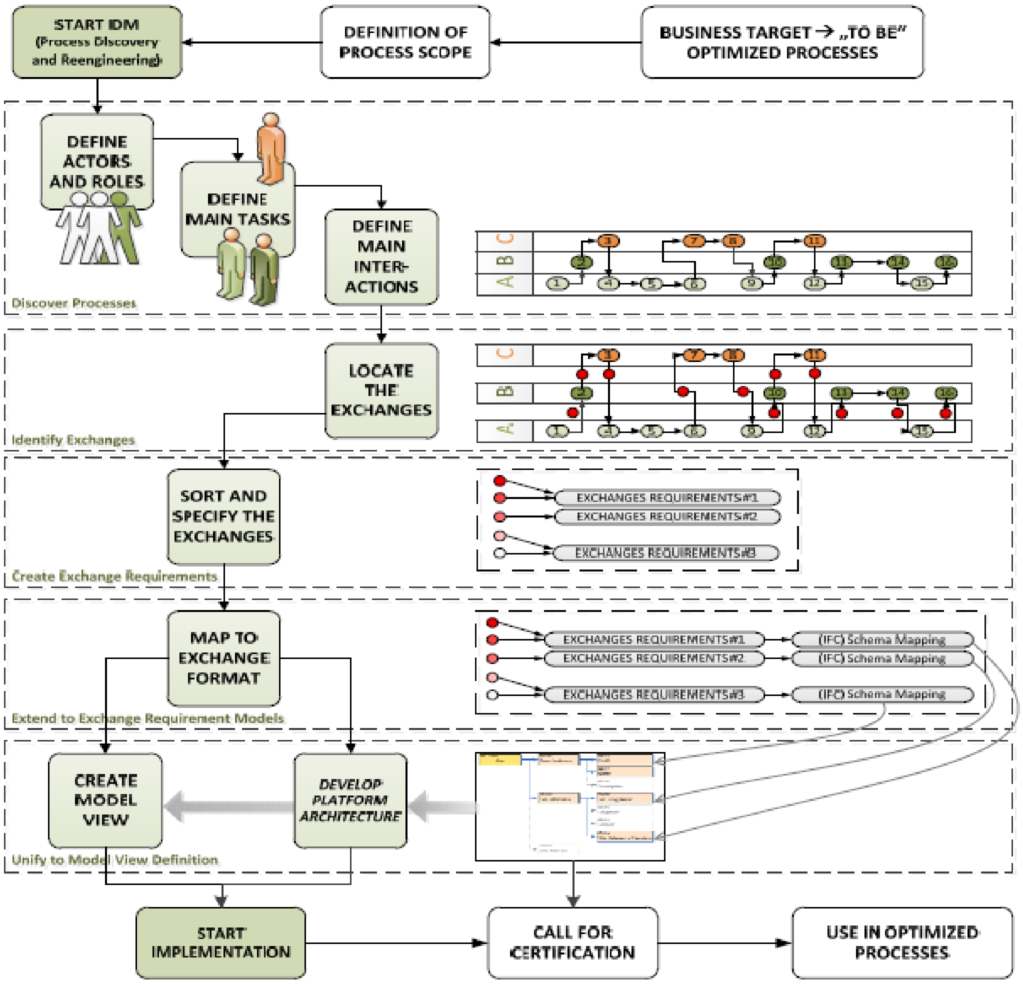


Figure 3.7. Schematic presentation of IDM-based development process (Sourced from Katranuschkov et al. 2011)

MVDs are not only used to define legal subsets of the IFC schema they also follow a similar format in representing requirements specification for XML schema 'mvdXML'. The definition format requires exchange definitions indicating import and export scenarios for each model view, concept roots (indicating entities of IFC), concept nodes (indicating for value attributes), concept templates, and exchange requirements indicating mandatory, optional, or excluded concepts for exchange. The MVD concept templates are part of the IFC4 specification which quickly allows expansion of generic concepts to cover specific requirements and business rules (buildingSMART International, 2013).

3.6 IFC AND THE NEED FOR SUBSETS

Nour (2009) identified several major questions based on the concept of being able to exchange shared data with a central data repository (a model server). The questions included; (i) does one need to map all the geometrical and context information to the database (ranging from 30-60% of the IFC model, depending on the types of geometrical description), (ii) does one need to map all the ifcRelationships (as previously noted in section 3.5; property sets are assigned to objects (*IfcObject*) through an objectified relationship), as on average the relationship elements descending from ifcRelationships was found to be only 3% (see Table 3.1 for elements such as ifcSharedBldgElements), (iii) does one need to map the objectified relationship classes means (ifcRelationships) into cross referenced tables in the relational database, the matter that makes the overall structure too complex and; therefore, causes much difficulty in formulating SQL queries and (iv) does the database structure need to be complicated in order to accommodate the entire IFC model. Nour noted that the 'Inpro project' (co-funded by the European Commission to identify business and legal issues of BIM in construction) delivered a description of business objects (classes for data integration) known as flat business objects; meaning their attributes contained data and did not reference other objects or any inheritance hierarchy classes. The importance of these attributes was the fact they were used to create a simple and flat relational schema. Nour's approach is based on four layers of architecture, as shown in Figure 3.4.

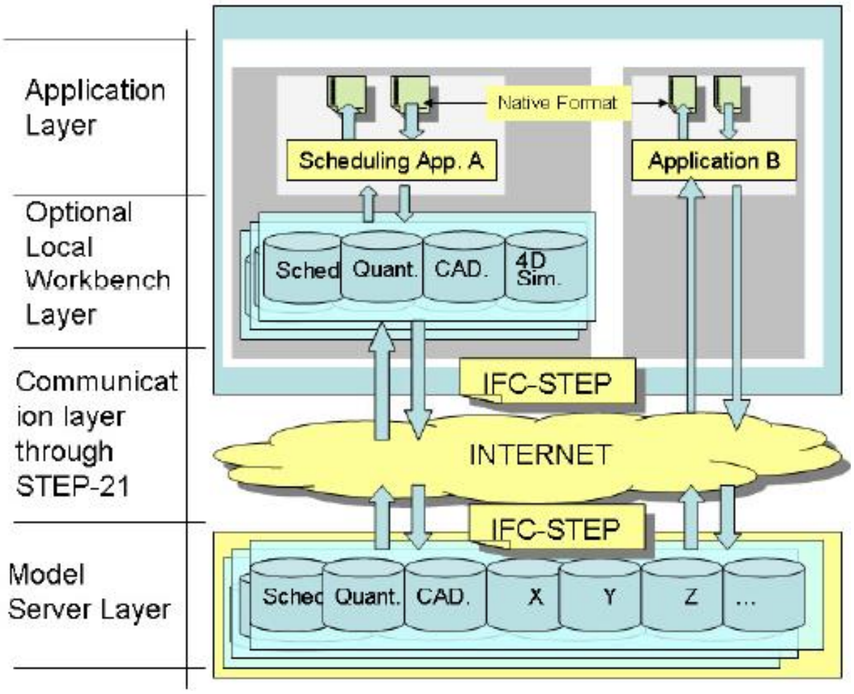


Figure 3.8. Nour's approach to an overall architecture of a developed system (Nour, 2009)

The 'application layer' allows one to freely use any type of software that has an IFC API or where the output data can be converted to IFC. The 'workbench layer' comprises of a simple and flat database structure, which hosts the attributes of the domain objects (intelligent entity beginning as an actor) in addition to references to any type of proprietary file formats. Any information that is not included in the database may still be obtained from reference of the relevant version to the saved IFC STEP file.

IFC Model Architecture	Automating Equipment Information Exchange
Layer of Sub models (Resource layer): contains data structures that represent general purpose concepts – with adopted STEP methodology, all of the data structures that compose the IFC model are defined in EXPRESS schema.	Core data type schemas – for extensions to basic data types to support engineering requirements (these are essential extensions added to the "XSD" base data types provided in the W3C XML Schema Standard);
The Core layer: delineates the basic structure and conceptual definitions of the IFC – composed of two parts a) the Kernel (IfcKernel) sub-model defines object, property, and relationship and the extensions to the Kernel 'core extensions' (IfcControlExtension, IfcProcessExtension, IfcProductExtension). Extensions construct product, process and control, and the relationship between them. The IFC core layer provides for explicit representation of whole-to-part relationships for example, a unitary pump assembly consisting of a pump, an electric motor, the base, valve, sensors, and actuators, can be represented by a composite object that is an aggregation of representations of its individual parts.	Core engineering object schemas – for reusable base engineering objects that can be used by multiple engineering disciplines and subject domains;
The Interoperability layer: contains a collection of data structures that define concepts or objects common to multiple AEC/Facility Management (FM) domain models. These are structured into five sub models: 1. IfcSharedBldgElements - define the principal architectural components of the building structure such as, walls, beams, stairs, doors, and windows; 2. IfcSharedBldgServiceElements - define concepts common among building services for example; Heating Ventilation and Air Conditioning (HVAC), plumbing, electricity such as flow and distribution systems; 3. IfcSharedComponentElements - define different types of small parts such as fasteners and accessories; 4. IfcSharedfacilitiesElements - define basic concepts used in facilities management such as assets, furniture types, service life, and occupants; 5. IfcShardMgmtElements – define basic common managements concepts used throughout the lifecycle of a building such as costs, project orders, and project order records.	Subject engineering object schemas – that provide schemas related to specific equipment items;
The Domain layer: categorized data structure for specific AEC/FM domains such as, architecture, structure, plumbing and HVAC.	Collection-container schemas – used to model engineering documents schemas. The collection-container schemas allow core and subject-specific engineering objects to be combined in various ways to support various data transactions and usage scenarios.

Table 3.1. The structure difference between ifcXML and AEX schemas (Adapted from Begley et al. 2005)

The ‘communication layer’ involves the split of models (to create partial models), merging, and comparing models at both the workbench side and the central model server side. Finally the ‘model server layer’ is similar in functionality to the workbench layer but has the capacity to handle bigger sizes of data sets and multiple domains.

In 2005 the U.S. Department of Commerce published the ‘Semantic Mapping between IAI ifcXML and Fully Integrated Automated Technology (FIATECH) Automating Equipment Information Exchange (AEX) Models for Centrifugal pumps.’ This report describes a semantic mapping between two XML specifications describing a centrifugal pump. The difference between these two XMLs formed the basis of the study from which the results were to be used to establish exchange mechanisms between information systems that utilize different XML applications.

The Centrifugal Pump test also highlights the difficulty of using IFC model architecture. Table 3.1 shows the hierarchy dependence of the model starting with the ‘resource layer’ containing the structure that represents the general purpose contents; for example; IfcActors, and IfcPropertyResource. The ‘core layer’ comprises of the Kernel (central core of the OS) and extensions to the Kernel; for example; IfcKernel and IfcProductExtension. The ‘interoperability layer’ contains a collection of data structures that define concepts or objects such as, IfcSharedBldgElements and IfcSharedFacilitieElements.

The final layer, the ‘domain,’ categorises data structure for specific AEC/FM domains for example; IfcBuildingControlsDomain. In order to speed up the process of exchanging files, property sets allow an application to exchange data in the same file without requiring a change to the EXPRESS schema. However, a problem with ifcXML in relation to the design of a centrifugal pump is that the schemas for IfcPumpType and IfcFanType have the same data structures because they inherit their definitions from IfcFlowMovingDeviceType. This means that a PredefinedType in IfcPumpType is declared to be IfcPumpTypeEnum for different kinds of pumps which is the same process for a fan. This highlights the issue of not being able to use aggregated composite classes to retrieve the basic information that one would need, for example, not having to go through the hierarchy of classes to obtain the section of a code that is required.

In contrast to ifcXML, the AEX schemas design was developed with the requirements that the base schemas structure would be capable of handling any equipment item or any engineering document. The AEX XML schema provides the use of “namespaces” (a container for a set of identifiers (names) usually applied as a prefix to the local name) to define thousands of element definitions, thus providing the ability to define a collection of conceptually-related data elements, where uniqueness is only required within the name space. For identifying objects anywhere in the object schema, the core objects could be applied across multiple subject domains through specific object XML schemas. The emergence of distributed client-server technologies, such as Web services, has highlighted the need for future versions of ifcXML to implement different mechanisms that facilitate referencing and exchanging partial sets of information (Begley et al. 2005).

3.7 EXCHANGING SIMPLE AND FLAT RELATIONAL SCHEMA

La Query (1999) identifies that the notion of simplifying a standard beyond Standard Generalized Markup language into XML, is possible via SML. SML essentially is XML without a Database Tuning Advisor. A Database Engine Tuning Advisor uses trace files, trace tables, or Transact-SQL (originally developed for querying, altering and defining relational databases, using declarative statements) scripts as workload input when optimizing and homogenizing the performance of a database. In using a subset of XML; many developers only use as much data as is needed to retrieve their required information.

Old Paradigm	New Paradigm
Data fits neatly into tables.	Our data does not fit in tables so use whatever structure (trees, graphs, key-value pairs etc.) that best fits the problem.
A single CPU is preferred; so focus on disk I/O RAM, caching and scale-up issues (known as “scale up”).	Use as many CPUs as you need and understand the problems associated with distributed computing and scale-out.
Use a middle-tier of business objects to store business logic and business rules.	Use documents to store business data and transform it when necessary.
Use complex object-relational mapping (OR-mapping) tools to attempt to automatically generate SQL based on object relationships.	OR-mapping is not needed. Use documents in your application and document storage.
Use procedural code and state management to manage transactions.	Use functional programming and MapReduce algorithms and partition the problems into independent tasks without side effects.
Train staff on how to debug procedural code and find memory leaks.	Use functional languages that focus on data transformation.
Hire and train logical and physical data modelers to build precise data schemas that are consistent with enterprise standards.	Load whatever data comes along and adapt the schemas as needed.
All transactions are ACID. All reports must always be consistent.	Use ACID (atomicity, consistency, isolation and durability) when necessary but focus on never blocking writers. Make the systems eventually consistent.

Table 3.2. Transferring from single table-oriented database architecture to the new paradigm ‘NoSQL’(Sourced from McCreary and McKnight 2011) [legend: ACID - a set of properties that guarantee that database transactions are processed reliably]

This means leaving out attributes, Document Type Declaration (schema that describes the data model of an XML-based markup language), processing instructions and non-character entity references. The widespread availability of XML parser (a document is processed by an XML application) has enabled program developers to experiment with XML in ways that do not involve conventional documents. La Query recognizes that eBusiness protocols use a reduced feature subset of XML, such as XML-Remote Procedure Call and Simple Object Access Protocol (SOAP) use simple XML, to achieve their ends, such as, messaging and configuration of files.

McCreary and McKnight (2011) define Not Only SQL (NoSQL), as any system that does not exclusively rely on SQL for data selection. Such systems include; native XML databases, graph stores, object stores and Online Analytical Processing (OLAP) (automatically pre-calculating sums in aggregate tables) for relational databases usually referred to as 'cubes' (a set of data, organized in a way that facilitates non-predetermined queries for aggregated information) using the MultiDimensional eXpressions (MDX) language developed by Microsoft in 1997. A key driver for early NoSQL solutions was the need to store large amounts of data and get rapid analysis. The MDX query language, instead of returning only tables, returned data that could be accessed through a pivot table-type interface (automatically showing data entries). In 2006, W3C standardised the XQuery language specification, which was one of the initial standardized languages that could query both tabular data and documents. Table 3.2 shows the difference between a relational model 'SQL' and 'NoSQL.'

3.7.1 Partial modelling

The scope of ISO 12006 part 3 which relates to defining concepts by means of properties, to group concepts in order to define relationship between concepts was recognised as the basic entities of taxonomy (classification) model for BIM. Beetz and de Vries (2010) identified that "the model described in this standard is proposed to bridge between classification systems as described in ISO 12006-2 and product modelling". However, they recognised that no explicit definitions had been included into the standard to regulate the use of taxonomies modelled with this meta-model. In order, to maximise the concepts defined in libraries Beetz and de Vries proposed the design of four hierarchical meta-modelling layers (abbreviated as M#). The product descriptions were based on IFD namely; (1) The kernel layer M0 – consisting of a straightforward translation of EXPRESS schema into using Ontology Web Language

(OWL - ontologies capture key concepts and their relationships in a machine interpretable form), (2) the concept library layer M1 – concepts and entities such as local taxonomies and classification system i.e. OmniClass, Uniformat and MasterFormat are gathered, (iii) the product kernel layer M2 – this layer acts as an instantiation (an abstraction) of M1 such as "door panel" defined as a concrete product "Door model 4711 by Manufacturer X" and, (iv) product instantiation layer M3 – developing concepts provided by a central repository on the product library layer.

With regards to partial modelling the added value attributes of Resource Description Framework (RDF - based upon the idea of making statements about Web resources such as expressing the relationship between a subject and an object) and OWL have several advantages in comparison to using STEP. With regards to Representational State Transfer (RESTful - Web service API) query endpoints in existing RDF query languages such as SPARQL (used to express queries across diverse data sources, stored natively as RDF or viewed as RDF via middleware) and SeRQL (Semsame RDF Query language, combines the best features of other languages and adds some of their own) can be used for much more efficient retrievals of complex graphs than currently with SOAP API in the ifd-library.org reference implementation and reducing the amount of calls and answers in order to retrieve for example; "all properties and measures and values of the door concept".

3.7.2 Semantic Web

Web services have been referred to as "new kind of Web-enabled applications" composing of self-contained and self-describing entities that can be published, located and invoked across the Web (Tidwell, 2000). Booth et al. (2003) recognised that Web services support distributed computing (multiple of computers that communicate through a network) and therefore offer the capability of creating SOA.

Mesmoudi et al. (2011) identified the added value of combining several Web services into a composite one such as the functionalities of travel planning and online shopping. They highlighted that composition consists of several steps; "(1) decomposing a high-level user goal into sub-goals, (2) finding Web services that implement of each sub-goal, and (3) orchestrating the interactions between composed Web services in order to fulfil user's requirements". The challenges associated with building an execution plan relate to over complex dependencies between services not offering a clear separation between discovery (finding individual Web services that implement functionalities required by sub-task's extracted from the user's goal) and orchestration (building an ordering for Web service invocation by means of configuration techniques) tasks.

SOA provides the underlying context for Web services (a family of middle-ware technologies that facilitate the use of service-based applications on the Web) and there are four key SOA categories that are satisfied by Web service technologies:

1) Web service is essentially a software compound accessible through an interface connected to a Web location for example; Uniform Resource Locator (URL). Web service can be defined in any programming language but they must be accessed through a Standard Web service interface.
2) The interface of Web services is specified through using XML-based Web Service Description Language (WSDL) which specifies the location of the Web service for sending and receiving messages.
3) Web services need to be registered and the process is usually done manually. These entries are obtained by others through invoking the service according to a category. Two of the most popular interfaces are the Universal Description, Discovery and Integration (UDDI) and electronic Business eXTensible Markup Language (ebXML) (Walton, 2006).

3.8 HIGH PERFORMANCE GRAPHICAL WORK STATIONS

The following desktop case study has been chosen as part of the literature review, in order highlight the cost saving benefits of using both cloud computing and BIM in the construction industry. The case study focuses on a SME architectural firm using ‘Cloud BIM’ to assist in reducing costs in hardware expenses, enhance collaboration with external consultants and have full physical human mobility through a high performance work station.

France (2010) identifies that most of the current discussion around cloud computing has been dealing with servers (or back-end systems), only recently have businesses begun to put their desktops and workstations into an off-premises centralised location ‘the cloud.’ France stated that their private cloud is the first AEC workstation cloud in production and is on track to reduce their workstation and laptop hardware expenses by 67% ($2m) over the next 10 years. France attributes the business benefits of workstation clouds to BIM, as designers are now able to construct a model of a fully documented, 3D building on a virtualised computer before it is actually built on-site. This process requires a lot of computer power and overcoming obstacles, such as;

(i) growing desktop computing needs – architectural applications which require a lot of simulation, analysis, rendering and 3D modelling, in order to design buildings. France's company spends between $250,000 and $300,000 on refreshing laptops with more software capabilities. Based on the cloud access devices, new laptops were purchased for less than $1000 and only when required,

(ii) collaborating with outside firms on the same model – with the widespread usage of BIM cloud technology can engage real-time collaboration between firms, allowing external consultants' employees to develop on the same models and

(iii) full mobility – the high performance workstation enables laptop connection through a Remote Desktop Protocol (RDP) to have full usage of resources such as a 20MB internet connection.

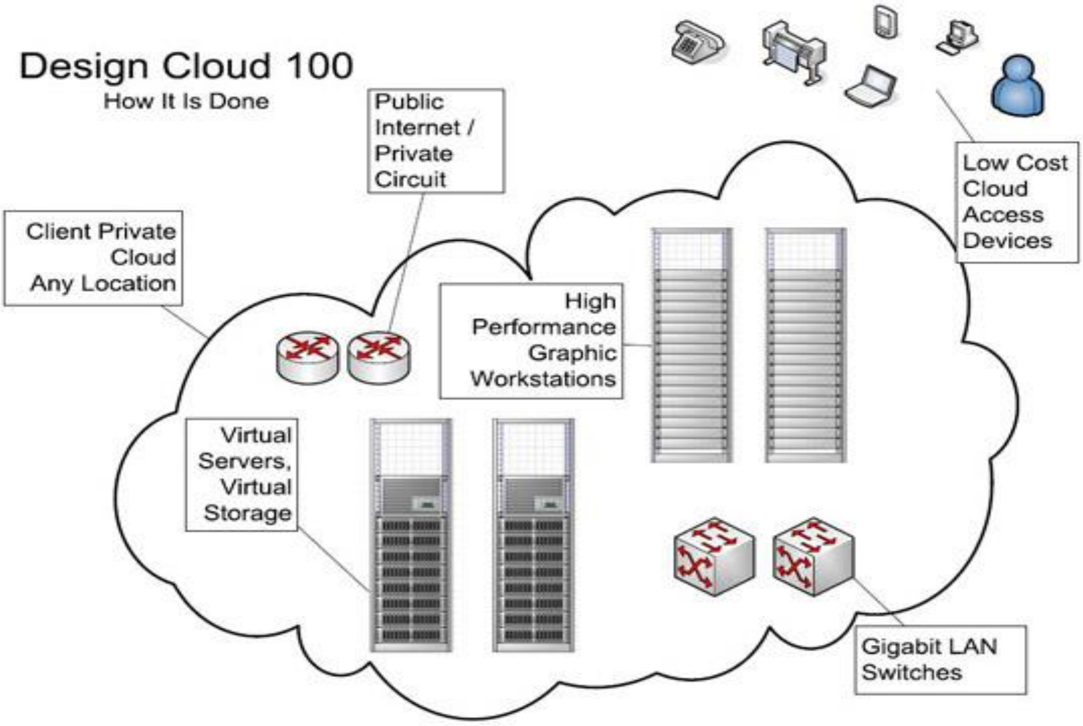


Figure 3.9. Implementation diagram of the HPGW cloud (Sourced from France, 2010)

In continuation of driving down costs and greatly increasing operational capabilities; such as, "instant" provisioning (grow to meet the changing needs of one's business quickly and cost-effectively), disaster recovery and business continuity, all servers were placed into a virtual infrastructure. Technically the workstations were not virtualised; they were viewed as more like a utility that creates the ability to share Windows 7 64-

bit operating system with many users at the same time. In order for the servers to be adapted the storage capabilities had to be reconfigured for the desktop virtualisation products (separating personal computer desktop environment from the physical machine using component), due to the inability to virtualise the Graphic Processing Unit (GPU), which would have led to a slower performance.

The model for GPU computing is to use a Computer Processing Unit (CPU) together in a heterogeneous co-processing mode, meaning the sequential part of the applications run on the CPU (physical machine) and the computationally intensive part is accelerated by the GPU.

France’s solution to constantly refreshing laptops with more software capabilities was to use a hybrid approach, turning a single-user workstation into a multi-user workstation (workstation server). To the end-users, it represented virtualisation and it was private cloud computing-based; to the ICT staff it was a piece of shared hardware that enabled 10 people to share this workstation. Figure 3.5 shows the implementation of the virtualised High Performance Graphical Workstations (HPGWs). By changing to cloud computing; France’s firm (of 225 people) can now provide design services on 20 HPGW cloud computers and the workstations will not need to be refreshed every two years. The result of this action will mean most of the computing load will be moved off the laptops, estimating a cost of $1m over 10 years, in contrast to $3m due to purchasing desktop hardware for the same period

3.9 CONCLUSION

In order for the construction industry to be able to embrace interoperability it will require the use of standardized exchange mechanisms that are usable and accessible by all disciplines. Currently IFCs are viewed as the main open standards for exchanging BIM data. However, the implementation of IFC object models to enhance the exchanging of shared data with a model server has delayed the speed of exchanging information. There is little guidance or incentive to assure vendors that their applications are similar to other vendors. In the previous chapter cloud computing as ‘a network platform’ was identified as a vehicle for enabling collaboration via Web technologies. Web services have the ability to support SOA and GIS technologies through WFS and have successfully exchanged BIM data. The combination of using BIM and cloud computing to support early design and production tasks provides a system for allowing multiple types of experts to have accessibility to various different applications simultaneously. The case study ‘High Performance Graphical

Workstations' highlighted the economical, real-time collaboration and mobility benefits of using 'Cloud BIM.'

Begley et al. (2005) identifies that XML a meta-mark language (provides data on how that markup is structured) which was designed to be easy to learn, write and implement; it is the exchanging language of the WWW. The approach of using the internet to access pertinent BIM data, enabling model views to be shared in discrete chucks; provides a more convenient process for exchanging data. In a similar anology, the ifcXML and AEX centrifugal test demonstrated the difference between the schemas' structures. The AEX schema contains much more detail than the IFC related XML, however, the AEX schema only focuses on technical information in contrast to ifcXML which provides information on a whole building. The prospect of retrieving information only, as one requires it would enable an easier exchange of information for all the parties involved. The need for IFC subsets has been documented in this chapter, with reference to business objects, known as flat business objects. The traditional approach of using complex object-relational mapping tools can be superseded, by exchanging information by using documents in one's application and document storage. Beetz and de Veries highlight the problems associated with recognised standard concept definitions to regulate the use of taxonomies modelled with IFD and proposed a system architecture based on four hierarchical meta-modelling layers. The use of this system would promote classifications such as Omniclass, Uniformat and Masterformat while retrieving library data via RDF and OWL.

Upon reviewing the literature, the author accepts that the construction industry needs to review the diversity of SML in order, to escape from complex exchange structures and the subsequent barriers that exist. There is a need to examine current exchange mechanisms, in order to create faster exchange methods by extracting only the required data needed at a specific stage. The prospect of utilising GIS and BIM file exchanges through Web services built upon a SOA platform can enhance the capabilities of a semantic Web. Future chapters will seek to present such a re-engineered interoperable solution that will allow an integration of applications on such a common platform.

Author's key findings in relation to the thesis objectives:

Objective 1: To describe the importance of design interoperability for BIM software through a Cloud BIM – Figure 3.2 BIM relationships, shows the facility life cycle exchanging data ontology of IFD which is used to connect IFC objects for implementing BIM software. The capabilities of combining both vehicles cloud computing and BIM relates to their unique similarities in having standards for data interchange and modular interactivity through object oriented architecture (similar to the manufacturing industry).

Objective 2: To discuss how cloud computing and BIM can support the future development of interoperable software - The high performance graphical workstation desktop case study; France (2010) highlighted the productivity benefits of a SME changing to cloud computing where the use of 20 HPGW cloud computers resulted with most of the computer load being moved off laptops (meaning they will not have to be refreshed every two years) estimating a spending cost of $1m over 10 years in contrast to $3m due to purchasing desktop hardware for the same period.

Objective 3: To investigate the potential of cloud computing and BIM in re-engineering early design processes – In this chapter Josuttis (2007) recognised the capabilities of Web servers and SOA as a simple and fast way to provide access to data or resources. Stair et al (2008) emphasized that the main contribution of APIs is its ability to link application software to the OS. In section 3.6 Nour (2009) and Begley et al (2005) highlighted the issues of not having to reference attributes to other objects or any inheritance classes. La Query (1999) identified how a subset of XML allows developers to retrieve only the information that they required through relational databases. Figure 3.4 identified an overall architecture based on the concept of being able to exchange shared data with a central data repository using a simple and flat database structure. Begley et al (2005) highlighted that IFCs are not able to use aggregated composite classes to retrieve basic information that one would need for example; not having to go through the hierarchy of classes to obtain the section of code that is required.

Objective 5: To identify the need for agreed information architecture framework that will create an interoperable layer of business processes - Anderson (2007) recognised that APIs have assisted Web 2.0 in creating an interoperable layer by facilitating the creation of mash-ups of data from various sources by providing mechanisms for programmers to make use of the functionality of a set of modules without having access to the source code. Also in section 3.4.1 AECOO-1 Testbed had an objective to create standards that would allow software providers to streamline communications during the design phase (the process involved IDMs and MVDs).

PART 2:

EXAMINING THE NEED FOR AN AGREED ARCHITECTURE-BASED INTEROPERABLE LAYER FOR EXCHANGING INFORMATION BETWEEN HETEROGENEOUS SOFTWARE PACKAGES

CHAPTER 4

METHODOLOGY 'TRIANGULATION OF DATA'

4.1 INTRODUCTION

Brause (2000) identifies that the exemplary studies of research should provide sufficient information to enable a reader of the study to envision all the steps which the researcher followed. Brause highlights the significance of the data which are informing the study and the procedures used to analyse this data, thus transforming separate pieces of information into a cohesive response to the research questions.

This chapter will clearly identify the structure of the methodology used to research the aim of the thesis ‘to design and test a prototype for exchanging partial sets of BIM information on a cloud-based service that will advance key decisions at an early design stage through faster information exchanges and best practices during collaborative work’ and the objectives identified in Chapter 1. The four stages of the research structure, (i) philosophical orientation, (ii) theory and practice, (iii) formalising domain knowledge, and (iv) applying the strategic framework to a case study, are individually analysed except for ‘theory and practice.’ Theoretical propositions were used throughout the methodology to take in to consideration the previous research results.

Sun and Howard (2004) refer to *data* as collections of facts, measurements or statistics, *information* as organised or processed data that is timely and accurate, and *knowledge* as information that is contextual, relevant and actionable. None of the techniques used for this methodology can be accredited to quantitative research alone. However, the majority of the research was measurable; for example; the surveys collected ordinal data through ranking the categories, in order to obtain relevant information.

The main emphasis of this chapter is to highlight the structure of the various techniques used to develop a business vision (core values – innovation, core purpose – direction of a firm and their visionary goals – targets), identify a process to be designed, and the measurement of an existing process, in order to be re-engineered (to develop a prototype, of a cloud platform for advancing interoperability between BIM Web service software and to test it on a real case study). This chapter identifies the structure of an evolving methodology, based on several survey techniques (triangulation of data); in investigating into how to integrate a process based on exchanging information through the vehicles identified in Chapter 2 and 3.

4.2 THE SURVEY STRATEGY

The methodology involved a series of phases relating to grounded theory, a process of discovery by developing theoretical propositions for interview data and field research. The full hybrid methodology is illustrated in Figure 4.1 and is based on a cross method of triangulation involving both quantitative and qualitative data collection derived from a series of surveys techniques; a main survey questionnaire, focus groups, two Delphi questionnaires, structured interviews and a case study.

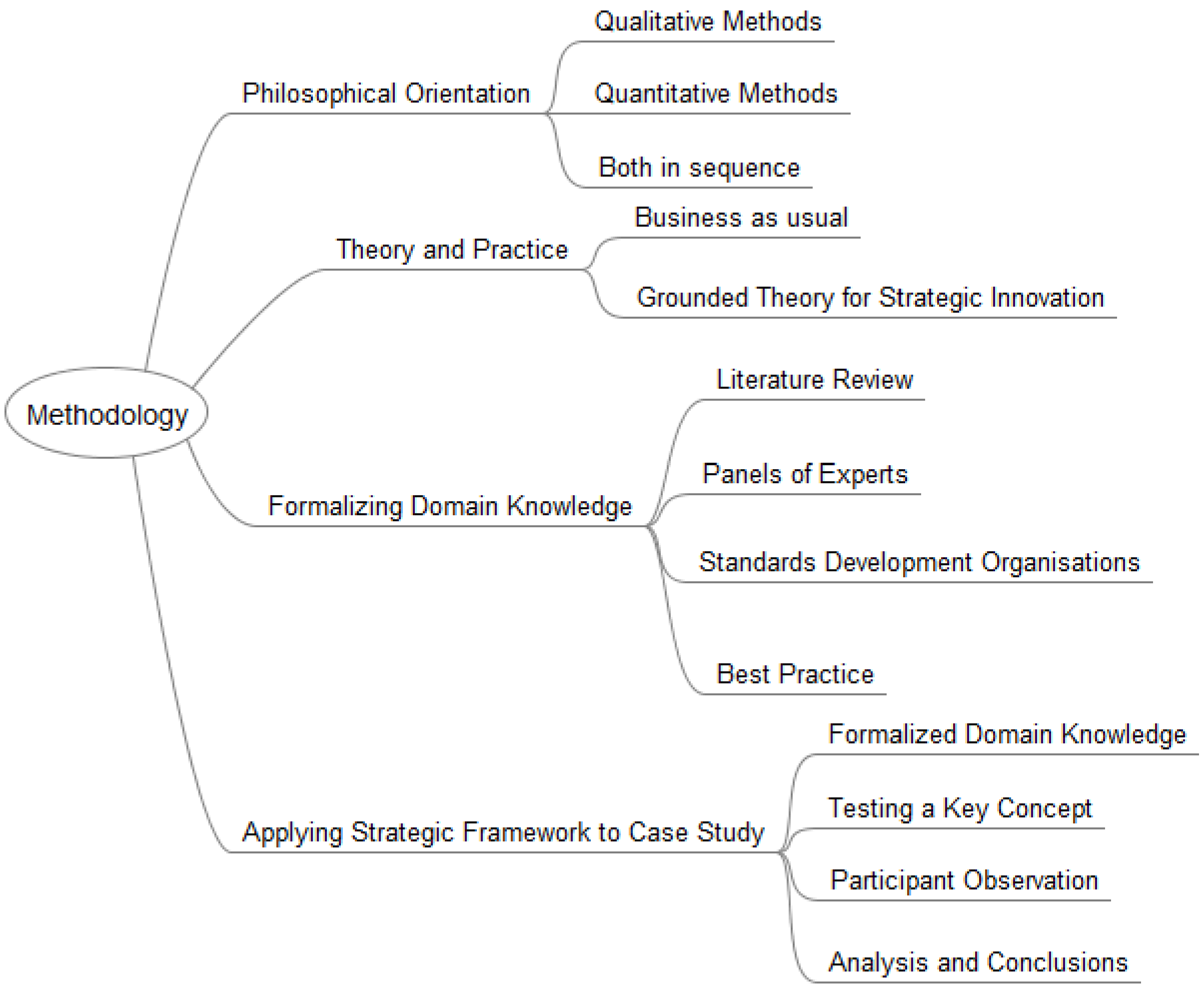


Figure 4.1. Formal belief network – knowledge mapping process

4.3 METHODS OF RESEARCH

4.3.1 Triangulation

The process of triangulation is used by both quantitative and qualitative researchers. It is a method that involves making observations from multiple positions (Neuman, 2003). There are several types of triangulation and the most common type is triangulation of measures. In this instance, by measuring something in more than one way, one is more likely to see all aspects of it. This is how the entire methodology of the overall research strategy was undertaken as multiple research strategies were incorporated. The overall objective of the research was to test a prototype's ability to freely exchange information data between various enterprises on a cloud platform.

Combined Methods

One of the benefits of using both quantitative and qualitative methods is that it enables the author to gather measured data needed to identify key problems, as they have been defined, and ask critical theoretical questions, such as, who benefits from the potential solution (exchanging information freely). In mixing both methods the survey provided specific data described in words relating to the concrete actions of the enterprises being studied (qualitative research) and data in the form of numbers representing precise measurement (quantitative research).

The idea of combining various methods is addressed in Hurmerinta-Peltomaki and Nummela (2004) who identify that it is commonly assumed, that if methods are mixed, the main one is quantitative and the qualitative results are supplementary and somehow subordinate. However, Peltomaki and Nummela acknowledged that a growing number of studies in the field of international business confirm that there are alternative ways of using mixed methods. The controversial topic of 'To mix or not to mix' is analysed in significant detail by Peltomaki and Nummela through citing various other researchers, such as, Patton (1990) who distinguishes between the characteristic of these diverse schools by viewing them as both philosophical and methodological. To the purist, methodological decisions are not made in isolation but are related to assumptions of the phenomenon itself (ontology), the basis of the knowledge (epistemology) and the relationship between human beings and their environment (Burrell and Morgan 1979). In view of this, Peltomaki and Nummela acknowledges that with a positivist/objective approach, the methods and values (facts obtained) of the research are bound to relate to quantitative methods while with a constructivist/subjectivist approach the research in question will be more hermeneutic (that is, interpretive) requiring the use of qualitative methods. Also within the same theme; Tashakkori and Teddlie (1998) state that purists also argue that compatibility between quantitative and qualitative methods is impossible because of the underlying different paradigms. On the other hand pragmatists argue that researchers should use both paradigms effectively, in order to increase their understanding of the phenomenon in question. After exhaustively analysing the various debates Hurmerinta-Peltomaki and Nummela conclude that, in their opinion, researchers should take advantage of the possibilities of mixed methods, in order to increase their understanding of the subject matter. Table 4.1 illustrates the differences between quantitative and qualitative research.

QUANTITATIVE RESEARCH	QUALITATIVE RESEARCH
Test hypothesis that the researcher begins with.	Capture and discover meaning once the researcher becomes immersed in the data.
Concepts are in the form of distinct variables.	Concepts are in the form of themes, motifs, generalisations and taxonomies.
Measures are systematically created before data collection and are standardised.	Measures are created in an ad hoc manner and are often specific to the individual setting or researcher.
Data are in the form of numbers from precise measurement.	Data are in the form of words and images from documents, observations, and transcripts.
Theory is largely casual and is deductive.	Theory can be casual or non-casual and is often inductive.
Procedures are standard and replication is assumed.	Research procedures are particular and replication is very rare.
Analysis proceeds by using statistics, tables, or charts and discussing how what they show relates to hypotheses.	Analysis proceeds by extracting themes or generalisation from evidence and organising data to present a coherent, consistent picture.

Table 4.1. Quantitative research versus qualitative research (Sourced from Neuman, 2003)

Linear and Nonlinear Paths

According to Neuman (2003), general quantitative researchers follow a more linear path than qualitative researchers. A linear research path follows a fixed sequence of steps; it is a way of thinking and a way of approaching issues directly. Qualitative research is more nonlinear and cyclical; it does not follow a rigid sequence of events but makes successive passes through steps. With each cycle or repetition, a researcher collects new data and gains new insights. In respect to the main survey in Chapter 5 the quantitative aspect was the dominant paradigm. However, the qualitative attributes were not used just as a source of pre-understanding. The local respondents identified in the main survey contributed to the focus groups in Chapter 5 and, likewise, some of the international respondents in the Delphi questionnaire in Chapter 6 were previously used in the main survey. The ideology associated with this approach is that the respondents answer the open-ended questions with a significant amount of detail.

Sampling

Neuman also highlighted that quantitative researchers are more concerned about the survey design, measurement and sampling because their deductive approach (thinking about a theory before confirmation) necessitates detailed planning, prior to data collection and analysis. This concept is valid in regards to the design of the main survey, as its technocratic perspective (research questions originated from the sponsor Construction IT Alliance, CITA) fits with positivism, following a structured path. With the considerable amount of insight gained from the literature review, the main survey focused on questions that would discover and document generalisations oriented towards increasing efficiency within the construction industry. However, the main survey does not only consist of questions of variables to be measured with numbers and is analysed with statistical procedures, but also has an interpretive and critical approach. The main survey supposed open-ended attitudinal questions with the means of extracting raw data through an inductive approach (exploring various theoretical propositions before following a sequence of studies) subjectively analysing the opinions or perspectives of the enterprises towards their particular expectations of cloud computing.

McDaniel and Gates (2002) emphasise that the concept of sampling in marketing research refers to the process of obtaining information from a subset (a sample) of a larger group (population or universe) from which the results of the sample are characteristics of a larger group. McDaniel and Gates are of the opinion that small percentages of a population can result in very accurate estimates, as larger surveys tend not to be as vigorously analysed due to the volumes of data. At the time of conducting this research the construction industry in Ireland was reporting a high unprecedented number of insolvency cases which presented a difficulty in establishing a registered sample. However, CITA's Enterprise Innovation Network (EIN) program had a registry of 50 members with an ICT background.

Summary

The philosophical orientation of the research will use both quantitative and qualitative methods in order to test the marketing decision-taking process. The quantitative analysis rely on collecting factual evidence, whereas the qualitative approach ascertained both exploratory (when one has limited amount of knowledge on a topic) and attitudinal research (subjectively evaluating the opinion, view or the perception of a person, towards a particular object) to obtain measurements of data.

4.4 FORMALISING THE DOMAIN KNOWLEDGE

4.4.1 Survey Questionnaire

Planning Phase

The planning phase of undertaking the questionnaire focused on three aspects:

1. Research questions.
2. Presentation of questionnaire.
3. Sample selection size.

Research questions

The aim of the survey was to collect data on the extent of use of cloud computing by Irish consumers and international vendors. However, the aim was also to act as a medium for identifying the benefits, barriers and drivers of implementing such a service. The structure of the survey followed the principles identified by Naoum (2007) which required the author to consider the following:

1. Which objective is the question related to?
2. Is the question relevant to the aim of the study?
3. Is the question relevant to the research abstract?
4. Can the answer be obtained from other sources?

In relation to the above questions, the information identified by analysing the literature review data influenced the types of question used in the surveys: ICT adoption, collaboration in the construction industry and cloud computing as a vehicle for sharing data more efficiently. The type of questions that were asked in the online survey featured similar business analysis strategies to SIIA (2001) such as, the technical and marketing issues. The ability of an online questionnaire to target a large sample in a short period of time, in order to obtain a business vision was the rationale behind using this technique.

The survey focused on a sample of two groups for comparison reasons; (i) vendors and (ii) customers of ICT applications. By selecting these two groups, a sample of the market's attitude would be obtained in relation to the need for cloud computing. The layouts of both questionnaires were similar, except for the rewording of some questions because the concept of designing and marketing a service is obviously different between sales, purchasing and using. The overall aim of the questionnaire was to investigate the construction markets '*business vision*' towards cloud computing. The structure of the questionnaire is as follows:

(i) Business strategy
(ii) Drivers, barriers and benefits of cloud computing
(iii) Business model (as part of the business strategy to capture value)
(iv) Market requirements

Consumer's Questions: The 'business strategy' questions queried the respondents attitudes towards purchasing software and their expected use of ICT in the next three years. The purpose behind these questions was to establish the market conditions for cloud computing. In identifying the most popular types of software being used in the marketplace, the survey would assist in selecting the main applications that might be included on the cloud platform and which lesser-known applications would have the potential to be deployed. The questioning of the management's purchasing strategy towards software is essential in understanding how the market would view the potential gains of using this service. This section of the questionnaire was also intended to investigate if there was a market for cloud applications or are companies content with their current software collection.

The 'drivers' of cloud computing (extracted from the literature review) presented to the sample included the ability to pay per user per month, the ability to access applications through the Internet anywhere in the world, and total cost (including maintenance fees). The 'barriers' included knowledge about construction cloud applications, security concerns in relation to data storage and lack of knowledge of actual services required. The purpose of examining the barriers and drivers was to assist the author in identifying the current views of the market to be structured into topics for future consideration. The 'benefits' presented focused mainly on material such as, that provided by Ramanujam (2007), as highlighted in Chapter 2.

The 'business model' questions examined the attitudes of the respondents interested in renting cloud applications and the various choices preferred in receiving a cloud service. The first question on renting options was derived from other industry models identified from Chapter 2. The purpose of the next question was focused on the needs of receiving the service, in order to recognise the required infrastructure.

The ‘market requirements question was a single open-ended question phrased to solicit the respondent’s perception of cloud computing in the Irish construction sector. This question was deliberately placed at the end of the survey to summarise the attitude of the respondents to cloud computing. As with all fully open-ended questions, it allows for positive and negative views to be expressed. Establishing the market need and interest for forming a cloud service in the Irish construction industry was the predominate purpose of this question.

Vendors Questions: The structures of both questionnaires were designed to be similar, in order to evaluate whether there is a strong relationship between the two samples. The principal difference was in the phrasing of the questions because vendors provide applications this was taken into consideration when structuring the difference between marketing and purchase type questions.

<u>The questionnaire</u>

The survey was an online questionnaire and registered with Survey Methods a host for surveys (http://www.surveymethods.com). The tools associated with this open-source software allows one to design and launch the survey, create an opening email letter to accompany it and to manage and analyse the results. The preferred option for distributing the online survey was via an identified URL Web address. This method sent an email with an invitation letter and an URL address attached to allow recipients to activate the survey. This mechanism allowed all the interviewee’s to be contacted easily and prompted rapid responses. A copy of the invitation letter and survey is included in Appendix A.

<u>Sample selection and size</u>

The screening criteria focused on international vendor enterprises, with their particular characteristics known, such as, background, size of company and type of work (non-random sampling) and firms based in Ireland that were consumers of AEC computer applications. The survey reflecting the vendors may be considered partially biased because their profiles were known. The selection criteria for the vendor were based on a software directory produced by the author for CITA. This platform acted as a screening mechanism that highlighted to the Irish construction industry the various software vendors and products available to both the domestic and international market. However, as the concept of cloud computing was relatively new to the construction industry; it is anticipated that this selection would have best represented vendors because their attitudes would have deemed to be similar to the majority of vendors within the industry at that time.

The survey's main target was high positioned respondents; for example, directors / managers (decision makers) from AEC companies and vendors. Israel (1992) highlighted that, in order for the sample size to be a true reflection of the market; the chosen population would need to be a similar size to a previous proven sample on the same environment. The author deemed the 90 respondents as being an adequate number in comparison to a similar conducted study of 100 contractors and suppliers in ICT (Hore and West, 2005b).

The main survey sample of 90 respondents represented a mixture of non-random (40 vendors) and probability (random) sampling (50 customers). The customers represented various backgrounds, such as professional architects, surveyors, contractors and engineers. The vendors were selected based on their profile; size, application type, geographical position; for example; North America, Europe, and Australia. The main themes of the research survey were the drivers, barriers, and benefits of this new phenomenon 'Cloud Computing' (Hore et al. 2010, and Redmond et al. 2010).

Structure of the Survey

The survey was the initial method used for identifying the market's attitude on cloud computing. The majority of the individual questions in the survey were designed to have elements of both quantitative and qualitative type questions. The purpose behind the close-ended question was to retrieve quantitative data (factual evidence), such as, identifying the most popular types of software currently being used in the marketplace. Open-ended questions were also used, such as requesting the respondents to rank the highest barriers and drivers associated with cloud computing.

In reference to Figure 4.2, the partially open and closed ended questions were integrated into the questionnaires by using a checklist system. A Likert scale (a form of opinion-type question featuring attitudes) was also introduced. This form of subjective measurement is based on an attitudinal response of the respondent ranging from one extreme to another. For example, in relation to the benefits of cloud computing, the respondents were asked to indicate their position in relation to attitudinal statements ranking from strongly agree to strongly disagree.

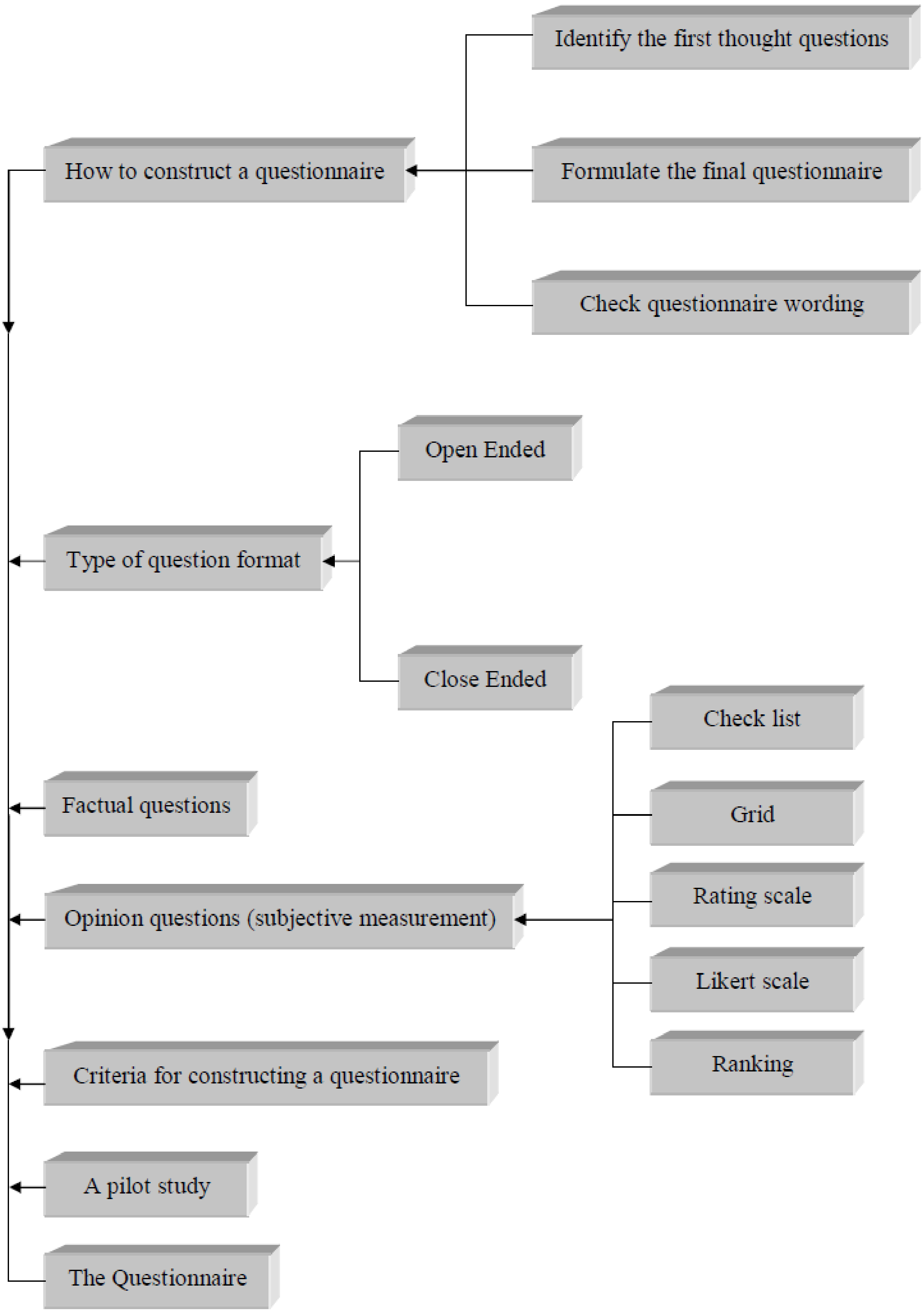


Figure 4.2. Questionnaire structure (Adapted from Naoum, 2007)

Groat and Wang (2002) identify seven general considerations to be referred to when designing a survey questionnaire. Table 4.2 illustrates the comparisons of the author's research with those of Groat and Wang.

General Considerations	Author's Research
1. Goals: Determine main topics to be covered. Clarify the purpose of each question.	Topic were: Demographic characteristics. Marketing Strategy. Management's philosophy. Methods of using and retailing cloud computing.
2. Response formats: Evaluate advantages of closed versus open-ended format.	Majority of demographic and marketing strategy questions used closed-ended format. Management philosophy and methods incorporated a combination of both.
3. Clarify in Phrasing the Questions: Use short sentences. Avoid making two queries in a single question. Avoid framing questions	Reviewed question design with others knowledgeable in research and the respondent sample. Piloted questionnaire with CITA Enterprise Innovation Network members.
4. Question Order: Use logical sequence of topics. Start with interesting, non challenging issues. Don't place important items at the end of a long survey.	The sequence of the questionnaires follow an adaption of introducing cloud computing and its potential to the market place.
5. Format: Use appealing, but simple graphics. Avoid prominent or flashy design.	Simple and user friendly design.
6. Format: Explain reasoning, context for survey. Provide description(s) of what respondents expected to do. Explain where respondents turn in survey.	Introductory explanation provided. Surveys were delivered via email. Survey conducted on line No issue with respondents returning survey.
7. Ethics: State provision for keeping individual responses confidential.	Statement of confidentiality provided. Survey submitted to Institute's graduate research school review board.

Table 4.2. Considerations in the design of a survey questionnaire (Adapted from Groat and Wang, 2002)

<u>Pilot questionnaire</u>

The dominant objective of the pilot survey was to act as a rehearsal for the main survey with the notion that a focus group would be formed from carrying out such an exercise. In relation to the pilot survey contributing to the main survey, the respondents were requested to check that the questionnaire was adequate and, if not, the respondents had the opportunity to state their reasons. Table 4.3 summaries the constructive criticism of the responses to the seven additional questions that were attached to the questionnaires. The pilot responses enabled the author to revise the questionnaires, such that it would be ready for the survey's main distribution.

	Question	Summary of Responses
1.	How long did it take to complete?	On average between 20 – 30 minutes. Deemed to be considered too long.
2.	Where the instructions clear?	The instructions were deemed to be clear for the majority of the questions. The exception was the ranking questions as the instructions did not state that a number could only be inserted once. This caused some confusion and if not corrected the respondents could not continue to the next stage of the questionnaire.
3.	Where any of the questions unclear or ambiguous? If so, which questions and why?	Too many of the questions were deemed to be similar to each other. The questions relating to ranking from one to ten with one being the highest was not an issue for the respondents but it did cause confusion when analysing the graphs. Generally ten being the higher number would indicate a more graphical indication on the graphs.
4.	Did you object to answering any of the questions?	The majority of the respondents did not object to answering the questions but when analysing the questionnaires a significant amount of the open-ended questions were not attempted.
5.	In your opinion, has any major topic been omitted?	As the title of the questionnaires and the invitation letter clearly indicated that the survey was based on the topic of cloud computing the majority of the respondents stated no to this question.
6.	Was the layout of the questionnaire clear/attractive?	All respondents were satisfied with the layout.
7.	Any further comments?	The question relating to the benefit of cloud computing did not necessarily signify construction benefits. And as the majority of the respondents had never heard of cloud computing applications for construction it was essential that the statements reflect construction issues.

Table 4.3. Summary of responses to pilot questionnaire for the online survey

4.4.2 Focus Groups

According to Goodwin (2009), focus groups can be informative if one is just starting out and want to get quick feedback about whether a product idea is viable. Sayre (2001) viewed focus groups as the most popular form of qualitative research, preferred over other data collection methods because of their ability to address a client's specific problem in a timely fashion. Sayre expressed that, in general terms, formal focus groups range in size from 9 to 13 participants.

The role of the focus group was to work in connection with the results of the main survey in investigating if a cloud process was required. It was anticipated that by using focus groups to analyse information, attitudes and beliefs in relation to the construction software marketplace, a pattern would form demonstrating whether or not there was the need for a new innovative service in this sector. Alternatively, the results could have indicated that there was no verification needed for this service's (cloud computing) significance. However, the process itself was viewed as a technique to provide an understanding of whether social agreement could be interpreted to generate new ideas. The results of the main survey prompted the establishment of the focus group comprising of 10 vendors in the Irish construction-marketplace; digital safety file service, building energy rating directory, eTendering solutions, IT vendor directory, software support services, cloud software provider, database provider, project management planning & scheduling software supplier, building software solutions provider and smart builder software provider . They analysed various issues, such as, security concerns relating to data being stored outside Europe and the potential to develop a hybrid cloud (mixture of both public and private) for the group.

The author acted as the facilitator for this group, setting the agenda, minuting the meetings and formulating the results of the discussions. Three focus group meetings were held on a monthly basis. The online software used to analyse the discussions of the recorded meetings was NVivo (www.qsrinternational.com/products_nvivo.aspx). The software provided a storage domain for inserting the minutes of the meetings. The software's main attribute is its ability to link meetings, for example, if the same topic had arisen several times then a comparison link would be identified and graphically the software allows the users to highlight it.

4.4.3 Delphi Technique

The Delphi technique is in essence a series of sequential questionnaires, interspersed by controlled feedback, that seek to gain the most reliable consensus of opinion of a group of experts (Linstone and Turoff 1975). Wissema (1982) underlines the importance of the Delphi method as an exploration technique for technology forecasting. Wissema further acknowledges that the Delphi method has been developed, in order to make topical discussions between experts possible without permitting a certain type of social interactive behaviour (influencing the results), as happens during a normal group discussion and hinders opinion forming. Powell (2003) suggests that the Delphi technique represents expert opinion, rather than indisputable fact and that further inquiry to validate the findings may be important. The structure of the questionnaires in Chapter 6 was also designed to evaluate whether there is a strong relationship between the groups of experts.

Weinstein (1993) identified that there are two types of experts: those whose expertise is a function of what they know (epistemic expertise), or what they do (performative expertise). Weinstein describes epistemic expertise as the capacity to provide justifications for a range of propositions in a domain while, performative expertise is the capacity to perform a skill in accordance to the rules and virtues of a practice. The experts selected for this research surveys are a mixture of both epistemic and performative. They are of senior position, in an established firm or institute relating to construction and ICT. The author used his position as member of buildingSmart Alliance (North America chapter) to connect with these experts. The experts were given full anonymity to their proceedings (such as a disclosure to prevent their identity known outside of the group). The series of Delphi questionnaires undertaken in 2010 were used to establish the necessity for a cloud computing collaborative system based on a common database for the construction industry and to identify topics that would be used to form questions for the next form of research.

This Delphi questionnaire forms part of the primary research based on 'Grounded Theorism' which was used to identify and categorize elements of cloud computing in the construction industry. Sayre (2001) views 'grounded theory' as a model of using modes of questioning to develop theories, rather than to study them, as a process whereby discovery by developing theoretical propositions from interview data and field research, often accompanied by establishing categories, refining them, and revisiting the questions repeatedly until specific propositions are developed for future testing.

Structure of the Delphi Questionnaire

The Delphi questionnaire was divided into three sections; namely; business process, cloud computing capabilities and cloud business opportunities, based on refining the results of a 2009 survey (reference by 'Building Support for Cloud Computing in the Irish Construction Industry,' Redmond et al. 2011a). Within each of these segments were questions designed to analyse the potential for developing a cloud service based on combining three individual applications, BIM, project management and accountancy. The format of the actual questions was similar to the main survey online questionnaire as illustrated in Figure 4.2. The majority of the questions were either Likert scale or ranking. The Likert scale questions consisted of attitudinal statements on the survey topic. The responses would range from strongly agree, agree, no opinion, disagree or strongly disagree. The ranking system used a similar structure, based on scaling from 1 to 5 (1 being the highest). Each of these questions always featured an open-end section to clarify the respondent's view and the questionnaire also featured entirely open-ended questions. The panel comprised of residents based in the United States (U.S.) (50% - 8 respondents), UK (34% - 6 respondents), and Australia and France both represented by an individual (16% - 2 respondents) totalling 16 experts. The questionnaire's ultimate aim was to allow an analysis of the potential to develop a cloud service based on combining individual essential applications, BIM, project management and accountancy, to demonstrate the interoperability capabilities of cloud computing.

The formatting of a second Delphi questionnaire was based on compiling the results of the initial questionnaire and structuring the questions based on these results. The layout of the questionnaire was similar to the initial Delphi questionnaire as the idea was to capture the same interviewees but to focus more in-depth on their original answers (Redmond et al. 2011b). The panel comprised of residents based in the U.S. (50% - 7 respondents), UK (36% - 5 respondents), with Australia and France both represented by an individual (14% - 2 respondents) totalling 14 experts. The experts were from varied backgrounds such as the following:

- Provider of online collaboration software for the construction, property and energy sectors..
- Computer-Aided Design Developers of Three-Dimensional Objects.
- Building cost information services.
- Building Smart Alliance Council of The National Institute of Building Sciences.
- Global software provider to support the complete life cycle of the built environment.
- Integrated Project Delivery procurement strategies consultant.
- Lecturer, School of Urban Development, Faculty of Built Environment and Engineering, Queensland University of Technology, Brisbane, Australia.
- Cloud Business Management Software Suite Vendor.
- Engineering technology and software market research firm.
- Professor of Construction Economics and chair in construction economics at the Northumbria University.
- Professor Emeritus Civil and Environmental Engineering Stanford University
- CSTB (Centre Scientifique et Technique du Bâtiment) public research establishment in the construction sector.
- Program Manager, Emerging Technologies and SWG Standards at IBM Canada.
- Cloud computing vendor for AEC, video game design, motion graphics.
- Team of architects and computer programmers developing Cloud BIM tools.
- Chairman of the UK government's BIM group.

There were no new experts added from the previous questionnaire; however, two experts declined from further involvement in the second study.

Presentation of the Delphi questionnaires

The Delphi questionnaires used the same techniques as before to contact the interviewees, however the online survey method used was surveymonkey (http://www.surveymonkey.com). The online process of targeting and analysing respondents contributed significantly to the rapid consecutive data collected from each of the Delphi techniques. A copy of the two Delphi Questionnaires and invitation letters can be located in Appendix B.

4.4.4 Structured interviews

Belson (1986); as cited by Foddy (1993); identifies that the principal causes of error in the gathering of data through surveys are:

a) respondents' failure to understand questions as intended;
b) a lack of effort, or interest, on the part of respondents;
c) respondents' unwillingness to admit to certain attitudes or behaviours;
d) the failure of respondents' memory or comprehension processes in the stressed conditions of the interview; and
e) interviewer failures of various kinds (e.g. the tendency to change wording, failures in presentation procedures and the adoption of facility recording procedures.

Foddy also acknowledges the advantages of using auxiliary questions to extract answers that lead to investigating more detailed aspects of the topic and the use of cross-cutting questions to assist the respondent in relating to the overall topic of the survey. Semi-structured interviews are quite similar to structured interviews, as the questions are structured and the interviewer maintains full control. However, it is focused on respondents with experiences regarding the questions being investigated. Prior to conducting the interviews, all of the 11 expert respondents were given a short passage highlighting the topic of each question. The original 19 questions were divided into 6 sections based on results gathered from the previous survey techniques and formulated in a cross-cutting style; for example, identifying interoperable software before analysing information exchanges.

Structure of the semi-structured interviews

The overall methodology had been constantly evolving depending on the results of each stage. The semi-structured interviews were the final stage of the research and the aim was to build on the results of the previous main survey, focus groups and Delphi questionnaires. The goal was to explore how to apply an integrated process that would enable faster information exchanges and best practices during collaborative work that can readily be transferred to project teams using Cloud BIM software. To expedite this goal, 5 main objectives were defined (i) To explore advancing interoperability for BIM software, (ii) To identify the various contractual issues associated with implementing Cloud BIM in a construction project, (iii) To discuss how BIM cloud-based services can benefit early design feasibility studies, such as, the adoption of new technology and the need to restructure business process work flows, (iv) To examine the need for an agreed architecture that will create an interoperable layer for exchanging data, common to a building project, that requires information exchange between specialised software packages, and (v) To explore the possibility of developing a prototype for exchanging information based on three software programs that would lead to advancing interoperability of BIM applications (Redmond et al. 2012).

Presentation of the semi-structured interviews

The semi-structured interviews were a compilation of features that included an invitation letter in the form of a 'semi-structured interview schedule,' a research participation consent form, and finally the 'interview questions.' The consent form included a series of statements relating to ethics. The statements requested the interviewee to agree to the interview being digitally recorded. The invitation letter highlighted the aim and objectives of the research interview, how the interview will be conducted and the potential benefit the semi-structured interview will have on developing a prototype. The final document containing the questions identified the outline of the particular sections relating to the questions.

The experts chosen for this survey are a mixture of either or both epistemic and performative. The interviewees comprised of three respondents in Ireland, six based in the UK, one based in the United States of America, and one from Croatia. All respondents were known to have a strong association with BIM, and or Cloud Computing. The group consisted of interviewees from firms that were internationally recognised and all participants were either CEO, Partner or Director of their respective firms. In categorising the representative's affiliations, there were two construction companies, one consulting engineering firm, one consulting environmental engineering firm, one architect firm known to practice BIM, one 4D Simulation software vendor, one cloud development company for construction, a Professor on digital architecture from the academic environment, one specialised software solution company, one automated building software development company and one Web-based BIM company.

A dictaphone was used to record the interviewees physically present and PowerGramo http://www.powergramo.com/ was used for the Skype interviews. After the interviews had been transcribed, the respondents were asked to return the content signed. Copies of all the associated documents for the semi-structured interviews forms are located in Appendix C.

4.5 APPLYING STRATEGIC FRAMEWORK TO CASE STUDY

4.5.1 BIMStorm

The objective of participating at BIMStorm (EcoBuild 2010) was to demonstrate the benefits of using a Cloud based BIM system to advance key decisions at an earlier stage through faster information exchanges between various design applications. By advancing the interoperability of these applications it would provide a design team with the necessary information to make key decisions, at a relatively early stage of the project i.e. the design phase. In reference to the Royal Institute of British Architects stages of design sequence this stage would be referred to as stage B 'Feasibility' at which the architect frequently finds it difficult to determine just how much the building client is prepared to spend and to reconcile the two major factors of cost and quality, which are so closely related (Seeley, 1996). The ecobuild America 2010 was a part of the NIBS annual meeting held in the Washington Convention Center, Washington D.C. 6 – 10 December 2010. BIMStorm is an event hosted by Onuma Systems that forms part of this conference. The author used this event as a catalyst to design his case study in order to test the ability of Onuma Systems BIM XML in exporting and importing Simplified XML files between various applications on a cloud platform.

The authors' case study's main objective was to define the software prototype requirements to transfer data between construction programs via Web services and Simplified XML. 'Grounded Theory' as a strategic innovation is used to identify and categorise components, in order, to explore their connections. Cloud computing was originally investigated and described in the literature review and analysed again in the main survey questionnaire. It was then revisited using 'qualitative methods,' such as, the Delphi technique and semi-structured interviews until a collaborative platform was identified 'Cloud BIM' for enhancing the exchanging of information with Simplified XML.

4.6 CONCLUSION

This chapter highlighted the structure of the evolving methodology used to investigate the first 3 parts of the BPR, (i) development of a business vision, (ii) identifying a process to be designed, and (iii) understanding and measuring an existing process for exchanging data. The overall methodology as illustrated in Figure 4.1 comprised of 4 major parts, philosophical orientation, theory and practice, formalizing domain knowledge, and applying a strategic framework to a case study. The 'philosophical orientation' approach identified the techniques used to undertake the various surveys, the 'triangulation of data' and compared the industry's view of the combined methods of 'quantitative and qualitative' approaches.

The 'formalizing of the domain knowledge' section examined the reasons for selecting each survey technique and how the data collected would be used for identifying a process for exchanging BIM information more efficiently and faster on a cloud platform. The various methods are analysed in their sequence of actual development to show why they were chosen and how they were presented. This process validates each section's linkage with the next. For example, the semi-structured interview questions were derived from the previous surveys. In identifying the format of the questionnaires the author used the initial survey, as a benchmark, to be compared with the industry's general conditions, such as, in Table 4.2 and Table 4.3.

The 'applying of the strategic framework to a case study' section involved testing the capabilities of an existing Cloud BIM file exchange method via direct participation. The previous surveys contributed to *identifying a business process and a process to be designed* 'Cloud BIM.' This section involved measuring an existing practice, in order, to redesign a business process model to meet the research objectives.

The following chapters within Part 2 will present the results of each of the individual surveys mentioned in this chapter. The main objective of these surveys was to enable the development of a prototype based on exchanging partial BIM data between applications using Cloud BIM.

Author's key findings in relation to the thesis objectives:

Objective 6: To measure the ability of advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform - Part 1 'Cloud computing & BIM' comprised of the two literature chapters that collectively reviewed both cloud computing and BIM. In a heuristic approach the following chapters were based on the information identified in these two chapters. Part 2 'Interoperable layer for exchanging information' had three prominent stages connected to the first three stages of BPR. Figure 4.1 'Formal belief network' in this chapter outlined the strategic plan for formalising the domain knowledge (converting information into knowledge) based on triangulation of data.

CHAPTER 5

TO INVESTIGATE THE USE OF CLOUD COMPUTING IN THE CONSTRUCTION INDUSTRY

5.1 INTRODUCTION

Cloud computing is a collective term that is used to describe ICTs ability to collaborate within a central repository that can act as a platform for interoperability between various construction interdisciplinary software applications through Web-based services. Cloud computing is a new layer of internet architecture that creates an opportunity to add standardisation to an increasingly global network. The characteristics of cloud computing, such as, shared infrastructure, on-demand applications, scalability and consumption-based costs, allow all disciplines in the sector to benefit.

Reeves (2009) classified the service models in reference to a tiered structure. The basic tier is Hardware Infrastructure as a Service (HIaaS): a virtual or physical hardware resource offered as a service, such as Amazon EC2 server. This is preceded by Software Infrastructure as a Service (SIaaS), a stand-alone cloud service that provides a specific application support capability, but not the entire application software platform service, such as Microsoft SQL data services. The next tier is Platform as a Service (PaaS) which is an externally managed application platform for building and operating applications and services, such as, Microsoft Azure and Force.com. The final tier is Software as a Service (SaaS): this is when a vendor designs the application and hosts it so that users can access the application through a Web browser or a Rich Internet Application (RIA) mechanism, such as Google Apps or Salesforce.com.

The objective of this chapter is to investigate if this Web-based infrastructure service, commonly known as 'cloud computing,' can support the future development of an interoperable software solution that will utilise the exchange benefits of Web services in the construction industry. This chapter will present the findings of an online survey carried out by 90 respondents (50 customers and 40 vendors). The main priority of the survey is to illustrate the drivers, barriers and benefits of cloud computing (relating to Avision and Fitzgerald (2003) key area of BPR 'developing a business vision') as a central repository vehicle for hosting and exchanging data. This chapter will identify the market need for such an infrastructure and highlight recommendations for cloud computing based on three focus group meetings to explore and discuss how BIM on a cloud platform can be offered, such as the adoption of Web-based architecture.

5.2 ONLINE SURVEY

The survey comprised of two samples types, customers and vendors, in the construction industry. The structures of both questionnaires were designed to be similar, in order to evaluate whether there was a strong relationship between the two samples. Beyer and

Holtzblatt (1998) alleged that for customer-centred design to be possible at all, the process needs to include techniques for learning about customers and how they operate. The survey attracted responses from a total of 90 customers and vendors from a mailing list of 100. All respondents were associated with decision-making positions within their company. A total of 50 customers, provided the highest number of responses, had backgrounds varied from general contractors, to professional architects, quantity surveyors, engineers, and third level institutions. The majority of the respondents were general contractors representing 18%, quantity surveyors 16%, architects 12%, and engineers 10%. The remaining respondents were of a dispersed representation of secondary disciplines health and safety analysts, software support, and building suppliers. The remaining 40 respondents represented vendors, ranging typically from construction related distributors of architect, engineering, or construction computing applications / services. There were however, 5 vendors that were affiliated to open source technology (allows people to access its source code, so that they can study, modify, and redistribute the source code, Beard and Kim, 2007) and cloud computing services. In comparison with the Hore and West (2005b) survey of over 100 Irish construction companies, this survey has achieved a significant response rate of 90% (in comparison with Hore and West) as the construction industry has declined by 23% since 2007 (Davis Langdon, PKS, 2010).

The survey primarily focused on establishing the extent of ICT up-take levels, the drivers, barriers, benefits and procurement aspects of cloud computing, in order to analyse the potential of creating a business case study for cloud computing in the construction industry. The business strategy aspect of the survey was to investigate the respondent's attitudes towards purchasing software and their predicted use of ICT in the next three years. This section was also to be used for categorising the software most used by construction SMEs (however, a large amount of the firms were larger than 250 employees) combined with the majority of the software packages distributed by vendors, which provides an indication of the preferred type of software to feature on a cloud platform. The driving forces identified the main attributes associated with attracting construction enterprises to the use of cloud computing. The barriers identified the industry's most common perceived causes for rejecting the adoption of a centralised heterogeneous network. The questions associated with the benefits of cloud computing acted as an investigative tool to allow analysis of whether a cloud-based model was suitable for the construction SME sector. The procurement questions related to the physical aspects of obtaining the services and identified the most suitable licensing option from a construction perspective.

5.3 ICT-UPTAKE

The purpose of this section of the survey was to investigate a firm's management strategy towards software and how the market views potential gains from future applications. The format of the questions in this section was based on the positivism approach of reasoning 'directed towards determining the actions.' The following sections analyse ICT uptake over the next three years and compares these results against market trends of SMEs. The philosophy of managerial decisions on adopting new products in relation to subsequent return on investment and economies of scale is investigated to highlight the marketing impact of developing software.

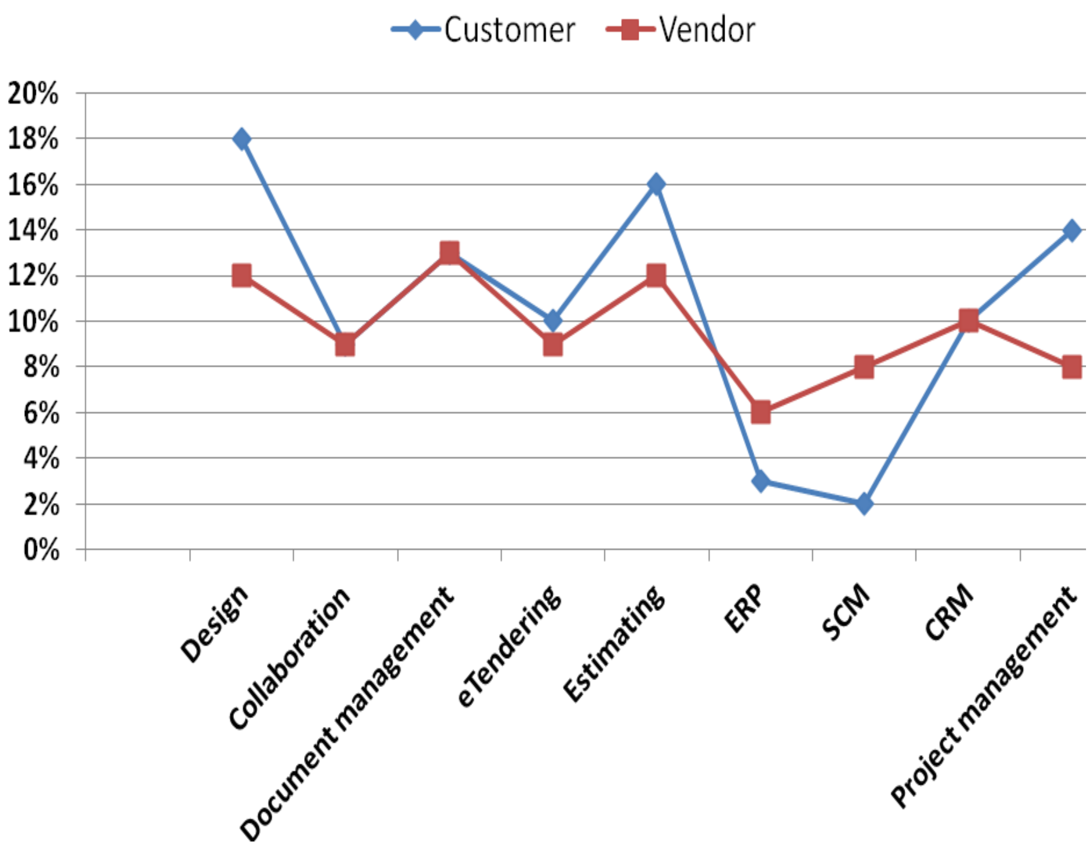
Summary of the results

In relation to ICT-Up take and identifying the market's future forecasts on growth, BIM/CAD, document management, estimating/costing, and project management are the main applications being used by the respondents (however, the majority of respondents were from an architectural background). The majority of the respondents think in terms of cost before purchasing software in comparison to Return of Investment (ROI) with a significant amount of vendors actually focusing on determining customer's needs before marketing.

Question: What category of software is mostly used by your firm, if other please specify?

This close-ended question provided the respondents with a list of nine software applications and requested the respondents to choose which application they used (customer) or distributed (vendor). The respondent was also given the opportunity to specify an alternative software application of their choice.

Figure 5.1 shows the combined respondent's totals for the software mostly used (customers) and distributed (vendors) in the construction industry. The main applications identified were, BIM/CAD, document management, estimating and costing, and project management. The open-ended section also led to a high response rate. However, the software indicated in this section was dispersed between accountancy, time management, and an energy rating directory. The BIM aspect of BIM/CAD referred to 3 dimensional drawings only in the questionnaire and resulted in a customer response of 18% and a vendor response of 12% preferring CAD to be in the cloud. The overall highest response average of 14% (16% customer and 12% vendor) was for cost estimating software.



ERP (Enterprise Resource Planning), SCM (Supply Chain Management), and CRM (Customer Resource Management)

Figure 5.1. Categories of software mostly used/distributed in response to the question:

What is the management's attitude towards new products which are currently available?

This close-ended question featured three statements to choose from namely; (i) management primarily thinks in terms of cost and maintenance fees of products before deciding whether they will make the firm more effective and efficient, (ii) management analyses the benefits of purchasing new software in terms of ROI rather than growth over a sustained period of time, and (iii) the company has an alternative approach.

Figure 5.2 shows that just over 50% of the customers sample thinks in terms of cost and maintenance fees of products before making a decision. In contrast, 26% of the respondents prefer to analyse the benefits of purchasing new software in terms of ROI rather than growth over a sustained period. A significant proportion of the results were allocated to an alternative approach, 'Business needs.' Figure 5.3 identifies both customer's (highlighted in blue) attitude on new products and products currently available and vendors' (highlighted in red) description of their firm's business philosophy.

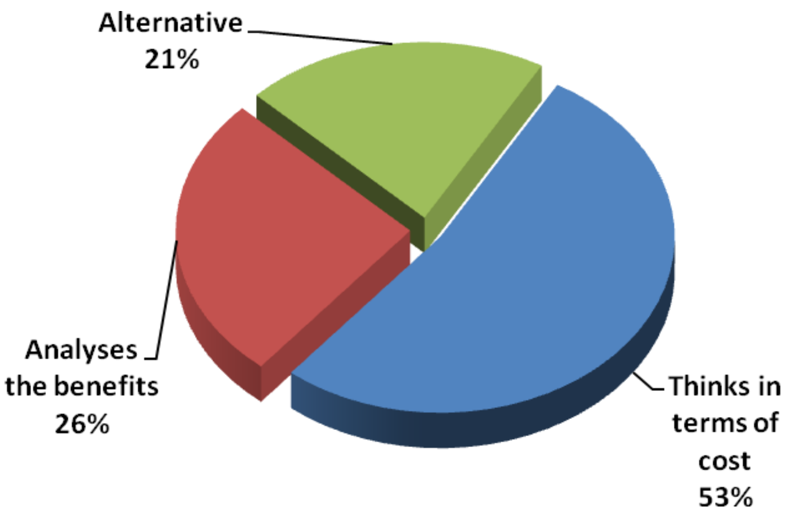


Figure 5.2. Management's attitude on new products and products currently available (customers)

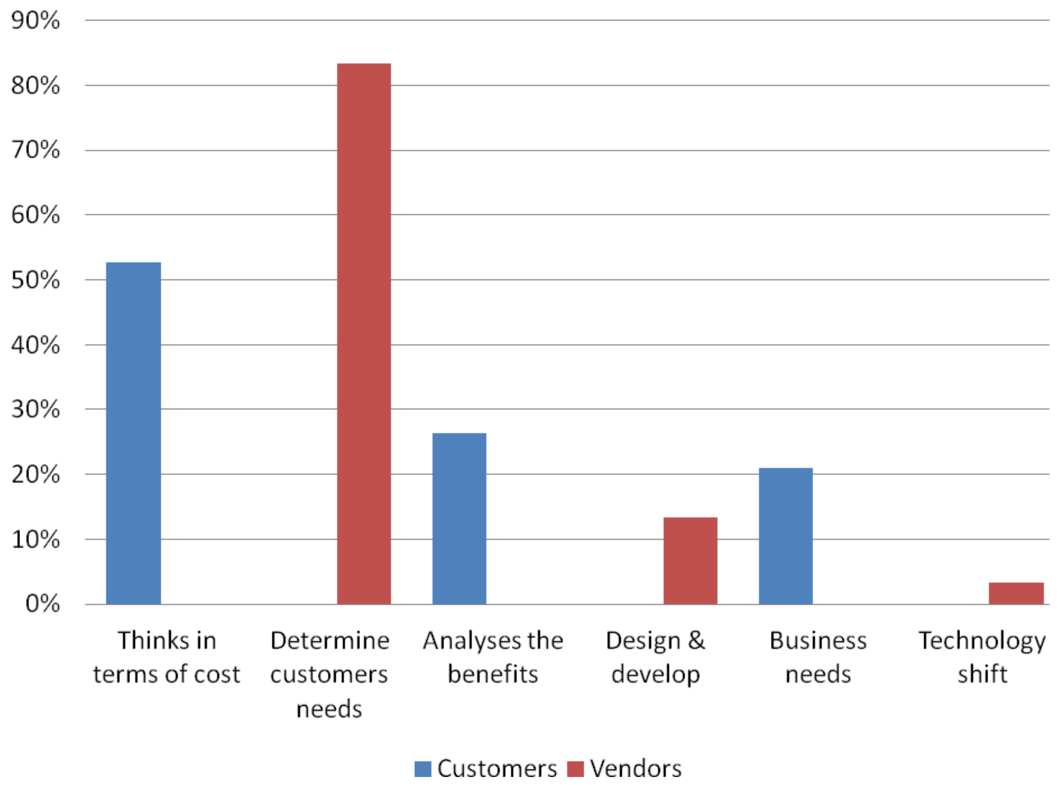


Figure 5.3. The findings of customers' attitudes towards new products (in blue) and vendors' business philosophy (in red)

The following list compares the findings of the customers' attitude towards new products with vendors' business philosophy.

- Thinks in terms of costs of software - 'customers' 53%.
- Determine customers' needs before marketing - 'vendors' 83%.
- Analyse the benefits of using the product - 'customers' 26%.
- Design and develop the product before analysing the market requirements - 'vendors' 13%.
- Review the business needs before purchasing software - 'customers' 21%.
- Develop a radical new product (technology shift) - 'vendors' 3%.

It is evident from these findings that there is a clear distinction between the attitudes of customers and the philosophy of vendors. For example; 13% of vendors analyse the market requirements before developing a product, where 23% of customers review their business needs before purchasing software.

Summary of the results

The issue of whether SMEs are the reason for the low performance of ICT uptake in construction, produced findings to suggest that the customers (a significant proportion of whom are SMEs) agreed with this accusation. However, the overall sample indicated further investment in eBusiness technologies for the next three years.

Question: Would you agree that the high concentration of SMEs in the construction industry is generally identified as the reason for the low ICT uptake in this sector? Please state the reason for your answer.

This partially closed and open-ended question investigated whether SMEs were the main cause for the low level of ICT up-take in construction coupled with the fact that the majority of construction firms in Europe are SMEs (97%, see EIDG, 2006).

The respondents expressed an overall mixed response to this notion. Table 5.1 summarises the respondent's opinion to the statement that the high concentration of SMEs in the construction industry is generally identified as the reason for the low ICT uptake. The most compelling outcome to this question is that the customers viewed this as the reason (43%) in comparison to ICT vendors (26%).

The supplementary open-ended question requested the respondents to express the reason for their answer. One of the customers expressed that because they are constantly occupied they have a problem with identifying what applications are available and how these can benefit their business. They do not know where to start with so much information being readily available online.

Opinion	Customer	Vendor	Overall
Strongly Agree	13%	13%	13%
Agree	**43%**	**26%**	35%
No Opinion	26%	39%	33%
Disagree	18%	19%	18%
Strongly Disagree	0%	3%	1%

Table 5.1. SMEs are the reason for low ICT up-take

Figure 5.4 illustrates a histogram of the open-ended response section (of which only 60% of the respondents answered). Over half of the 40% of the respondents that disagreed with this statement were vendors.

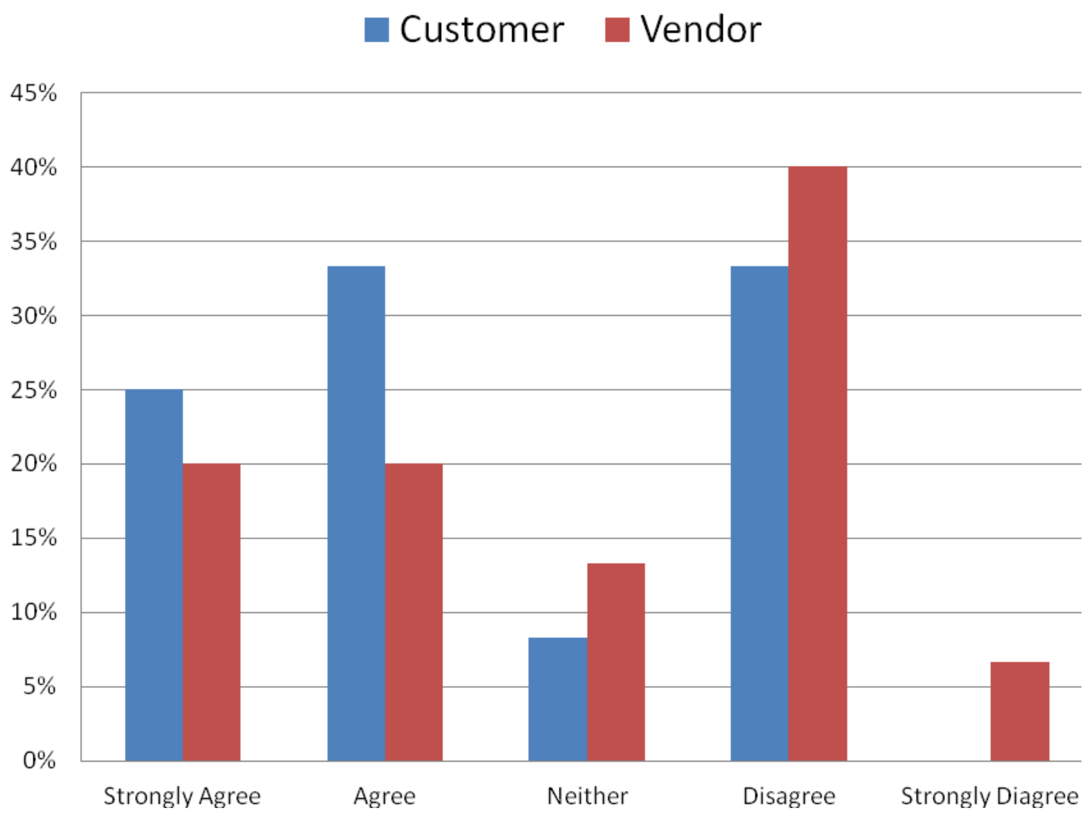


Figure 5.4. Qualitative analysis of SMEs as to the reason for low ICT up-take

In order to identify if vendors/agents were developing/providing products for the SMEs construction market the survey requested the vendors to state if they had identified construction SMEs as a particular niche section for their software products. The initial response indicated a 71% assurance that they will continue to support software for the construction SME sector. However, after further analysis of the descriptive responses, the figure increased to 87%. The increase of 16% related to converting negative responses that actually indicated in their reasoning that any market that can feature their product would be a potential future market, and suggestions that their services are marketed across a whole range of firms; however they are probably of more value to SMEs.

Question: How is your company's involvement in eBusiness and the use of ICT expected to change in the next three years?

This close-ended question investigated the market's future spending patterns on ICT for the next three years.

In identifying the market's beliefs on capital expenditure, 32% of the combined vendor and consumer totals indicated a great increase in their firm's involvement in eBusiness and the use of ICT in the next three years. 50% of the respondents showed some increase while only 10% of almost 90 enterprises predicted no increase. Figure 5.5 illustrates the portions in graphical terms.

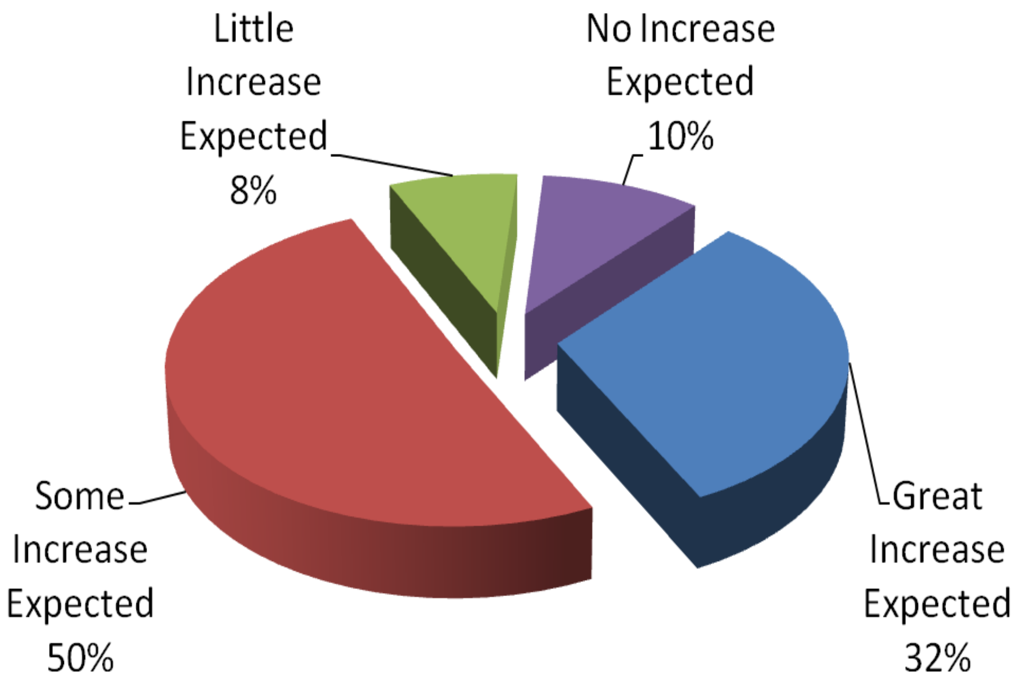


Figure 5.5. Firm's involvement in eBusiness and the use of ICT in the next three years

5.4 DRIVING FORCES FOR CLOUD COMPUTING

Summary of the results

In comparison to ICT up take, the results of the survey identified that the driving forces for using cloud computing were mostly associated with ROI rather than customer's access or greener solutions (eradicated the need for firms to house server rooms).

Question: Please rank in order 1-10 (10 is the highest) the following drivers that have attracted or are likely to attract your organisation to using cloud computing for construction SMEs.

The driving forces question in both questionnaires requested ranking of the factors that will attract their organization to providing cloud services (in the case of vendors) or using it (in relation to the customers). A summary of the overall results is shown in Table 5.2.

In combining both vendors' and customers' opinions, Table 5.2 indicates how the construction industry perceives the valuable aspects of cloud computing. The driver associated with a green solution surprisingly ranked the lowest in comparison to the highest driver value, 'added service'.

Ranking	Drivers
10	Value added service - Improves the businesses product standard.
9	Sales - Increases market share.
8	Total cost - Total cost of ownership is predictable, visible, flexible and lower.
7	IT Costs - Eliminate IT costs and concerns associated with maintaining and upgrading separate applications.
6	Payment flexibility - Pay per user per month (user numbers can change per month).
5	Choice – select ICT solutions that are quick to deploy, easy to use, and will support your business processes.
4	Closer collaboration – more frequent communication and improve relationships along the supply chain and partner's networks.
3	Access – 24 x 7 access from any online PC anywhere in the world.
2	Contract - No commitment (contract is month by month).
1	Greener solution – particularly for organisations that traditionally have operated their own data centres in regions with high electricity costs.

Table 5.2. Drivers for cloud computing

The unprecedented decline in the Irish construction industry may be a strong contributor as to why improving business needs is ranked high in contrast to sustainability needs. In separating the two sample populations, the ranking of the vendors and customers can be examined in further detail. Table 5.3 identifies the results of both samples.

The separate rankings of the samples in Table 5.3 illustrate some correlation between the two populations. The averages of all the values from the respondents of both samples were used to determine the overall ranking. Table 5.3 shows that both payment flexibility and closer collaboration were ranked significantly differently by customers and vendors. The most concerning point to note is the possibility that customers have either not experienced the use of collaboration tools in the Irish construction industry or having availed of them, found their purpose to be inadequate to their needs.

Ranking	Customer	Vendor	Ranking
Value added service	9	10	10
Sales	10	9	9
Total cost	8	5	8
IT costs	7	4	7
Payment flexibility	4	8	6
Choice	6	6	5
Closer collaboration	3	7	4
Access	3	2	3
Contract	2	3	2
Greener solution	1	1	1

Table 5.3. Individual sample driver rankings

It is evident from Table 5.3 and Figure 5.6 that there is some divergence of opinion between the customers and vendors ranking opinions in relation to the responses. Figure 5.6 is separated into four quadrants representing, high vendor and low customer drivers (such as closer collaboration and payment), high customer and high vendor drivers (such as value added service, choice and sales), high customer drivers and low vendor drivers (such as total cost and ICT cost), and low vendor drivers and low customer drivers (such as contract, access, and providing a greener solution). For example, total cost is a higher driver for customers in comparison to the vendors. In summary, Figure

5.6 identifies that in relation to the triple bottom line of costs: environmental, economical, and social, the least favoured option in an economic crisis is the environment.

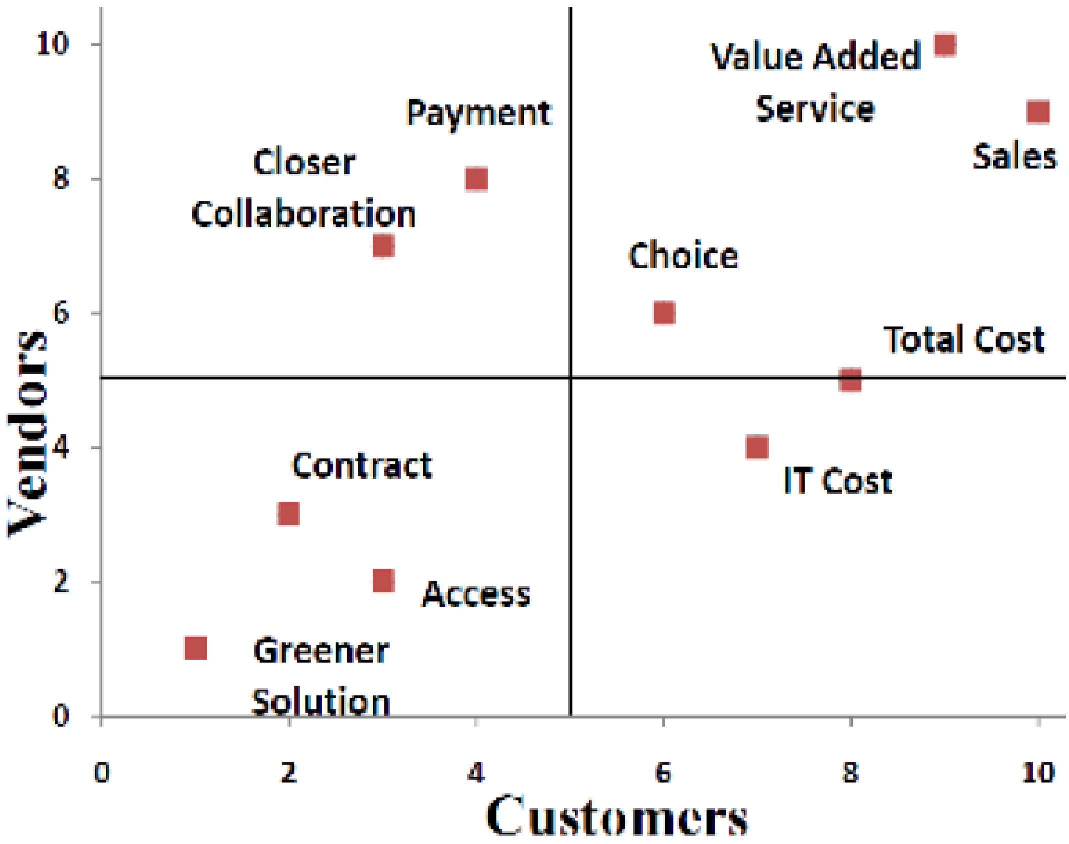


Figure 5.6. Correlation drivers of cloud computing

5.5 BARRIERS TO CLOUD COMPUTING

Summary of the results

The realistic barriers which are perceived by SMEs will have to be overcome before widespread adoption of cloud computing becomes a reality in the construction sector. The respondents may not have indicated any problems with regards to contracts and data lock-in (retrieve one's information if their cloud provider has stopped trading) but it was ranked as a major barrier by Armbrust et al. (2009).

Question: Please rank in order 1-10 (10 is the highest) the following barriers of using cloud computing?

The barriers for adoption question was formatted identically to the drivers question with both samples being requested to rank in order 1 – 10 the barriers for using or providing depending on the sample. The attitudinal barrier statements provided were collected from various perceptions of cloud computing in the media reports and literature.

Barriers	Customers	Vendors	Overall Ranking
Knowledge - Lack or awareness of knowledge:	**9**	**10**	**10**
Security - Security concerns:	**10**	**8**	**9**
Cost - Total cost of ownership concerns:	**8**	**6**	**8**
Capabilities - Customers may not possess adequate eBusiness capabilities:	**3**	**9**	**7**
Choice - "We can't find the specific application we need":	**7**	**5**	**6**
Integration - Lack of integration and interoperability of software:	**4**	**7**	**5**
Customisation - Lack of customisation:	**5**	**4**	**4**
Pricing - Complicated pricing models:	**6**	**1**	**3**
Performance - Application performance:	**2**	**3**	**2**
Contract - "We're locked in with our current vendor":	**1**	**2**	**1**

Table 5.4. Barriers for adoption of cloud computing

Figure 5.7 illustrates the correlation between the two samples. From a review of Table 5.4, ‘lack of awareness or knowledge’ is ranked the overall highest. This is a similar response to a customers expressed opinion in the third question referring to ICT up-take by SMEs. One respondent felt that there was too much information online in an unstructured format. This barrier is clearly evident in Table 5.4 overall rankings. The next major barrier was ‘security’. Armburst et al. listed this as number 3 in their top ten obstacles and opportunities for cloud computing. The lowest ranked barrier was surprisingly ‘contract’. The customers, ranked this the lowest whereas ‘pricing models’ was ranked the lowest by the vendors. The two of these components are interlinked, as one model is dependent on the other and generally customers view this area as confusing, as indicated by SIIA, (2001).

The correlation diagram (Figure 5.7) illustrates that there is very little evidence of divergence of opinion between customers and vendors, with only two exceptions; capabilities and pricing. In order, to fully appreciate the implications of these responses, customers are of the opinion that they would have the technical ability to use cloud applications in contrast to vendors assuming customers would not be able to adapt. The market value of such products was listed as the lowest barrier by vendors (as initially they set the market price) but was subjected to a lack of confidence by the customers (possibly relating to the aspect of how to achieve a favourable purchasing/renting mechanism).

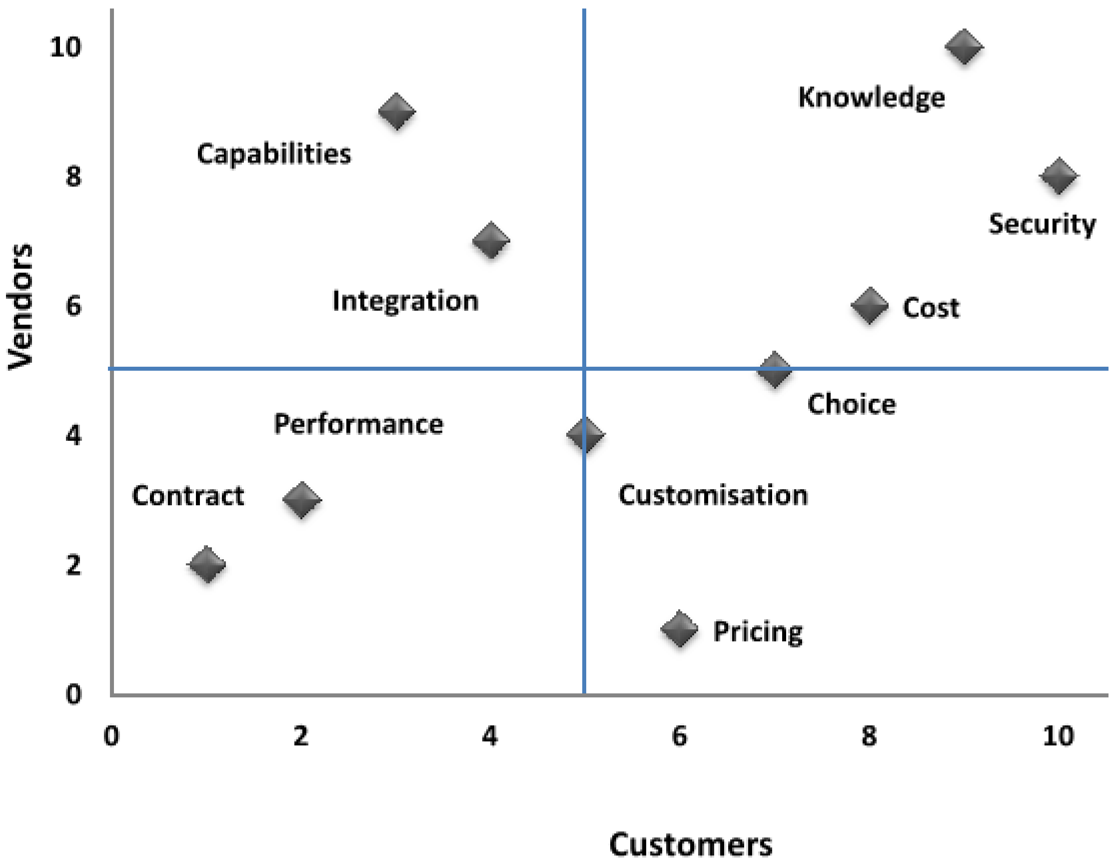


Figure 5.7. Correlation barriers on adoption of cloud computing

5.6 BENEFITS OF CLOUD COMPUTING

Summary of the results

The findings of the survey have indicated that both vendors and consumers could avail of the potential benefits of cloud computing such as speed, agility, and accelerated information access from communication in real-time and assisting collaboration internally and externally. Cloud computing has the potential to improve the competitive positions of SMEs by allowing them to have access to software that was previously only the domain of large enterprises and to streamline their fragmented operations.

Question: Please indicate your opinion on the following perceived benefits of cloud computing. Please indicate your preference by ticking the appropriate cell.

The seven perceived benefits of Cloud computing were asked in both questionnaires. The actual statements relate to Ramanujam's (2007) key points as to why Cloud/On-Demand would be a smart choice for companies (please refer to Appendix A for the full detailed list of perceived benefits).

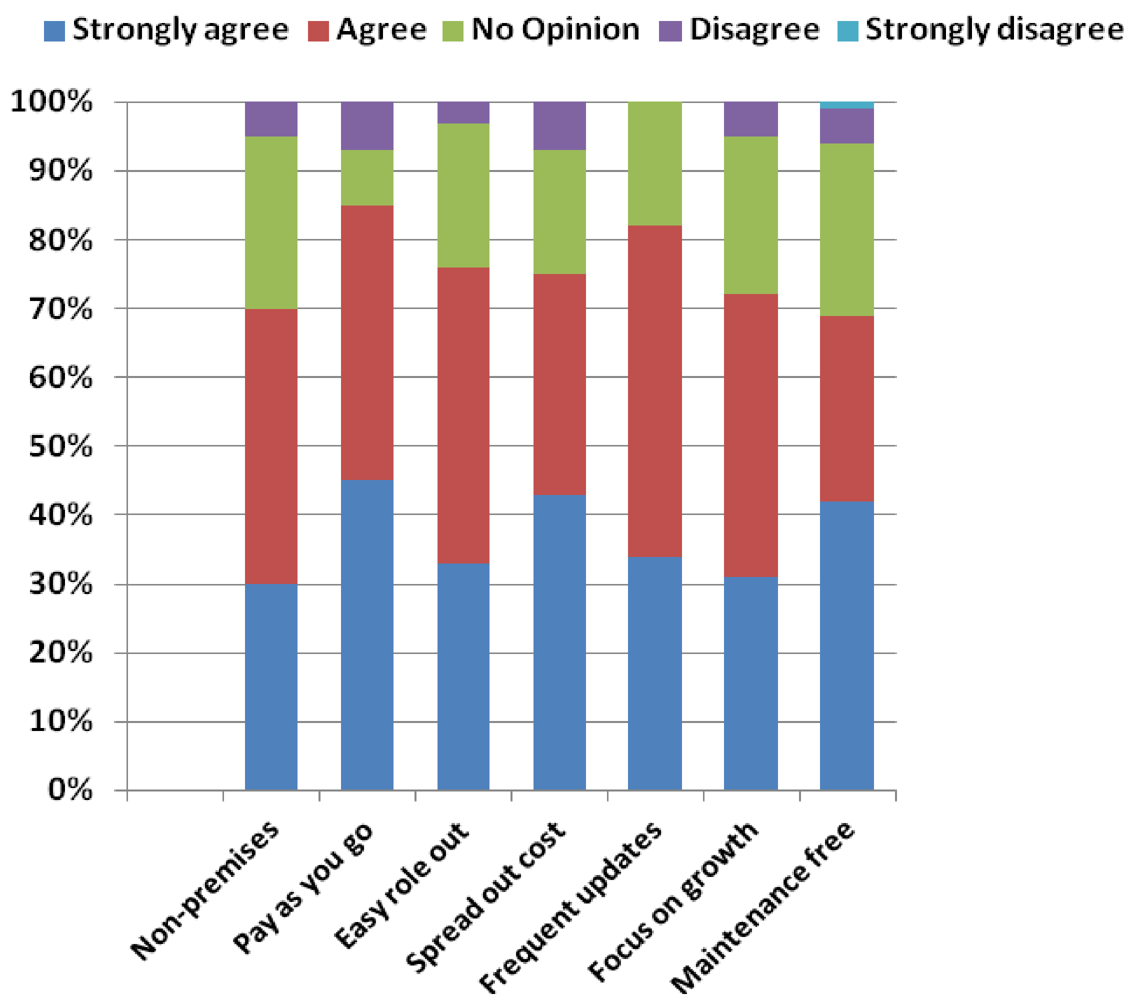


Figure 5.8. Perceived benefits of cloud computing

The combined responses to this question indicate that the majority of the respondents in the construction industry are in concordance with Ramanujam's list of perceived cloud benefits. This factor is evident with only 10 percent disagreeing or strongly disagreeing. The graph illustrates this by contributing the two largest proportions of colours to strongly agreeing and agreeing (blue and red). In relation to such benefits as cloud computing reducing, the managing facility of software and not having to worry about disaster recovery, 25% of the respondents indicated caution in relation to this benefit (possibly relating to the industry's suspicion of the Internet). Table 5.5 indicates the scores associated with this survey's customer respondents.

Perceived Benefits of Cloud	Strongly agree	Agree	No Opinion	Disagree	Strongly disagree
Non-premises	52%	38%	7%	3%	0%
Pay as you go	64%	25%	7%	4%	0%
Easy role out	45%	38%	14%	3%	0%
Spread out cost	48%	31%	17%	3%	0%
Frequent updates	52%	31%	17%	0%	0%
Focus on growth	48%	34%	14%	3%	0%
Maintenance free	52%	24%	24%	0%	0%

Table 5.5. Customers perceived benefits of cloud computing

It is evident from Table 5.5 that overall the customers in the Irish construction industry are not concerned about having their services managed online and that having the benefit of no facilities (non-premises) would enable ICT services to focus their attention towards the customer instead of worrying about unnecessary ICT problems. Table 5.5 also shows that the customers are in agreement with both the benefits of spreading out costs (capital cost of purchasing software) and being maintenance free (disaster recovery). In relation to the results of the combined scores (Figure 5.8) both non-premises and maintenance free values yielded the highest percentage of no opinions. This 25% should be identified as the percentage of the industry that needs to be persuaded on these specific benefits of cloud computing. To conclude, the construction industry perceives that cloud computing can be an influential addition in assisting them to becoming more effective and efficient. The tabulation of individual respondent's rating for drivers, barriers and benefits of cloud computing which were used to develop the correlation graphs, can be found in appendix A.

5.7 PROCUREMENT OF CLOUD COMPUTING SERVICES

In summary, the two most preferred or recognized models for delivering and receiving cloud computing are Web service architecture and client server architecture. Web-based applications are supported by SOA infrastructure, as the software components are accessible through a defined Web location. The client service architecture 'thin client' provides a client machine with the usage to query/access functions supported by a server. SIIA (2001) selected several licensing and pricing options for SaaS as part of a value chain services analysis. These options included a subscription-based , transaction-based and value-based model. The findings from this survey identified the subscription-based model as the most preferred option.

Question: Please indicate which of the following approaches to delivering (vendors) / receiving (customers) cloud computing you would prefer.

The following approaches to delivering cloud computing were offered in both vendor's and customer's questionnaires:

- Server-based Computing (thin-client): an application is run on an internal organisation server.
- Hosted Client Computing (HCC): an application is run on the user's desktop, but it is served, or "streamed," from a server.
- Web-based applications: Web-based application is developed to be maintained on a server and viewed through a browser.
- Rich Internet Application: Adobe (2009) describes this term as the new category of applications that connects the client to the Internet cloud. It enables Internet applications connectivity capabilities to connect and deploy models (if the internet delivery fails, the application can still function on the premises OS).

Figure 5.9 illustrates the combined results of the survey's most favoured approach to delivering cloud-based software. The majority of both vendors and customers selected a Web-based application maintained on a server and viewed through a browser, as the most preferred method for delivering and receiving a cloud-based model. The next most preferred option was the server-based computing solution. Surprisingly less than 20% of the vendors and customers considered RIA as their preferred option. Unlike static Web and desktop applications that are constrained by their domain, RIA can be used in either connected (Internet) or disconnected mode. This would give the customer the benefit of having the ability of using desktop applications applied to a lightweight (small with basic features) application. It is important, however, to clarify that there is a degree of overlap between all four categories, as they all are hybrids of Web-based applications.

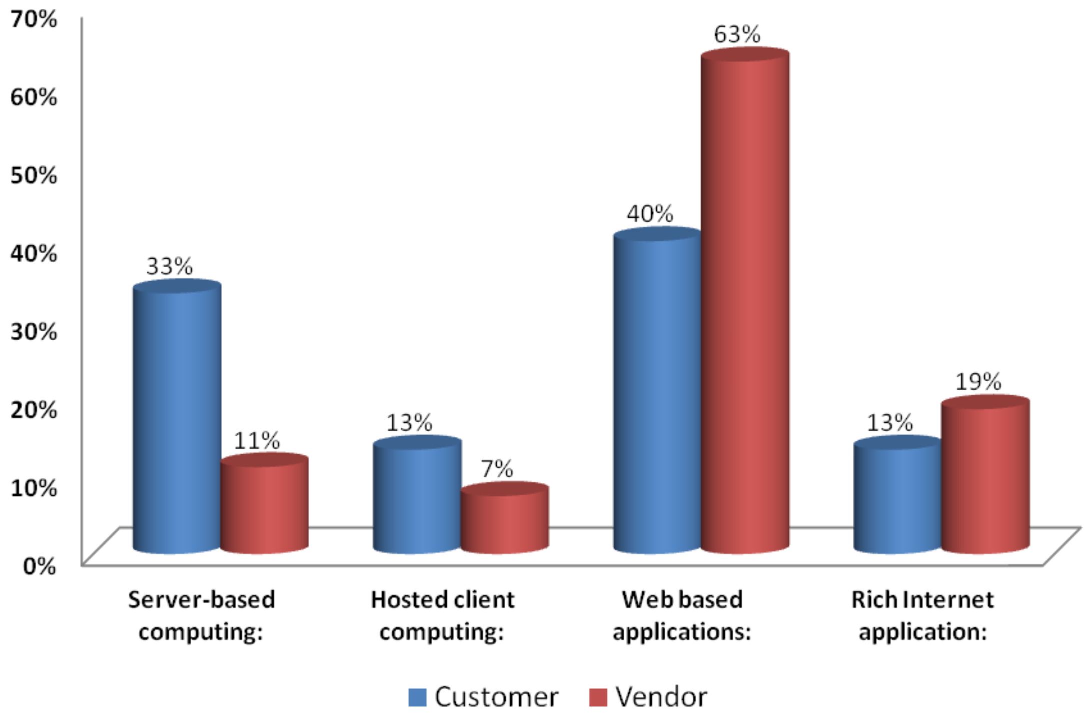


Figure 5.9. The most favoured approach to delivering cloud-based software

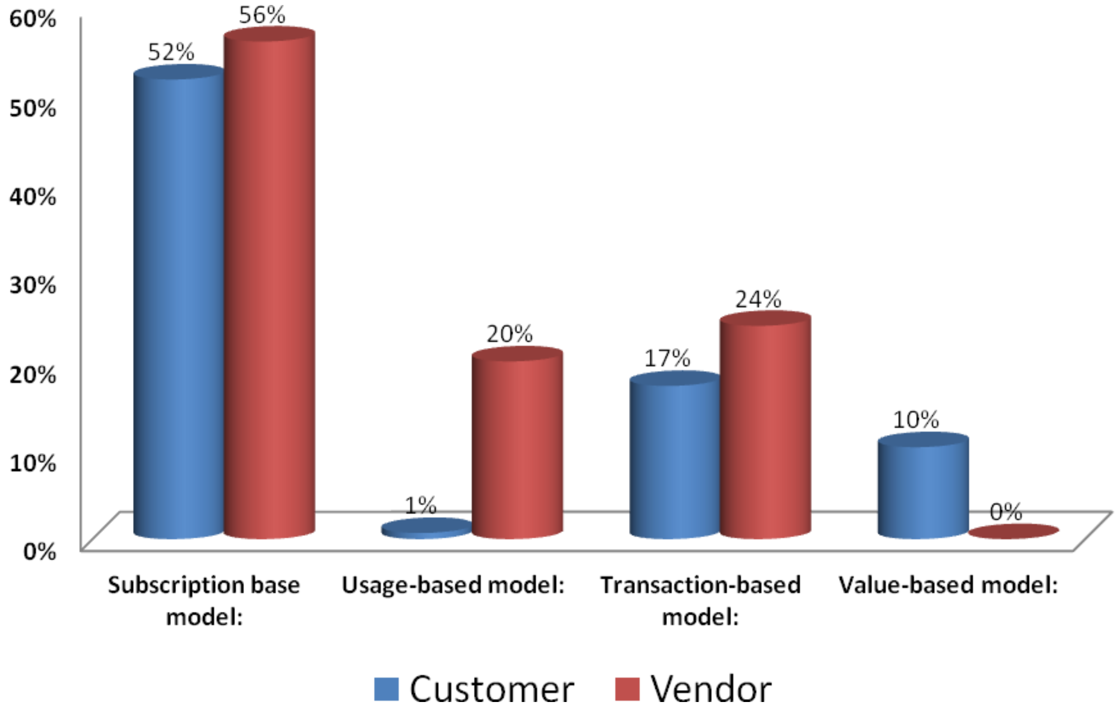
The following points are the choices presented to the respondents in relation to the question:

"If your firm was interested in cloud computing which of the following licensing options (vendor) / renting (customer) options would it choose would it choose?"

- Subscription-based model: monthly payment of the software actually used.
- Usage-based model: payment is determined by application usage (customers are charged for every computer that runs a hosted application).
- Transaction-based model: charge customers for each business transaction.
- Value-based (share risk or revenue) model: whatever software is needed to achieve business goals, payment is linked to the goals.

The subscription-based model was the most favoured licensing option selected by both vendors and customers. The option of charging for each business transaction was also identified by both samples as the next preferred licensing option for cloud computing. The subscription-based model allows one to control one's cash flow more efficiently by being charged on a monthly basis for software that is actually used. The downward adjustment in the Irish construction industry may have contributed to the chosen option as it does not create an environment for long-term commitment.

Figure 5.10 shows the results of the surveys most sought after licensing option for cloud computing.



5.10. The most favourable licensing option for cloud computing

5.8 FOCUS GROUPS

As identified in the introduction to this chapter, SaaS is the final tier of the cloud computing service model and had been adopted by the Focus group (see chapter 4.4.2) as the generic term for cloud computing. The consolidated flow model illustrated in Figure 5.11 is a representation of three cloud focus group meetings. Internal meetings 1 to 3 are all connected to 'Directory and SaaS window' which was the most featured theme within each of the meeting. The summary of each of the group's internal meetings were categorised in relation to the topic's being discussed; for example, a discussion on developing a software directory was mentioned in both meeting 1 and 3. The procedure involved screening statements from each of the meetings to identify positive influences which can be interpreted into a concept that facilitates the requirements of the group's objective which was to 'increase their market presence.' The main purpose of the meetings was to identify and connect to the group's key issues. The key finding taken from the three cloud group meetings was the development of a 'Directory and SaaS window.' The cloud group model (Figure 5.11) is formatted to illustrate that the core topics are deduced from each of the meetings that created the concept.

Results of internal meetings

The 'SaaS group cloud computing' discussion featured in all three meetings. The main topics identified to be investigated were (i) security concerns about data being stored in locations outside Europe, (ii) the potential to develop a hybrid cloud for the group, and (iii) the friction caused by the notion of having to recode vendor software that was not cloud compatible. The group also recognised the need for a virtual operator hosting a cloud window for showcasing other companies as not all vendors can be individually supported in today's market. The concept of implementing a cloud network or similar was identified by the members with concerns for disaster recovery and business continuity.

The case study discussions reviewed the need for supporting cases on various issues, such as the benefit of having a software directory. The case studies also highlighted the possibility of using the focus groups members who implement cloud computing as potential participant observers. The case studies were to be viewed as an area that should add educational benefit to the Irish market on cloud computing. In review of this prospect, an investigation was proposed to research why Irish consumers should purchase the members products. This aspect was further identified in the 'education group' where the members requested a recognised section of the Web portal to be dedicated only to their products. The final feature was that a Website should be used as a portal to provide answers to the questions relating to the products hosted on the directory. In relation to the 'marketing group' discussion, the members revealed that the majority of them do not have a sales and marketing functionality, and that firms preferred to form clusters and market themselves.

The main potential development solutions of 'Directory and SaaS Window' are the common topics named at the three focus group meetings. The focus groups did provide a means to increase communication and address the immediate vendor's problems. However, due to certain aspects of how the group meetings were conducted, such as the antagonistic environment as all members were vendors, greater clarity was needed. The main benefit of undertaking the focus group research was its ability to extract information on the 'key issues' to be further developed.

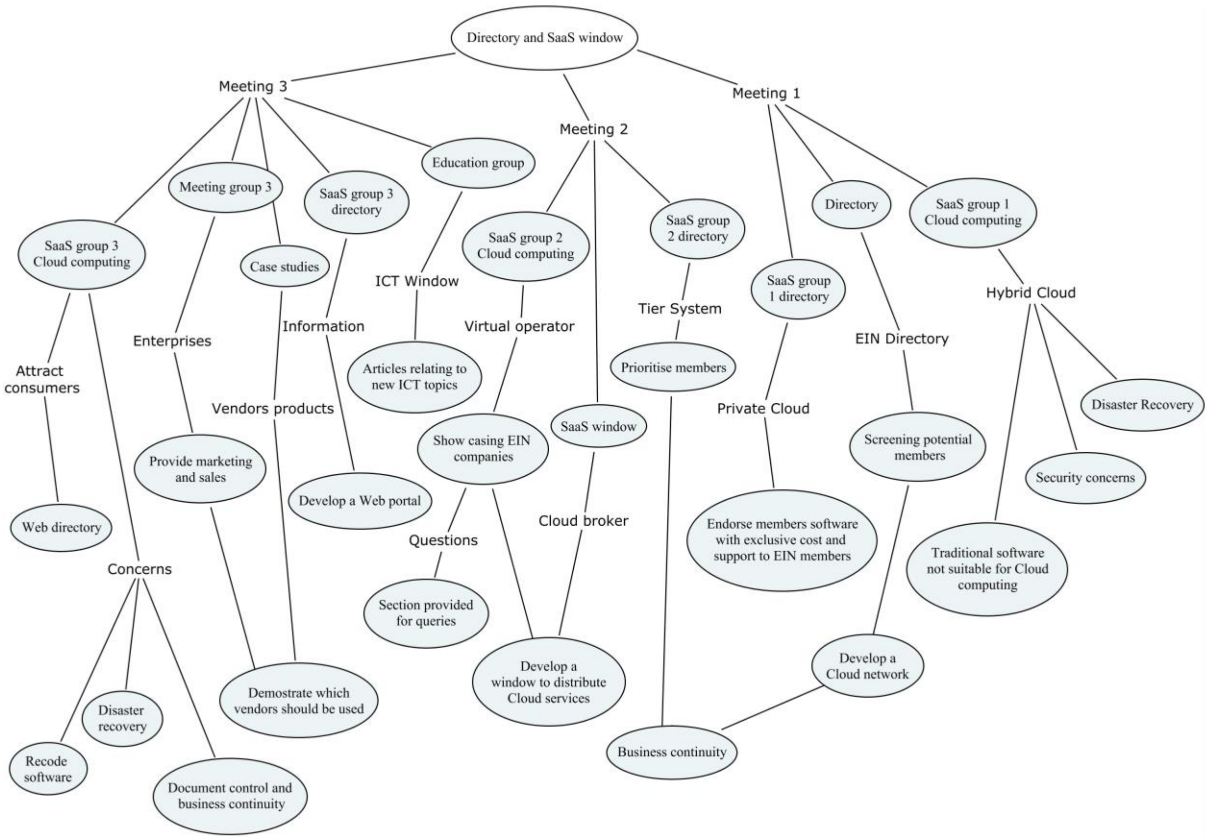


Figure 5.11. Cloud group flow model

5.9 CONCLUSION

The results of the survey presented in this chapter have revealed mostly positive attitudes towards the market need for further investment in ICT, and in particular, cloud computing. The sample of 90 respondents identified CAD/BIM, document management, and estimating/costing as the main applications required for a cloud platform.

Value added service and sales ranked as the highest drivers for the adoption of cloud computing services, indicating the respondent's preference for a good return on investment. Lack of knowledge and concerns about security were ranked as the highest barriers to adoption of cloud computing. The majority of the respondents in the sample acknowledge Ramanujam's list of cloud computing benefits. However, non-premises and maintenance free values yielded the highest percentage of no opinions. The preferred delivery option chosen was Web-based applications, which is supported by cross-platform compatibility via SOA. The majority of respondents preferred paying for software actually used on a monthly basis. The survey results have identified the market for a cloud-based model but further investigation is needed on the actual components that can create a typical supply chain of applications for an entire project for use by all parties involved. The findings have identified that within the current construction software, environment the majority of SMEs cannot obtain applications that are available to larger enterprises. It is for this reason that the benefits of cloud computing received such a positive response from the respondents. The perceived benefits of having convenient on-demand network access to a shared infrastructure, with scalability and consumption-based pricing has highlighted to the construction industry the advantages of this new layer of Internet architecture.

The focus group, comprising of 10 vendors in the Irish market-place, analysed issues, such as, security concerns about data being stored in locations outside Europe, the potential to develop a hybrid cloud (private 'Evergreen ICT' chapter 2.6 and public 'saleforce' combined) for the group and the friction (for and against the idea of cloud computing) caused by the notion of having to recode vendor software that was not cloud compatible. The group recognised the need for a virtual operator (specified cloud computing provider) to host a Web-portal window for connecting and supporting all Irish vendors. The concept of implementing a cloud network or similar was supported by the members, however, there was concern about disaster recovery and business continuity (internal and external threats).

In order to identify a process to be designed the next chapter will involve carrying out a detailed business analysis of potential cloud-based applications such as BIM/CAD, document management, estimating and costing, project management and accounting. As a means to obtaining international opinion, experts with experience, either in using or developing construction services will be interviewed on the product life cycle, capabilities and opportunities presented by cloud computing in the construction industry.

Author's key findings in relation to the thesis objectives:

Objective 2: To discuss how cloud computing and BIM can support the future development of interoperable software - Table 5.3 identifies that the respondents rank value added services (improve the business product standard) and sales (increase market share) as the highest drivers.

Objective 3: To investigate the potential of cloud computing and BIM in re-engineering early design processes – The online survey of 90 respondents concluded that the most preferred delivery option for cloud computing was Web-based applications.

Objective 5: To identify the need for agreed information architecture framework that will create an interoperable layer of business processes on – The survey results in this chapter identified contracts as a low driver referring to Ramanujam (2007) drivers, but it was ranked the least barrier to entry in relation to Armbrust et al (2009) obstacles

Objective 6: To measure the ability of advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform – Figure 5.1 highlighted that CAD/BIM, document management, and estimating/costing should be the main applications considered for a cloud platform. This chapter also determined that vendor’s attitude towards new products relates to terms of costs whereas customers analyse their needs.

CHAPTER 6

THE USE OF CLOUD ENABLED BUILDING INFORMATION MODELS – AN EXPERT ANALYSIS

6.1 INTRODUCTION

To the eBusiness environment 'cloud computing' serves as an umbrella term for the provision of services, such as storage, computing power, software development and applications, combined with service delivery through the Internet to consumers and business. However, to a fragmented industry, such as, construction, the benefits of this service have still to be recognised. This chapter presents the results of two Delphi questionnaires. The initial questionnaire, undertaken by 16 international experts on construction ICT, allows an analysis to be undertaken into the expert groups' opinion on the future of ICT in construction, based on a cloud service, which hosts construction-related applications. The survey was designed to evaluate opinions and screen alternatives, in order, to determine new ideas relating to the topic. It was structured into three main core sections; business process, cloud computing capabilities and cloud-based business opportunities. In each of the sections the potential for developing a cloud-based construction service was analysed by identifying standardised deliverables, obstacles and opportunities for growth compared to the perceived benefits (as previously identified by Ramanujam, 2007). The questionnaire itself is derived from the online survey results presented in the previous chapter. In order to establish if there was a strong correlation between the international experts, this chapter presents quantitative results supported by the comments obtained from the qualitative analysis.

In the second Delphi questionnaire the results of the initial questionnaire were compiled and categorised into topics, such as, interoperability for BIM software, contractual issues, information exchange, and developing a BIM Life Cycle Costing service prototype (model). It had been previously identified in the literature review that advancing interoperability between design team applications was a major challenge for advocates of open standards.

In 2009 the buildingSmart alliance and Open Geospatial Consortium Inc in the U.S. had developed and implemented AECOO-1 Testbed that streamlined communications between parties at the conceptual design phase, to establish an early understanding of the tradeoffs between construction cost and energy efficiency. To highlight the methodology involved with the Delphi Technique; the findings of the AECOO-1 and the on-going collaborative Research and Development (R&D) project 'Inpro' was originally suggested by an expert in the first Delphi questionnaire as a main area of research to be used in the second survey.

The author anticipates that the results of this chapter will contribute to (i) identifying whether or not the popular applications from the previous chapter survey (accountancy, project management, and BIM applications) are deemed appropriate for advancing interoperability at the early design stage, (ii) detecting the most severe barriers of BIM implementation from a business and legal viewpoint, (iii) examining the need for standards to address information exchange between design team, (iv) exploring the use of the most common interfaces for exchanging information, and (v) investigating the expert's perception on whether the development of a Cloud based BIM Life Cycle Costing package (purchase, operating, support, maintenance and disposal) would be of significant use to the construction industry.

6.2 DELPHI QUESTIONNAIRE (A): THE FUTURE OF ICT THROUGH THE USE OF CLOUD COMPUTING

The methodology used for the questionnaire included both quantitative and qualitative (open and closed-ended) questions. The attitudinal research focused on subjectively evaluating the opinion or view of the respondent in particular topics. The exploratory research (when one has limited amount of knowledge) was used to evaluate the situation, screen alternatives and form new ideas. The structure of the survey comprised of the following sections:

Business process: Identify if a cloud collaboration tool, based on combining the open API's of accountancy, project management and a BIM application, would benefit the industry. The benefits of re-engineering a previous tested solution with the concept of construction as, a manufacturing process were investigated and compared to Kagioglou et al. (1999). Kagioglou et al. had identified that traditionally ICT had been seen as a driver behind changes in the design and construction process and indeed in many BPR initiatives.

Cloud computing capabilities: This section investigated Armbrust et al.'s (2009), obstacles to adopting and opportunities for growth of cloud computing. This section also referenced Lowe's (2010) five challenges associated with moving backup to the cloud, in order, to provide new knowledge on the capabilities of cloud computing in contrast to traditional network infrastructure. However, as cloud computing becomes ever more successful there are leading experts making comparisons with the Dot.com era (Internet companies pushing their stock value up through speculation) and rebutting them, such as Wohl (2008). The final question in this section investigates if cloud computing has learnt from the many mistakes made during the Dot.com bubble, such as, rapid investment into companies with little or no strategic plans for capital investment.

Cloud based business opportunities: The key features of this section are the benefits associated with cloud computing, in comparison with traditional premises-based facilities. The primary question requests the respondents to refer to their own company when making a decision on their response, such as, would cloud computing be a cost benefit to one's firm? The respondent's opinion is also called into question asking for expert advice on whether cloud computing benefits are essential for business growth and do SMEs have the capability of using such a service.

The findings of the papers listed in the structure of the survey (Kagioglou et al. etc.) have been complied and redesigned as question for the Delphi questionnaire. This technique is used, in order, to provide additional information from the international experts' perspectives which can form new knowledge in the areas being investigated.

6.2.1 Findings and Discussions

Business Process

Question: The experts were asked if they would agree that developing a cloud collaboration tool based on combining the open API of accountancy, project management, and BIM applications, would benefit the industry in having a standard supply chain service.

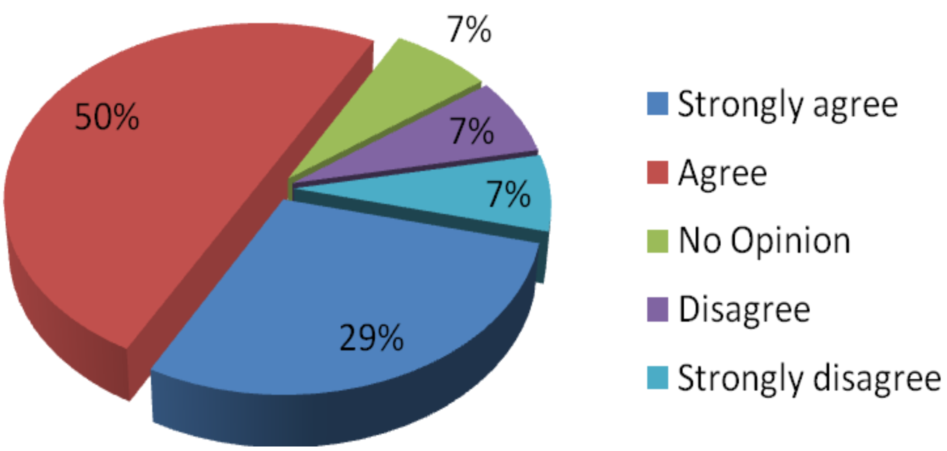


Figure 6.1. Survey response to the question developing a cloud collaboration tool based on combining open APIs of accountancy, project management, and BIM applications (located in appendix B)

The overwhelming positive response to this question, illustrated in Figure 6.1, has 50% of the experts agreeing and 29% strongly agreeing. However, after further analysis of this open-ended question, the experts identified areas for concern; such as security and the difficulty involved with combining open API's with different applications. One expert supported the concept of developing a cloud collaboration tool but was unsure of the approach of using existing API's to address the interoperability task. Another potential issue is the notion of developing a Hypertext Markup Language (HTML) for BIM, thereby allowing multiple software vendors to offer their software on that new Web-based platform. The majority of the experts acknowledged that the key to integrated BIM is a common database, preferably in the cloud; containing information about component parts of buildings modelled in discrete software programs.

Question: The second question asked for the strength of their organisations agreements or disagreements with statements made by Kagioglou et al. (1999) regarding the identification of ICT requirements needed to support a process protocol (refer to Table 6.1 for statements).

According to Kagioglou *et al*. (1999), the term BPR was first introduced in a 1990 article of the Harvard Business Review by Michael Hammer suggesting that re-engineering is "the fundamental rethinking and radical redesign of business processes to bring about dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed." In conjunction with these qualities, Kagioglou et al. listed the main findings of Engineering and Physical Sciences Research Council funded project (UK). The experts were asked to grade the process findings as illustrated in Table 6.1. The experts only had a concern about two statements, namely, (1) the need for a coherent and explicit set of principles to be standardised by the whole industry with the intention of changing the strategic management of their traditional process and (2) construction operations that form part of a traditional process controlled by a single integrated team. The problem relating to the first matter can be traced to the fact that companies prefer to manage their own standard procedures until they have to collaborate with the rest of the design team. The second problem refers to the notion of proprietary integrated systems being less competitive in comparison to an open standard system. In contrast, the expert panel strongly agreed that the identified model should be capable of representing the stakeholder's interest and be interchangeable allowing interfaces between existing software.

Construction as a Manufacturing Process	Strongly agree	Agree	No Opinion	Disagree	Strongly disagree
The required model should be capable of representing the stakeholders involved in the construction process.	57%	43%	0%	0%	0%
There should be a generic and adaptable set of principles that allow for a consistent application to be used in a repeatable form.	23%	77%	0%	0%	0%
A need for a coherent and explicit set of process, related principles , the new process should be able to be managed and reviewed by the whole industry with the intention of changing and systematising (organising) the strategic management of the traditional management process.	14%	43%	29%	0%	14%
The need for standard construction operations that form part of a traditional process controlled by an integrated system.	7%	50%	22%	14%	7%
A need for a model that can be interchangeable allowing interfaces between existing software and practice support tools to be operated.	57%	36%	7%	0%	0%
Standardised deliverables and roles associated with achieving, managing and reviewing the process during construction.	14%	79%	7%	0%	0%
Key emphasis on designing and planning to minimise error and networking during construction.	7%	57%	29%	7%	0%
Construction industry involvement to be extended beyond completion - a post completion phase.	50%	21%	22%	7%	0%

Table 6.1. Construction as a manufacturing process (Adapted from Kagioglou et al. 1999)

Other strong indicators identified were the need for a generic and adaptable set of principles, standardised deliverables and a key emphasis on designing and planning to minimise error and networking during construction. The concept of the construction industry involvement, being extended beyond completion, received a high level of agreement (71%). The majority of the experts agreed with the process model, however having the whole industry reviewing the process and controlling the integrated system did receive negative responses. This is further identified in the open-ended answers (in appendix B) where a respondent stated ‘We need to treat facilities and infrastructure like manufactured “products” instead of chaotic “projects” delivered by a disparate rag team of individuals and companies with no common purpose.’

Cloud Computing Capabilities

Question: The third question featured statements relating to the top 10 obstacles for growth of cloud computing and the potential solutions as identified by Armbrust et al. (2009) (refer to Table 6.2 for statements and appendix B for the full question).

The option of using FedExing Disks (international mail service) to solve the issue of data transfer bottlenecks for large data transfers received an insufficient agreeing response of 43% and a disagreeing response of 28%. The no opinion response of 29% indicated that this should not be the main deterrent and alternative options should be identified. One of the highest agreeing responses by the expert group were allocated to standardizing APIs, suggesting that a SaaS developer could deploy services and data across multiple cloud computing providers so that failure of a single company would not take all copies of customer data with it, and scalable storage (refer to Chapter 5). This option of scaling presented an environmental solution (not having to purchase hardware) by carefully utilizing resources, which could reduce the impact of the data centre on the environment through short-term usage. Scalable storage and data lock-in received a total agreeing result of 78% and 85% respectively with no disagreeing responses. Another high level of agreeing response was the data confidentially and auditability with its suggested solution of deploying encryption, virtual Local Area Networks (LANs) and networks middle boxes (a device in the internet that provides transport policy enforcement), for example firewalls.

The solution for data confidentially, which suggested having geographical storage, such as, servers located in both the U.S. and Europe to deal with concerns about international law enforcements having the power to search email communications and various records, received no negative responses. As Table 6.2 illustrates, the majority of the obstacles and their solutions received a high level of agreeing responses, with such obstacles and solutions as; creating reputation, guarding services similar to trusted emails services and inventing a debugger that relies on distributed Virtual Machines (VM) or Microsoft Hyper-V, resulting in a high undecided response.

Obstacles and growth of cloud computing	Strongly agree	Agree	No Opinion	Disagree	Strongly disagree
Availability of service - ***Use multiple cloud providers***	29%	35%	29%	7%	0%
Data lock-in - ***Standardise API's***	14%	71%	15%	0%	0%
Data confidentially and audit ability - ***Deploy encryption***	46%	39%	15%	0%	0%
Data transfer bottlenecks - ***FedExing Disks***	21%	22%	29%	21%	7%
Performance unpredictability - ***Improve Virtual Machine support***	14%	43%	29%	14%	0%
Scalable storage - ***Create a storage system***	21%	57%	22%	0%	0%
Bugs in large distributed systems - ***Invent debugger***	21%	43%	36%	0%	0%
Scaling quickly - ***Careful use of resources***	29%	57%	14%	0%	0%
Reputation fate sharing (blacklisting) - ***Services similar to trusted emails***	7%	50%	36%	7%	0%
Software licensing - ***Pay for use licenses***	21%	57%	22%	0%	0%

Table 6.2. The top 10 obstacles for growth of cloud computing and the potential solutions (Adapted from Armbrust et al. 2009)

Other ideas, such as, improving VM support to combat performance and unpredictability, and using multiple cloud providers to prevent Distributed Denial of Service resulted in an average agreeing response of 57%. The expert group also concluded that the option of pay-for-use licenses did seem attractive (78% agreeing).

In summary, the solutions to the obstacles were broadly favourable to the group; however, the solution for bottlenecks (Fedexing) needs more consideration. This section effectively highlights the infrastructure of cloud computing and demonstrates how the obstacles can be reduced.

Question: The experts were asked to rank their opinion on attitudinal statements relating to the major challenges for moving backup to the cloud (refer to Table 6.3 for statements and appendix B for the full question).

The issue of additional costs increasing because of the lack of knowledge on how backup is achieved to meet one’s requirements in comparison with selecting vendor’s pricing produced a disagreeing response of 36% and an undecided response of 14%. This response was the highest disagreement result out of all the challenges indicating that it is not a major challenge. The challenge of backup services outsourced to the cloud with the upstream speeds often capped at very low rates in contrast to the downstream, meaning a cloud-based backup would saturate an upstream connection, received only a 57% agreeing mark and disagreeing mark of 29%. A considerable challenge noted by the expert group was security (79% agreeing), which is a repeat of the answer for the third question, where deployment of encryption was one preferred solution. However, this statement relates to compliance issues, such as, special attention to contractual language, geographical diversity (if your provider offers geographical redundancy in their service) and termination agreements.

Challenges for moving backup to cloud	**1 (High)**	**2**	**3**	**4**	**5 (Low)**
Cost - not understanding backup requirements	7%	43%	14%	22%	14%
Bandwidth - cloud saturate connection	14%	43%	14%	22%	7%
Security - encryption data	50%	29%	14%	7%	0%
Recovery - assess providers ability	22%	64%	0%	14%	0%
Vendor reliability - what happens to your data	43%	57%	0%	0%	0%

Table 6.3. The 5 major challenges for moving backup to the cloud, (Adapted from Lowe's 2010)

The expert group's main concern was that of vendor reliability, which received a 100% agreement rank. This statement raised the issue of negotiating 'up front' about what happens to one's data if a company goes out of business or is acquired. In continuation of the previous challenge, the statement citing the possible solution of working with one's provider to assess their ability and willingness to help one quickly recover from disaster scored an agreement of 86% and a low rank of 14%. All of the noted challenges are recognized as potentially serious issues for customers moving backup to the cloud, however, none more so than vendor reliability and recovery.

Question: This question asked the experts for their opinion on the potential improvements made by cloud computing in contrast to the mistakes made by the Dot.com bubble (refer to Figure 6.2 for statements in appendix B for the question).

In this question the expert group were requested to rank their opinions on statements relating to the problems of the Dot.com market crash and why cloud computing will not become a similar ordeal. The two most significant differences were market requirements and a better educated market, both receiving just over 90% agreement mark. The market requirements referred to new cloud applications that attempt to match what the best application in their category offers and then proceed to provide a better interface, better integration with other applications, and more Web features. A better educated market exists in the sense that cloud computing would provide access to applications more quickly than traditional services, thus enabling faster decisions and implementation processes. This statement reflects the fact that cloud computing customers do not own the physical infrastructure, instead avoiding capital expenditure by renting usage from a third-party provider.

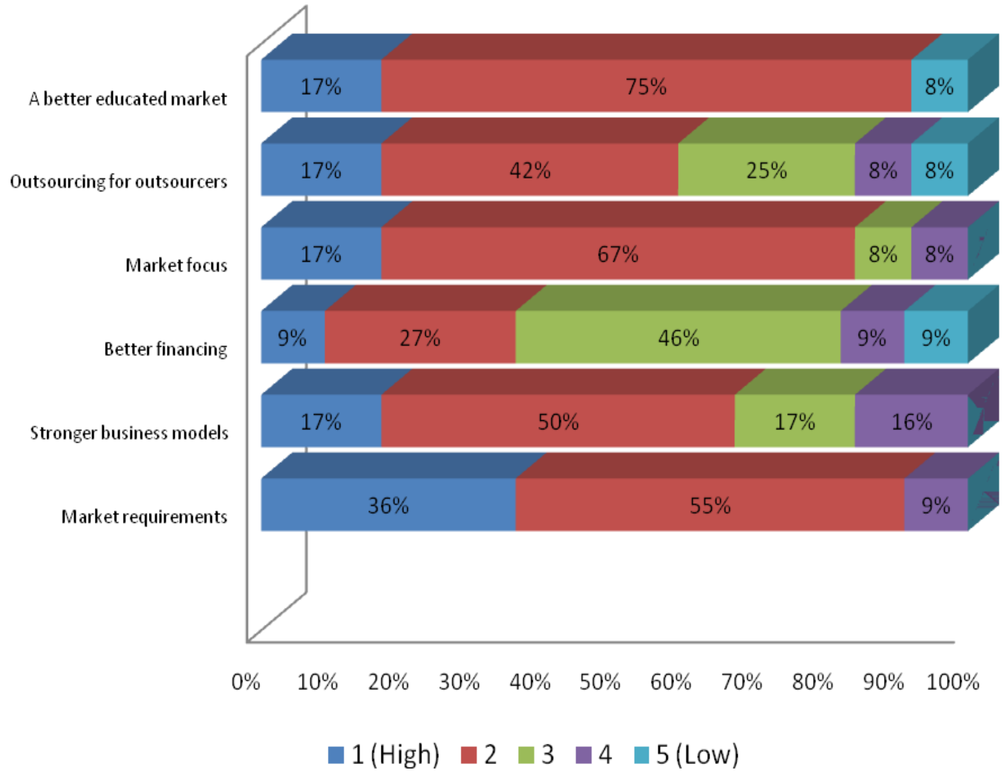


Figure 6.2. Histogram of cloud computing improvements on the mistakes made by the Dot.com bubble, (Adapted from Wohl, 2008)

The market strategy of vendors concentrating only on a particular part of a marketplace meant that vendors are not actively focusing on multiple demographics, unless they have multiple product and market strategies; this resulted in an agreeing response of 84% (Market focus). The issue surrounding stronger business models identifying that cloud vendors plan to monetize their software by either making a charge for each user or each transaction received a modest agreeing response of 67%. This was probably in recognition of the fact that different size enterprises will require different models. The most undecided response of 46% was in relation to better financing, taking into context that venture capitalists have swarmed into the market and provided additional development and more sustainable marketing investments. The reason for the expert group's lack of awareness associated with this improvement is possibly related to the fact that the western world has not yet recovered from the global recession. One of the least positive responses was outsourcing for outsourcers referring to the idea that vendors now believe it is better to seek out a partner for infrastructure than to invest in and run it oneself. The caution shown at this point was similar to the bandwidth issue (if backup services are to be outsourced to the cloud) in the previous question; it was identified as a challenge. The expert group has clearly indicated that the advancements in cloud computing are significant enough to warrant that there will not be a repeat of the Dot.com bubble collapse, however there is still a considerable amount of caution to be exercised in relation to the techniques involved.

Cloud Based Business Opportunities

Question: The experts were asked for their opinion on cloud computing relating to the statements highlighted in Figure 6.3. The attitudinal statements that are used in this question are a summary of the perceived business opportunities that have been identified from secondary research (refer to Figure 6.3 for statements and appendix B for the full question).

In the expert group's opinion, there is a lack of knowledge in the construction industry of the various types of construction cloud applications and, because of the fragmented nature of the industry, a collaboration tool that provides interoperable software is a necessity. This claim was further enhanced by the group's agreement of 85% that the future of ICT is a service deployed from a centralized data centre across a network providing access to applications from a central provider and that cloud computing can act as a major agitator for improving ICT within the industry in the long run. The highest disagreement rank of 46% was related to the notion that the traditional packaged desktop and enterprise applications will soon be made obsolete by Web-based, outsourced products and services which is in contrast to the 77% agreeing response that suggests that cloud computing is an efficient and cost effective outsourcing process that gives company management the time to focus on their business.

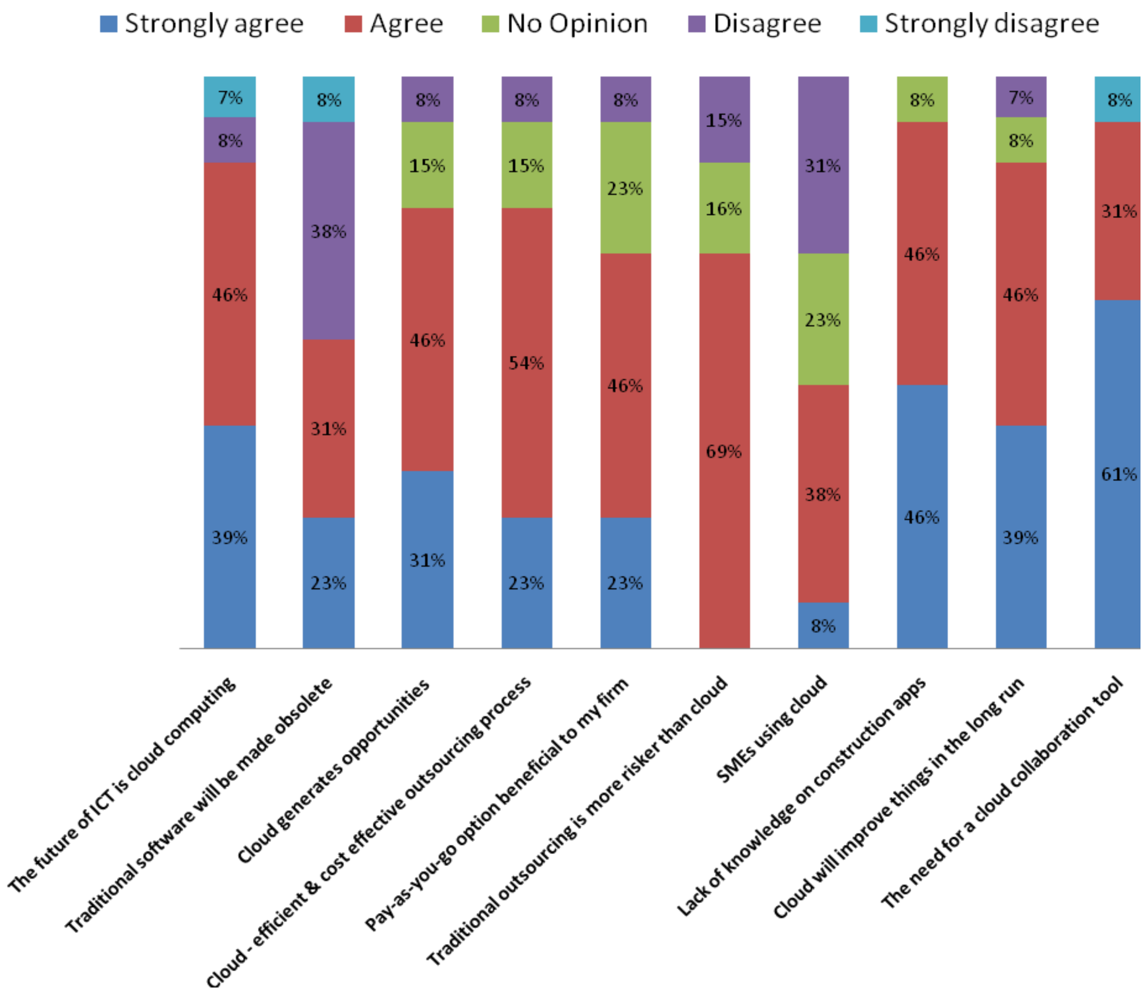


Figure 6.3. Summary of cloud computing.

A similar result to the 77% efficiency of cloud computing was also recorded for the statement that cloud solutions generate better opportunities by enabling enterprises to select more ICT priorities from an ever-growing menu of applications. The expert group has overwhelmingly stated that cloud computing is the future of ICT but they are still reluctant to predict that it is the end for traditional packaged desktop and enterprise applications. As in one expert opinion ‘I don’t believe that desktop applications will disappear. We need to provide strong information assurance for the cloud to progress. We should provide several options for payment, from per-use to annual licenses’. The pay-as-you-go payment option did only receive a modest 69% approval, however, this question was also subject to asking the respondent would they themselves implement it. In contrast to previous questions relating to the risk of security, the view that cloud computing presents information risk, but probably not significantly more than in a traditional outsourced environment, illustrates that the group does acknowledge the potential for cloud computing. Redmond et al. (2010) identified through a study of the barriers for adoption of cloud computing that vendors do not necessarily believe that construction SMEs have the capability of using cloud computing. The expert group's opinion resulted in a mixed outcome of 46% in favour, 23% undecided, and 31% disagreeing. In summarising the industry's productivity; one expert stated that 'Web-based solutions are critically important to increasing efficiency and productivity throughout the construction industry'.

Question: The experts were asked to rank the perceived benefits of cloud computing for the construction industry based on the findings adapted from Ramanujam's (2007) *(*refer to Table 6.4 for statements and appendix B for the full question*).*

The seven proposed perceived benefits of cloud computing were key points as to why Cloud/On-Demand would be a beneficial choice for companies. In analysing the expert group's responses, again disaster recovery was evidently a concern, with the experts indicating a disagreeing response ranking of 4 out of 5 (23%). The highest disagreeing response of 25% was directed towards having the ability to manage a premises-based facility so attention can be redirected towards the customer. The highest agreeing response of 92% highlighted the benefit of allowing one to pay-as-you-go, pay for usage rather than for software licenses and hardware infrastructure. This was in contrast to the previous question concerning summary of cloud computing where the response was only 69%. Both 'managing a premises facility' and 'frequent updates,' (as soon as a new edition of the software is released it is automatically updated on the system) had the highest undecided percentage rank of 25%, thus illustrating the experts prudence towards the potential benefits of cloud computing. The notion of having access to the best of breed technology did, however, result in a 75% agreement whereas 'managing a premise facility' represented the most negative responses of all the benefits. 'Easy roll out and maintenance,' 'spread out costs' (avoiding capital expenses and installation), and 'passing the onus of supporting growth onto the SaaS vendor' (adding additional applications) all received above average agreeing response. In assessing the problems associated with premises-based facilities, one expert carefully summarised this issue, thus; 'Premises-based facilities must serve the mission of the company that builds such facilities. A cloud-based as-built-BIM should be utilized intelligently and effectively by the owner to make better business decisions more quickly. Not all premises-based software needs to be outsourced. That said, increased access to higher quality information is critically important and hosting that information on the Web makes sense'.

Perceived benefits	1 (High)	2	3	4	5 (Low)
Allows one to get out of the business of managing a premise facility	25%	25%	25%	8%	17%
Allows one to pay as you go	33%	59%	8%	0%	0%
Easy roll out maintenance	25%	50%	9%	8%	8%
Spread out cost	23%	54%	23%	0%	0%
Frequent updates	42%	33%	25%	0%	0%
Focus on growth	23%	38%	23%	8%	8%
No day to day maintenance	31%	46%	0%	23%	0%

Table 6.4. Perceived benefits of cloud computing, (Adapted from Ramanujam's 2007)

6.2.2 Summary of Findings

The main findings of the first Delphi questionnaire can be summarized as follow:-

- The results indicated that there are several positive reasons as to why cloud computing should be considered, such as, its ability to increase efficiency and productivity throughout the construction industry.
- In relation to BIM, the experts acknowledged that the key to an integrated BIM is a common database (cloud infrastructure) where component parts of the building are modelled in disparate software programs.
- The experts emphasised, through the business process, that construction development should be treated like manufactured products with standard deliverables managed by a team of professionals with a common purpose but only when the contract had been agreed (as the internal supply chain should only be monitored and structured by the firm undertaking the tendering procedure).
- The expert's reference to the Dot.com era emphasised that cloud was not hype and that its potential has real substance/benefits for SMEs.
- According to the expert's security, vendor reliability and recovering data are the main barriers to cloud computing.
- The main benefit of a cloud-based as-built-BIM is its potential to increase access to higher quality information resulting in faster business minded decisions.
- The matters of whether accountancy and project management applications are the most suited interoperable applications still needs to be determined and the process involved in developing such a service needs further investigating.

- The experts have evidently shown support for the concept but more data must be obtained and analyzed on how this service can be developed to meet the individual needs of professional practices at the design stage of a project.

6.3 DELPHI QUESTIONNAIRE (B): DEVELOPING A CLOUD INTEGRATED LCC ANALYSIS MODEL THROUGH BIM

The methodology used for this questionnaire was designed as an extension to the previous questionnaire (A), for example; using open and close-ended questions were used to evaluate expert opinions towards a particular topic based on revisiting and categorising the results of the initial questionnaire. The initial results for interoperability between three potential BIM applications required further investigation and rethinking, as justifiable findings were not retrieved. The respondent's concern about vendor reliability and recovering data in the previous questionnaire highlighted the barriers against a cloud platform but also prompted contractual measures to be investigated for BIM applications. Integration of BIM applications on a common database had been singled out as a major benefit but the issues of successfully exchanging data at a particular stage needed further research. In relation to the previous findings, the survey comprised of the following sections:

Interoperability for BIM software: This section of the questionnaire comprised of questions based on the Testbed AECOO-1 and the Inpro projects. The starting question requested the experts' opinions on whether the outlined process for advancing interoperability of BIM software should be focusing on Building Performance Energy Analysis (BPEA), 5D BIM cost estimating software or information exchange. The second question queried the need for increasing interoperability standards in the BIM marketplace. Testbed AECOO-1 had effectively identified the need for communication throughout the building's entire lifecycle, so every software application would become interoperable. The Inpro project and Smith (2007) emphasised, that by using open standard BIM there was no need to start from the basics as a large amount of data was already available.

Contractual issues: As this section related to the legal matters associated with BIM, the Inpro project was used. A rating scale of 1 to 5, with 1 being the highest, was used for both questions. The initial question was based on the most severe barriers to BIM implementation from business and legal viewpoints and the second question introduced statements based on the type of contractual terms that should be included in a BIM based project to facilitate open and neutral collaboration processes.

Information Exchange: Being a part of the three key processes for advancing interoperability (BPEA, quantity takeoffs for cost estimation and request for information), the information exchange section comprised of two questions formatted to the Likert scale, and rating scale. The first question requested the opinion of the expert by ranking statements relating to using the industry's most common exchange file mechanisms IFC-STEP and IFC-XML. The second question referenced two statements taken from Testbed AECOO-1 examining the need for an open exchange data model and whether IDMs (used to define what building information is required to achieve a particular specialty analysis) and MVD (used to express information requirements of a particular IDM) are required for incorporation into specifications. The remaining questions were taken from literature (such as Hecht, 2008), questioning the use of Sensor Web Enablement (SWE) in relation to using Web portals to manage energy consumption through BIM and CISCO and Johnson Controls (2008), analyzing whether BIM Facilities Management would be greatly enhanced by BASs.

Developing a BIM LCC system: This section of the survey featured specific statements investigating the need to develop a BIM LCC system. The first question focused on the development of a BIM LCC system that would integrate SWE and BASs. The second question related to the use of IDMs for quantity takeoffs and energy performance analysis, which were then used to define MVDs – standards based subsets of IFCs, as the most efficient solution for integrating 3D models with scheduling and costing for LCC.

The results of the research findings taken from the literature identified in section 6.3 and the findings from the Delphi questionnaire A had been complied and redesigned as questions. As in the previous questionnaire it is envisioned that this technique would provide additional information from the international experts.

6.3.1 Findings and Discussions

Advancing interoperability for BIM software

Question: This question had evolved from the previous Delphi questionnaire with an expert suggesting that the most favourable option for advancing interoperability of BIM software are: (i) BPEA, (ii) Quantity Takeoffs for Cost Estimation, and (iii) Request for information (RFI).

The results indicated that 57%, representing 8 respondents, felt that these three applications were the most favorable services for advancing interoperability. However, 36% disagreed and one individual had no opinion. The question itself analysed the idea that the most beneficial phase to advance interoperability is at the conceptual stage (as in the question RFIs relates to communication project delivery and decision support) and that the three main business areas that are most likely to require interoperability are as previously stated. The open-ended answers revealed several different approaches to advancing interoperability, such as, one respondent's view that data transparency and quality, spatial co-ordination, understanding of data in a spatial context and management of the supply chain data are the main business processes. Another respondent identified RFI workflows, quantities and estimating, and quantities by location for scheduling as the main processes. There was also a respondent who correctly pointed out that building performance is not only about energy, but it is also about comfort and future services provided by buildings. Probably the most significant statement was 'there are dozens of other processes enhanced by BIM and hundreds more we haven't even imagined. These three are important, but are only the tip of the proverbial iceberg'. In summarizing the result given for this question (as shown in Figure 6.5), over half of the respondents agreed that the most favourable processes for advancing interoperability for BIM software are (i) BPEA, (ii) Quantity Takeoffs for Cost Estimation, and (iii) Request for information.

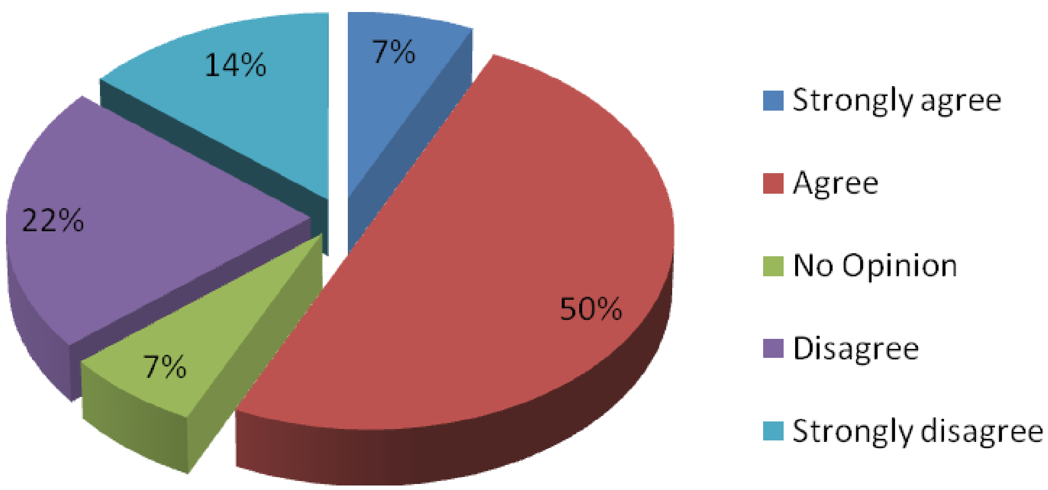


Figure 6.5. Advancing interoperability for BIM software

Question: ‘The second question featured statements relating to increasing interoperability standards in the BIM marketplace, as viable exchangeable software becomes ever more available (refer to Table 6.5 for statements and appendix B for the full question).

The notion that the market is increasingly demanding that open standards are more broadly applied to BIM technologies, so that each partner in a project can comfortably adapt their internal processes received a majority positive indication of 93%. Only one respondent disagreed, which clearly identifies that the way forward for interoperability for BIM is to engage in open standards.

The second statement relating to viable software interoperability in the facilities industry requiring the acceptance of an open data model and the use of service interfaces contained within provider’s software obtained a positive 72% and negative 14% with another two respondents indicating no opinion. This 72% can be seen to support the National Building Information Modeling standards view that an open data model would provide an industry-wide means of communication enabling every software application used throughout the lifecycle to become interoperable. The Testbed AECOO-1 maintained that within a design project, there is little need to share all aspects of the design between project participants, and what is relevant is to exchange elements of design between the architectural firms or general contractor and subcontractors with specific areas such as lighting, energy usage, building cost and HVAC. The expert panel had a mixed response to this statement with only 57% agreeing. The 43% of the expert panel that did not agree with the Testbed AECOO-1 model was because some of the experts may be inclined to believe that all information should be shared no matter what process stage the project is undertaking.

The next statement was designed to clarify the necessity to have interoperable applications shifting away from stand-alone legacy systems. Testbed AECOO-1 had identified the potential benefits of having multidisciplinary project teams that work together with data sharing tools and common information models thus achieving better and faster results. The expert panel clearly agreed with this concept, delivering a positive response of 93% and only 7% having no opinion. The final statement referred to using open-standard BIM, in which designers do not need to start from the basics because a large variety of building typological systems and subsystems are available as the basis of their design.

Increasing interoperability standards	*Strongly Agree*	*Agree*	*No Opinion*	*Disagree*	*Strongly Disagree*
• The market is increasingly demanding that open standards be more broadly applied to BIM.	14%	79%	0%	7%	0%
• Viable software interoperability requires the acceptance of an open data model.	22%	50%	14%	14%	0%
• Within a design project, there is little need to share all aspects of the design between project participants.	21%	36%	0%	43%	0%
• Multidisciplinary project teams that share tools and information achieve better results than using traditional applications.	36%	57%	7%	0%	0%
• With open-sourced BIM, designers can plug into an existing variety of typologies, systems and subsystems.	7%	36%	36%	21%	0%

Table 6.5. Increasing interoperability standards in the BIM marketplace

Having open-sourced design systems that have incorporated BIM enables buildings with high architectural quality to be designed, produced and delivered according to systematic procedures, which allow effective control and value optimisation for the clients and end users. Only 43% of the expert panel agreed with this theory, 36% had no opinion and 21% disagreed. The open standard aspect was meant to represent a model server (hosting BIM software) and an open communication platform for information sharing. It is possible that the expert group confused this with Open Source Software (OSS) where co-operation is promoted between the user and owner of a software product by removing obstacles imposed by the owner, such as copyright law. The overall findings of this section illustrates that there is a need to share information through open standards with an industry demand for applications to become more interoperable.

Contractual issues

Question: The experts were asked to rank in order the most severe barriers to BIM implementation from business and legal viewpoints taking into consideration the issue of intellectual property rights (refer to Table 6.6 for the barrier statements and appendix B for the full question).

The barriers were categorized into five main issues and structured in a rating scale format. The first barrier asked if there is a lack of immediate benefits of BIM for the stakeholders. This produced a response of 50% disagreeing and 36% agreeing indicating that the expert panel partially sympathizes with the stakeholders need for immediate ROI. However, the 50% level of disagreement demonstrates that there are immediate benefits to BIM possibly referring to its ability to identify early cost savings, such as modifying a previous design.

The next barrier highlighted the issue of changing roles, responsibilities and payment arrangements resulting in 50% agreeing, 21% disagreeing, with no opinion at 29%. The Inpro project claims that there is a lack of clarity over the changing roles and responsibilities; for example, is the architect still the lead designer in the integrated design and engineering? Who is in charge of the total quality of the design? Who assures that all interface problems (clash detection) are solved and that the model is fully secured from cyber attack against confidential data? These are just some of the issues and the results of the expert panel opinion showed a 50% acknowledgement of this barrier and 29% unsure, which demonstrates that this is an issue that needs to be resolved.

The barrier associated with the uncertainty of the legal status and intellectual property rights attributed to the model generated a 79% agreement with this statement of which 22% of the panel ranked it as number 1 (their highest barrier) and only 14% disagreed. The major issue relating to this barrier is to what extent anyone can claim ownership of the intellectual property; if the model is deemed to be collaborative work, then ownership may not be vested in a single party.

Eastman et al. (2008) acknowledged that there are no obligations to adopt an agreement or integrated contract for BIM; however, if stakeholders intend to achieve open collaboration, they should opt for an integrated contract.

The next barrier concerning the inadequacy of the existing contractual frameworks, including the agreements on liability and risk locations featured a response of 62% agreeing and no opinion of 23%. There are major concerns with who is liable for information in the digital model and how the users are protected and this may be the reason for 62% of the expert panel agreeing with this barrier.

The final barrier referred to the lack of consensus on the protection of information during conversion and interoperability and against loss and misuse of data.

Barriers of BIM Implementation	1 (High)	2	3	4	5 (Low)
• Lack of immediate benefits	7%	29%	14%	36%	14%
• Changing roles/responsibilities	14%	36%	29%	14%	7%
• Uncertainty of the legal status	22%	57%	7%	7%	7%
• Inadequacy of existing frameworks	23%	39%	23%	15%	0%
• Lack of consent on protection of information	7%	14%	43%	22%	14%

Table 6.6. Barriers to BIM implementation

The response received a mixed reaction from the panel with a no opinion of 43% and 36% disagreeing, and 21% agreeing. The final barrier in Table 6.6 is connected to the perception that there is a necessity within the industry for an agreement on the standard of care and possible conflict resolution in data management as an integral part of the contract.

The results of the survey are inconclusive possibly because there are already standards and agreements available for data managements; however, they are country-specific. The results of the 5 statements emphasised the major barriers to implementing BIM reflecting a single model created by many disciplines as the main problem due to claim of ownership, who is liable, who is in charge of the total design, whether it should be an integral part of a contract and can the stakeholders benefit from such a model.

In response to the open-ended question requesting further barriers to be identified, the expert panel views varied. One expert claimed that there is a lack of understanding of how to use BIM and lean business methods particularly in a collaborative business arrangement; this view was supported by another expert who also considered the lack of understanding of how to effectively use BIM in a team environment as a major barrier. For another expert the biggest challenge is the cultural shift that is needed as traditionally the status quo is the largest drawback for skeptics. The most significant statement identified the issue surrounding insurance: ‘In the U.S. market, integrated teams are hamstrung by the lack of effective insurance products that protect the team; as a whole there is a huge market opportunity on the horizon for project insurance that protects the integrated team as a whole’.

Question: The focus of this question was about drafting contractual terms based on problems associated with implementing a BIM project. These terms would also facilitate an open and neutral (transparent) collaboration process, thus, increasing the interoperability standards in the BIM marketplace (refer to Figure 6.6 for the barrier statements and appendix B for the full question).

The question was formatted to rating scales 1 – 5 (1 being the highest). The first statement highlighted the contractual issue of agreeing modeling protocols, sharing and integration of open technology and then proposing a solution, endorsing internationally accepted open standards. The expert panel rated this as 58% in favour and 24% against.

The ability to have clauses relating to the workflows, level of authorization, and access rights in a BIM-based decision-making virtual project received a response of only 50% in favor and a low 14% against. The highest no opinion of all the statements (36%) was in reference to this statement. This response was very much in line with question 3 relating to the level of clarity over the changing roles and responsibilities, where the results of both statements indicate a high rate of no opinion and an average of 50% in favour. The concept of including a clause for the intellectual property of the foreground and background information and knowledge received an average 62% in favour.

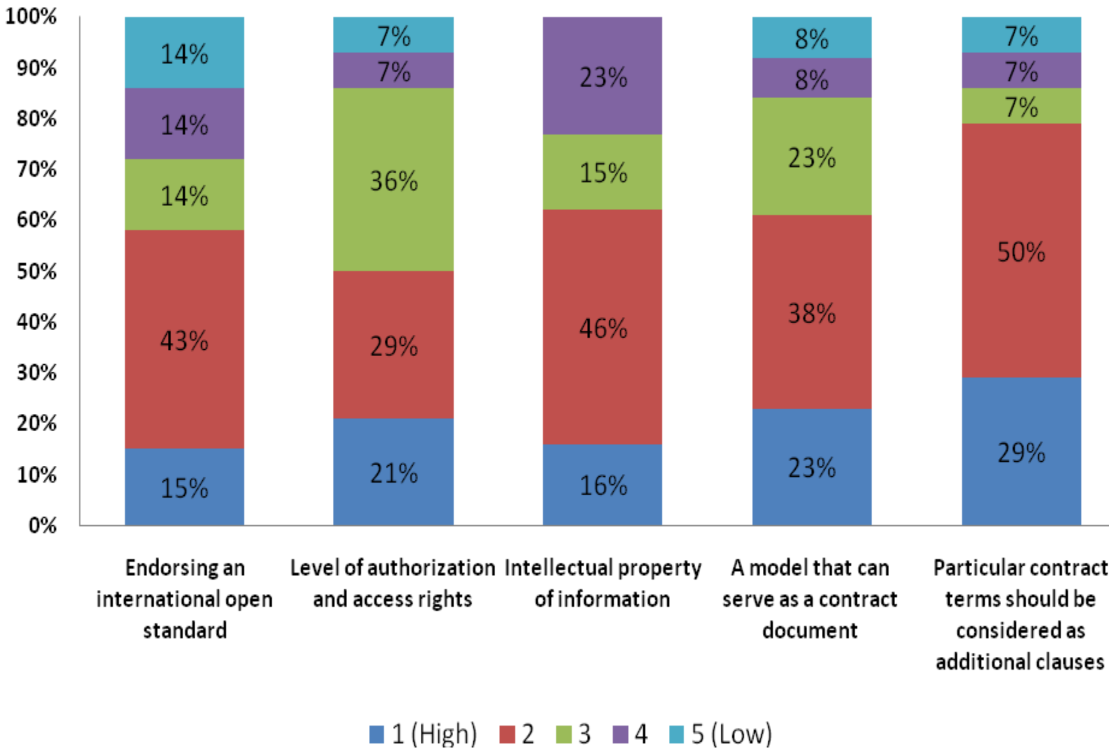


Figure 6.6. Contractual terms to facilitate open and neutral collaboration

The Inpro project had identified an alternative approach for the legal status of such a model by enabling the model to serve as a contract document that is used between contractual parties, but is not to be submitted to permit-issuing agencies (local authority). This received a favorable response of 61%, 23% no opinion and 16% not in favour. The Inpro project identified that if this is not the case, the model may become a document which provides the visualization of the design intent from contract documents. This may also be the reason why the results reflecting the previous suggested terms (Figure 6.6) had such a mixed response.

The final statement emphasises that depending on the selected contract form and procurement method, particular contract clauses should be considered and added to the contract. The clauses identified were establishment of partnering, the legal entity of the enterprise, clarify roles and responsibilities, agreement on payment, and dispute resolution using BIM. The survey results supported these clauses with 79% of the expert panel agreeing and only 14% not.

In summarizing the key issues identified, one expert stated ‘integrated agreements only work if the team members trust each other, trusted business relationships emerge over time; it is naive to think we can “catch the magic in a bottle” via a contract’. The expert suggested that the best opportunity for creating such teams is the marketplace, and owners can advance the creation of such teams through effective Requests for Proposals.

Information Exchange

Question: This question investigated the expert’s preference on which open standard exchange mechanism (IFC and XML) would they be more in favour of using (refer to Figure 6.7 for statements and appendix B for the full question).

This question allows analysis of statements based on whether the construction industry will pass files via STEP or XML. The first statement identifies the computer language EXPRESS, which is one of the main products of ISO-STEP which can represent conceptual or abstracted objects, materials, geometry, assemblies, processes and relations as a unfamiliar format for providers to maintain and stresses that it is not presently in their source-code product offerings and that IFCs will continue to be marginalized. The results showed that there were an equal number of experts who agreed with those who probably did not understand the statement, with comments such as, ‘I’m not sure what EXPRESS is’ (36% - not understanding the statement, while 28% disagreed).

The following statement investigated the issue of using an EXPRESS language to exchange information in a Web service, and referencing it as a weak implementation with insufficient mainstream market adoption. This statement received a high no opinion of 57%, 28% disagreeing and only 15% agreeing. The notion that the industry has already moved towards the exclusive use of XML standards with services protocol to enable communications such as Open Building Information eXchange made for Web services integration to BIM software resulted in a no opinion and disagreement of 36% with only 29% agreeing.

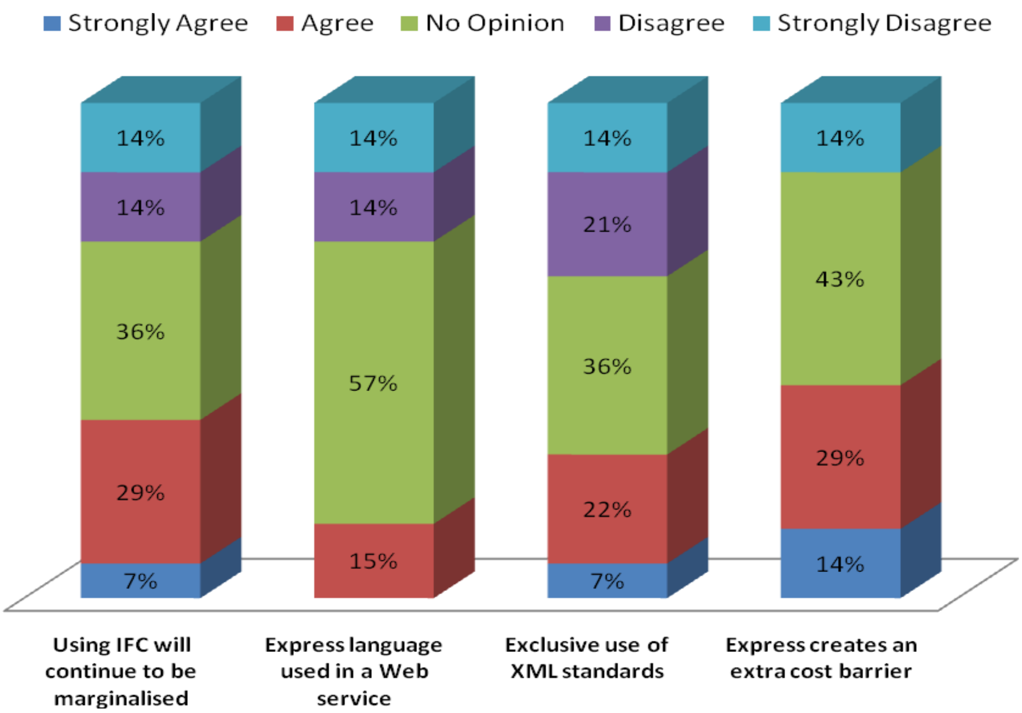


Figure 6.7. The respondent's preference of exchanging open standards; IFC (STEP) – ifc XML

The final statement summarised that XML is designed to work with Web services and there are already available software standards to facilitate the adoption of existing AEC-based XML encoding and schema. The issue as to whether EXPRESS creates an extra cost barrier received a high no opinion from the expert panel (43%). However, the open-ended question provided mixed comments from the experts, with one expert stating that he was unsure of what EXPRESS relates to (a data modelling language). For those who did, the response varied from stating that XML is fine as a short term solution (to exchanging data) but will be problematic in the long term, to the identification from another expert that he is trying to incorporate Associated General

Contracting (agc) XML (a set of XML schemas designed to automate and streamline the exchange of information) in to the main stream construction industry with IFC-compatibility. In summarizing the comments of one expert; 'EXPRESS needs to address a complex environment such as this, and there needs to be debates as to how data and process tools are implemented as Web services, but essentially one cannot escape the fact that the model needs to be designed and completed before trying to achieve any other adaptations.'

Question: This question focused on the respondent's attitudinal opinions in relation to information exchange requirements for software interoperability. It also featured the possibility of using schemas for enhancing BMS (refer to Table 6.7 for requirement statements and appendix B for the full question).

This question was a series of statements relating to information exchange and the concept of using semantic tagging (allowing one to describe items put on to the Web in order to allocate them), sensor Web enablement (a type of sensor network on geographic information system that is especially suited for environmental monitoring) and Building Automated Systems. The initial statement targeted the industry's requirements for software interoperability through exchange definitions, adoption of an open exchange data model and a common interface to the exchange data model for use by any participating application. The results were overwhelmingly in favor of this concept with only 7% either disagreeing or of no opinion. The following statement reviewed the concept of using MVDs and IDMs for incorporation in specifications to be implemented into the structure of software. The majority of the experts agreed with this concept (76%). The notion of using semantic tagging to assist the overall schema for building information in identifying (i) energy efficiency, (ii) manufacturer name, (iii) serial number and (iv) warranty, received only a 50% in favour for using this service. In identifying if sensor Web enablement (see section 6.3) should be incorporated into a BIM model to optimize energy usage, the expert panel gave the highest negative response of 43% disagreeing, while only 21% were in favour. The final statement related to analysing a BIM system for facilities management by importing HVAC and utility meter readings into accounting systems and automatically generating tenant bills. The expert panel was more in favor of this concept with 46% agreeing, however 23% had no opinion and 31% disagreed (8% + 23%), illustrating that neither of these systems have the potential to be successfully adopted.

Information Exchange	1 (High)	2	3	4	5 (Low)
• Adoption of an open exchange data model.	36%	50%	7%	0%	7%
• Incorporating IDM and MVD into specifications.	29%	43%	14%	0%	14%
• Semantic tagging assist overall schema for building information	0%	50%	29%	14%	7%
• Sensor Web Enablement incorporated into a BIM	14%	7%	36%	36%	7%
• BAS would greatly enhance a BIM FM	15%	31%	23%	8%	23%

Table 6.7. Information exchange requirements

Developing a Cloud BIM LCC system

Question: This question asked the respondents for their opinion on whether it was viable to actually develop a BIM Life Cycle Costing (LCC) system that included the integration of Sensor Web Enablement and Building Automated Systems.

As noted from the previous answer, this concept received a mixed reaction which may have evolved not from the uncertainty of the technical aspects but more from the need of having such a system when so many BMS systems already exist. One expert listed some of the the enterprises who are already involved with BMS; Onuma System, IBM, Siemens, and DASSAULT Systems. The expert respondent continued by clarifying that only Onuma System purports to do this in a way that enables typical BIM users to implement open standards. The final comment attached to this experts view was that 'the question is whether the Construction Industry is ready for the tsunami of change that will occur when this becomes economically viable'.

Question: The NBIM V1 document (NBIMS, 2007) had highlighted extensively the benefits of using MVDs and IDMs for defining how and when to exchange data, thus creating an efficient solution for integrating 3D models; the additional aspect of using scheduling and costing for LLC was an afterthought that needed to be fully investigated.

This question was derived from the existing case study Testbed AECOO-1 in the U.S. and, presumably, because this concept is relatively new, it may have needed more clarity, as the majority of the responses were unsure. Of the 6 experts who did respond 5 were in favor and 1 disagreed. The open-ended question identified that out of the 6 responses, the majority of them were confused, however, 2 experts did provide interesting feedback with comments, such as 'eventually, but it may be worth progressing through an intermediate COBie style stage (a formal schema that helps organise information about new and existing facilities) and to progress more quickly with smaller steps' and 'yes – we are also working on a stakeholders activity model – an activity node tree program with common activities to link independent MVDs (subsets of IFC)'.

6.3.2 Summary of Findings

The main findings of the second Delphi questionnaire can be summarized as follows:

- The interoperability for BIM software section highlighted that the most beneficial stage in which to advance interoperability is at the conceptual design stage with BPEA, 5D, and information exchange identified as the most favourable design processes.
- The results also suggested that, in the opinion of a small selection of international experts, the market is increasingly demanding open standards to be applied to BIM and that having multidisciplinary project teams that work together with data-sharing tools and common information models achieve faster results in comparison to standard legacy systems.
- The contractual issues associated with BIM listed several barriers of which the uncertainty of legal status and intellectual property of the model were ranked as the highest, followed by concern over the inadequacy of existing frameworks, including the liability and risk locations.
- In addressing some of the major issues related to facilitating open and neutral collaboration, the expert panel identified that, depending on the procurement route, particular contract clauses should be considered. These included the establishment of partnering and the legal entity of the enterprise, format roles and responsibilities, agreement on payment features, and dispute resolution using BIM.

- The emphasis on standardised passing of information between systems recognised that only when every design software package can read and write to and from a centralized Web hosted database, will this concept be achieved, which reiterates the notion of using an integrated model.
- The most disappointing factor of the information exchange section was the amount of uncertainty in relation to the questions, partially because the concept of using a marginalized IFC or a set of XML schemas designed to automate and streamline the exchange of information was not investigated effectively.
- The need for the construction industry to have software interoperability through exchange definitions was clearly evident, and it is this adoption of an open exchange data model and a common interface to the exchange data for use by any participating application that will allow the LCC model to succeed.
- The final section of the survey based on developing a Cloud BIM LCC system showed that certain elements of FM, such as BAS and SWE, are beneficial if used through Web services but at the moment these tools are not generally viable and are very complex.
- In further analysing the information exchange concept of IDMs and MVDs, one expert issued caution but insisted that it would be worth progressing through an intermediate COBie style stage with the industry focusing on small steps to adoption.

6.4 CONCLUSION

The results of the first Delphi questionnaire highlighted the risks involved with using a cloud platform to share applications openly, such as, vendor reliability and recovering data. However, the majority of respondents viewed cloud computing as a positive form of physical infrastructure that would increase efficiency and productivity. The potential of using an integrated BIM, through a cloud service, was registered as a key benefit to aggregate parts of the building modeled in disparate software programs. The 3 main core sections of the initial questionnaire, namely business process, cloud computing capabilities, and cloud-based business opportunities, all provided evidence that a service based on cloud computing and standardized deliverables would provide greater market opportunities for the construction industry. Cloud-based as-built-BIM (built to the models specifications) was acknowledged as a service that would improve earlier design decisions. However, whether applications, such as, accountancy and project management should also feature as the main applications for interoperability failed to receive a positive response.

In further analysing the three main suggested BIM applications to be tested for advancing interoperability at the early design stage, BPEA, 5D, and request for information, the majority of the respondents agreed. The respondent's requests for open standards between multidisciplinary project teams highlighted the issue of using a propriety-file based exchange mechanisms between BIM applications. A centralized Web hosted database was recognized as the main platform for creating a standardized passing of information between systems.

The respondent's response to the issue of whether to use IFC-STEP as exchanging language instead of IFC-XML favored XML because of its Web services integration ability with BIM. However, on further investigating EXPRESS, the majority of the respondents were unsure of its meaning. In respect to semantic tagging SWE and BAS for incorporation into BIM, the majority of responses related to a high level of 'no opinion,' reflected a lack of knowledge on the topic. However, the respondents did acknowledge overall the value of exchanging information on a Cloud BIM for analyzing energy performance and costing of buildings through the use of 5D estimating.

The fact that many of the results were inconclusive prompted the need for undertaking semi-structured interviews based on refining the results of the data collated from each of the surveys. In the following chapter, semi-structured interviews will analyse the results of face-to-face interviews with industry experts, based on information extracted from the Delphi questionnaire, such as using cloud computing to exchange BIM data through XML.

Author's key findings in relation to the thesis objectives:

Objective 2: To discuss how cloud computing and BIM can support the future development of interoperable software - The expert respondents in this chapter viewed cloud computing as a benefit to increasing efficiency and productivity throughout the construction industry.

Objective 3: To investigate the potential of cloud computing and BIM in re-engineering early design processes - In this chapter the international experts acknowledged that the key to an integrated BIM was through a common database (cloud infrastructure) and that the business process should be treated like a manufacturing process.

Objective 4: To establish expert opinion on advancing interoperability of data exchange through the use of Cloud BIM - the applications identified in Chapter 5 were not fully supported by the experts in the first Delphi Questionnaire and in the second Delphi questionnaire: BPEA, 5D, and RFIs were recognised as the most favourable business processes

Objective 5: To identify the need for an agreed information architecture framework that will create an interoperable layer of business processes - The second Delphi questionnaire identified that IDMs and MVDs should be incorporated into specifications to be implemented into the structure of software. This section also recognised that when only every design software package can read and write to and from a centralised Web hosted database then standardisation will be achieved. Section 6.3 initiated the investigation of contractual issues associated with BIM. The findings reported that uncertainty of legal status and intellectual property of the model was ranked the highest. Further analysis suggested that particular contract clauses should consider including the establishment of partnering, format roles and responsibilities, agreement on payment features and dispute resolution using BIM.

Objective 6: To measure the ability of advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform - The international experts acknowledged that the main benefit to a cloud-based as-built-BIM is its potential access to higher quality of information resulting in faster business minded decisions. Also in this chapter IFC-XML was favoured as the exchanging format instead of IFC-STEP as XML creates Web service integration.

CHAPTER 7

EXPERT'S OPINION ON ADVANCING INTEROPERABILITY OF DATA EXCHANGE THROUGH THE USE OF CLOUD-BASED BUILDING INFORMATION MODELING

7.1 INTRODUCTION

The emphasis in this Chapter is to present the results of structured interviews of 11 industry-related expert's views on how to achieve significant improvement in cost, value and carbon performance by applying an integrated information exchange process that can be readily transferred to project teams using 'Cloud BIM' software. The concept of using Cloud BIM middleware (see Figure 2.3 Chapter 2) was based on creating and modifying new data by using SOA and plugins. In order to eradicate the old model of 'importing' all data into one desktop-bound system and supporting a new process based on a similar concept to CAD-BIM integration but extending the connectivity through an open platform for facilities management and creating the possibility of linking with many other applications.

The structured interview questions were derived from the previous series of techniques; a main survey questionnaire, development of focus groups and two Delphi questionnaires, as highlighted in Chapter 4 section 4.4. In general, the research questions focused on 'human centered design', a process in which the end-users of a product are given extensive attention at each stage of the design process. The categorised sections of the second questionnaire had identified topics for investigation, such as, integrated agreements, adoption of new technology, standard business practice for exchanging information, the debate on whether to use IFC XML rather than IFC STEP (referring to the importance of Web-based exchanges), and the value of using an internet platform such as cloud computing to host 5D BIM, BPEA software for post-occupancy calculations, specified documents and building performance. One of the major issues addressed within the semi-structured interviews, described in this chapter is how to develop a simple exchange format for compiling building information that could contribute to exchanging information more effectively and efficiently throughout the building life cycle. A possible solution is the binding of heterogeneous applications through a central repository platform, such as in "cloud" computing, which has created a way for different applications to openly interoperate and exchange information.

The author contends in this chapter that for the industry to eradicate inadequacy when producing construction information; which has influenced the fragmented industry processes of using standalone legacy applications to produce data; a simple automated process must be implemented. This chapter will identify the core principles of how the industry can change, in order, to streamline BIM data exchanges based on using a middleware platform, such as cloud computing (to identify the potential adoption of Cloud BIM and the need to restructure business process work flows by re-engineering the design process).

7.2 STRUCTURED INTERVIEWS

The aim of the semi-structured interviews was to explore how to apply an integrated process that would advance key decisions at an earlier stage through faster information exchanges and best practices during collaborative work that can readily be transferred to project teams using Cloud and BIM software. To expedite this goal, 5 main objectives were defined (i) To discuss advancing interoperability for BIM software, (ii) To further identify the various contractual issues associated with implementing Cloud and BIM in a construction project, (iii) To explore and discuss how BIM cloud-based services can be offered, such as the adoption of new technology and the need to restructure work flows by re-engineering the design process, (iv) To examine the requirements for an agreed information architecture framework that will create an interoperable layer for open data exchange, common to a building project that requires information exchange between specialised software packages, and (v) To explore the possibility of developing a model for exchanging information based on software programs that would lead to advancing interoperability of BIM applications. The 5 objectives were then formatted into 6 categorised sections, namely: Capabilities of cloud computing; Interoperability of BIM software; Contractual issues (relating to Cloud and BIM); Business processes; Information exchange; and cloud-based BIM life cycle service. These sections were classified in a structured sequence that enabled the interviewees to reflect on the previous section to allow them to identify how the topics were related in a manner which would extract the knowledge content needed to formulate an educated taxonomy.

Capabilities of Cloud Computing: This section comprised of two questions initially inquiring if the interviewees had an understanding of how cloud computing could assist the industry and their company, in particular. It also tried to define what the most important barriers were from a construction perspective.

Interoperability of BIM software: This section was designed to investigate the interviewees' opinions on what is the most beneficial stage for advancing interoperability for BIM software and the importance of open standards for BIM. The final question in this section was an inspection of whether cloud computing could contribute to advancing interoperability.

Contractual issues: This section focused on Cloud Computing as an integrated platform for BIM applications 'Cloud BIM' as they all share similar legal uncertainty relating to risk, such as, who is responsible for managing the content of a Cloud BIM service and the barriers associated with using a Cloud BIM system when exchanging information. The final question in this section was designed to identify the potential of having a contractual agreement for facilitating open and neutral collaboration.

Business process: This section, in conjunction with the next section on 'information exchange', was designed to highlight standard business practices. The initial question concentrates on identifying the drivers of Cloud BIM before moving on to the main question, which explores the use of standard business practices to address the information exchange requirements. The next question focuses on identifying the most suitable procurement route. The final question refers to advancing technology, whether the industry is ready (known as e-readiness) for this radical change and, if so, is it due to a technological shift or is it simply due to software vendors' marketing psychology.

Information exchange: The main focus of this section is the need to enable faster design decisions based on exchanging and retrieving construction data. In order to identify a framework based on exchanging data the two main mechanisms, namely, IFC XML and IFC STEP were investigated.

A Cloud-Based BIM Life Cycle: This section of the interview process examined the notion of using a service that has an ability to host 5D BIM and BPEA data for post-occupancy calculations, specifications and building performance. The respondents were requested to identify potential features of an integrated platform that could utilize a Web-based energy performance analysis service, in order, to estimate the Life Cycle Costs of a building.

It was anticipated that by engaging the 11 interviewees (see Chapter 4 section 4.4) associated in this semi-structured interview process and investigating the 6 key areas, a practical interoperable solution for a cloud-based Web service model for exchanging BIM related applications would be achieved.

7.3 CAPABILITIES OF CLOUD COMPUTING

Introduction

The capabilities of cloud computing section was the first of six that were designed to investigate the potential for developing a framework based on exchanging BIM data on a cloud computing platform. The first two questions focused on what cloud computing may possibly mean to the construction industry and the perceived obstacles for using it.

Question: What are the capabilities of using Cloud computing that are most prominent to you?

In identifying whether or not the interviewees actually understood what cloud computing is, their responses were compared to The National Institute of Standard Technology definition Petri (2010), which refers to cloud computing; as a model for enabling convenient, on-demand network access to a shared pool of configurable resources that can be rapidly provisioned and released with minimal management effort or service provider interaction, or to the definition Armburst et al. (2009) that cloud computing is both the applications delivered as a service over the internet and the hardware and systems software in datacenters that provide those services. All of the 11 respondents mentioned some aspects of the two definitions. The majority of the responses recognised it as an Internet-based service over the Web with one statement highlighting the on-demand aspect and defining a key feature, as one for which the user can have a server running simultaneously with other servers and which allows users to login to that server and request specific data. Only two of the respondents referred to the various deployment models, ‘public and private’, with general reference being made to a private cloud, as a collection of servers being used by large organisations restricting the amount of open access services available. In assuming how cloud computing can assist their associated company, 7 of the respondents viewed sharing and accessing information as an asset relating to various departments within their company and with their supply chain. The remaining 4 respondents highlighted its ability to reduce the level of investment in terms of computer power and using an infrastructure based on a service rather than a purchase. There were clear references made to both BIM and energy savings with the notion that ‘families’ (architectural building block that are categorised by specific properties) in BIM are perfect for the cloud computing arena and to the possibility of having some algorithms in energy saving techniques including monitors for different types of buildings (BMS). The concept of having multiple servers to enable ‘mash-ups’ (mixture of software) was viewed by one interviewee as a vehicle for reducing the barriers of interoperability.

Question: What in your opinion are the main obstacles to using a cloud platform?
The main barriers against using a cloud platform were security and legal issues. The security problems predominantly focused on data security - not knowing where your data is and who can access it. In relation to legal issues, one interviewee identified the problems associated with exchanging data, such as, the need to define the process, so that people can transact using contractual and changing ownership of data through the life cycle of the project. Some respondents did, however, suggest that the cloud is no different in its security issues than relating to how one may manage one’s data over the internet. The next major barrier identified was bandwidth due to the problem that some construction sites, being located remotely, experience with connectivity. The notion of the users not having the necessary knowledge as to how to simply use cloud computing was also identified, with one such respondent stating ‘Cloud computing can achieve much but it will take a lot of education and considerably more participation between companies.’ The top obstacles to and opportunities for the growth of cloud computing (Redmond et al. 2011a and Armburst et al. 2009) were such obstacles as data confidentiality and auditability, with solutions involving deploying an encryption, and firewalls (see Chapter 6 section 6.2.1). However, encryption was listed as a drawback by one interviewee who acknowledged that because government agencies have secure servers and firewalls, it makes it difficult to collaborate and to connect to the cloud.

Q1	**Cloud computing assisting their companies**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
	1	Share and access information	■				■	■	■	■		■	■	7
	2	Reduces levels of investment		■	■	■					■			4
Q2	**The most important barriers**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
	1	Security and legality	■				■		■	■	■	■	■	7
	2	Bandwidth		■		■		■						3
	3	Education			■									1

Table 7.1. Summary results: capabilities of cloud computing for respondents 1 to 11

Summary of the results

The respondents have identified that there is credibility in using a shared platform that can provide a service that integrates with other Web-based applications, thus reducing the level of investment on infrastructure. However, security is an issue but probably the greatest drawback is privacy; as one respondent described it, he does not want everybody to be analysing his changes in real-time, only when, and if, he has published it. This respondent's point also highlighted the debate on whether or not to have a private or public cloud. In relation to the said statement, the respondent preferred a private cloud up until the stage of full openness with other design team members.

7.4 INTEROPERABILITY FOR BIM SOFTWARE

Introduction

The interoperability for BIM software section not only investigated the most interoperable stage for BIM software but also whether cloud computing could contribute to advancing interoperability of BIM applications.

Question: At what stage of the project do you think value can be most gained by advancing interoperability for BIM software

The question of what stage can most value be gained by using interoperability for BIM software delivered four different outcomes, namely; (i) the whole life cycle, (ii) the design stage, (iii) operation and maintenance, and (iv) design, operate and maintenance stages. The 3 respondents who identified the whole life cycle were adamant that every stage of the project would receive benefits from advancing interoperability. One such respondent stated that 'the contractor does not really impinge on the early design stage, however, the contractor should be interested in interoperability due to its impact on adding value when designing the project and putting it together, as it impacts on the total cost of the facility.' The most favoured stage was design, 'the early CAPEX (capital expenditure) stage,' based on the reason that this key decision stage uses cost, carbon and value information, with corporate social responsibility (encourage a positive impact through its activities on the stakeholders), to define the class of building, where it will be situated and how it will be created from the best of new technology available. The respondents also acknowledged that as soon as one is working with a consultant who is using a different software format then interoperability becomes an issue and, in order to bring a consortium together to develop a project, a platform has to be decided on straight away. However, as one respondent identified, there is an assumption that all of the information will be provided in a BIM model at the early design stage, which is not necessarily so. With BIM there is a lot of information but the model needs to grow and with interoperability changes can be updated more easily. The operation and maintenance stage was viewed as the phase that has the biggest opportunity to gain value, as energy usage is considered as a priority in modern buildings. The notion of not requiring interoperability after the design stage was viewed as being irresponsible as there is a significant need to share specific data after a building has been completed and the current procedure to collect and manage data is slow and expensive.

Question: In your opinion, can cloud computing contribute to advancing interoperability of BIM applications?

The overwhelming majority of respondents felt that cloud computing could contribute to advancing interoperability for BIM applications. There was, however, a number of interviewees that questioned the need for this process with statements, such as, 'As sharing information becomes more and more common, if one wants to share information, then interoperability / open standards are quite important but one could use these files and data without cloud computing'. Two other respondents' statements similarly supported this notion that interoperability of software is between two pieces of software and it does not matter if the software is hosted in a cloud or locally. However, on reflection of their answers, each respondent did give a positive conclusion, such as, 'I suppose what it can do is provide a central repository that people can feed information into but there needs to be the development of an application that can read various formats and combine them into a single format'. The majority of the positive responses focused on the issues of reducing expenses from the point of view that using BIM information from a cloud would reduce the need for having all the data hosted on premises, to the fact that small highly technical companies who implement design in a two- or three-man office would have the technology for a large project without the requirement of large capital investment in computing power. The issue of using IFCs through the Web was also featured in the responses, with references relating to performances, such as ecology, people, emergency planning, carbon footprint, and cost plans being connected to Web-services implanted on top of conventional GIS layers by different sets of IFC data. However, one interviewee did contest the issues of using only IFCs 'I think the challenge of organisational bodies is that they are very focused on IFC, without challenging it and we cannot only focus on IFC; we need to focus on very simple exchanges, much like sensor connection and data which can be very simple.'

		At what stage can value be gained from BIM advancing interoperability	1	2	3	4	5	6	7	8	9	10	11	Total
Q3	1	The whole life cycle	■	■						■				3
	2	The design stage				■		■	■		■	■	■	6
	3	Operation & maintenance					■							1
	4	Design and O & M			■									1
Q4		Can cloud computing contribute to advancing interoperability for BIM applications	1	2	3	4	5	6	7	8	9	10	11	Total
	1	To some extent	■			■	■							3
	2	Definitely		■	■			■	■	■	■	■	■	8

Table 7.2. Summary results: interoperability for BIM Software for respondents 1 to 11

Summary of the results

In the responses to the 'Interoperability for BIM software' questions, the concept of using the early design stage of a project for advancing interoperability started to become more prominent through a respondent's statement that, with interoperability, existing data can be upgraded to new data (meaning previous existing models can be bastardised to develop features of new models). It was noted that because applications are becoming more machine readable (computer, can read and interpret the data in a record), the internet is having a major part to play in promoting standards and, unlike what previously existed where one vendor's software could become the industry standard, now many applications will be integrated through the Internet. The prospect of using the cloud eradicates the different problems of working environments having different firewalls, technologies and hardware/software.

7.5 CONTRACTUAL ISSUES WITH CLOUD AND BIM

Introduction

In developing a framework for using Cloud BIM the author viewed existing contractual problems of exchanging digital data and the need to have terms that facilitated open and neutral collaboration as key points to be examined.

Question: What, in your view, are the major contractual barriers for implementing BIM cloud based software?

The ability to share and access information may have ranked highly in regard to cloud computing assisting the respondent's associated companies, however, this openness was also deemed to be a barrier. In response to the identification of the major contractual barriers for implementing BIM Cloud based software, seven of the interviewees viewed both the inadequacy of current contracts and the lack of clarity over ownership, as major barriers. One respondent stated that the current contracts do not cover information exchange and that the issue of ownership does not surface until the project is completed when the client requests the model for their system. In reply the designer may state that they have the copyright for the models and as the contract does not require delivery of intellectual property, the model will reside with him/her. This dilemma prompted similar comments, such as, the fact that intellectual rights are currently being handed over anyway when using a 2D model and the fact that the document will be a 3D model should not affect this matter. In parallel to this was the dilemma of why should an architect develop a 3D model that would contain fully co-ordinated drawings that would only benefit the contractor in completing the project earlier but not have any financial gains for the architect. The most common solution identified by the respondents was to have a shared risk reward for the whole of the project team from beginning to end. The other recognised barriers were education and vendors. The educational issues arose due to a lack of training and cultural problems because the entire supply chain on a project will have different interests and may not be willing to change. The issues that were identified relating to vendors were the provision of an open service, such as, open standard IFC models or a Web-based service, and the contractual problem of deciding where the server is to be located. The conservative nature of the construction industry was also noted as a challenge, with one respondent stating 'the biggest challenge is the status quo as organisations and contractors are generating money from the inefficiencies that exist within the current process, which promulgates a lack of incentive to use cloud computing even if it can dramatically improve the management system.'

Question: How is the prospect of having contractual terms that facilitate open and neutral collaboration, such as agreeing on modelling protocols that allow sharing and integration of open technology, a significant benefit to the construction industry?

The early design stage was highlighted as a phase that had significant influence on how the potential of having contractual terms that allows sharing and integration of open technology can be of benefit to the construction industry. Prominent statements, such as, 'I think it creates better design of buildings because the industry has the tools to analyse and run simulations of the buildings before they are actually built' and 'I think the transfer of information early, being able to visualise the building clearly, is a key aspect'. In reference to the responses, 6 interviewees acknowledged that by getting everybody to clearly define their roles within the project, it would bring clarity and by being able to collaborate and share information the process would produce more valuable information, as the potential to open up and share enables more connections. The ability to have more connections generates more relevant information for building systems. By comparing this service to Web 2.0, one respondent stated 'this practice develops a kind of a cloud environment in which, at the early planning stages and, indeed, throughout the project, one can test things quickly to see what fails and what works.' Traditional contracts such as JCT and to a lesser extent NEC (UK, 1995) were viewed as having significant benefit by creating an acceptable standard because of their status within the UK construction industry legal framework. However, the view that faster proposals, better calculations, better process management, building management, and construction management, which means better site management, would benefit from having such contractual terms as exchanging BIM information gave rise to some negative responses, such as, 'I think for the larger sites Cloud BIM offers tremendous opportunities for lowering of the expenses/costs of the life cycle but for smaller sites I do not see any benefits.'

Q5		**Major contractual barriers for implementing BIM Cloud based software**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
	1	Current contracts	■			■	■	■	■		■	■		7
	2	Training and cultural issues		■	■									2
	3	Vendors								■				1
	4	Transparency											■	1
Q6		**How is the prospect of having contractual terms that facilitate sharing & integration a significant benefit to the construction industry**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
	1	Creates standards & specifications	■		■									2
	2	Not enough benefits		■						■			■	3
	3	Clearly defines roles and reduces mistakes				■	■	■	■		■	■		6

Table 7.3. Summary results: contractual issues with Cloud and BIM

Summary of the results

The notion that different parties within the supply chain will have different interests enhanced the fact that the improved interoperability of a Cloud BIM can only be of benefit to the construction industry. The open standards predicament relating to the contractual terms supported the early design stage as the phase with the greatest potential to benefit the industry because Cloud BIM has the ability to measure early design and costs before actually committing to a project.

7.6 BUSINESS PROCESS

Introduction

The core values and direction of a firm's visionary goals are embedded in developing a business vision. In order for a business vision to succeed a business process (an activity or set of activities that will accomplish specific organizational goals) must be identified. This section 'Business process' with the largest set of questions focused on investigating the main driver for Cloud BIM, the need for a standard business practice to address information exchange requirements, the possibility that Design and Operate is the most suited procurement route and whether the construction industry is ready for such a technological shift. Figure 7.1 illustrates the findings extracted from the four key areas under investigation; drivers of Cloud BIM, standard business practice, Design and Operate procurement route, and technological shift.

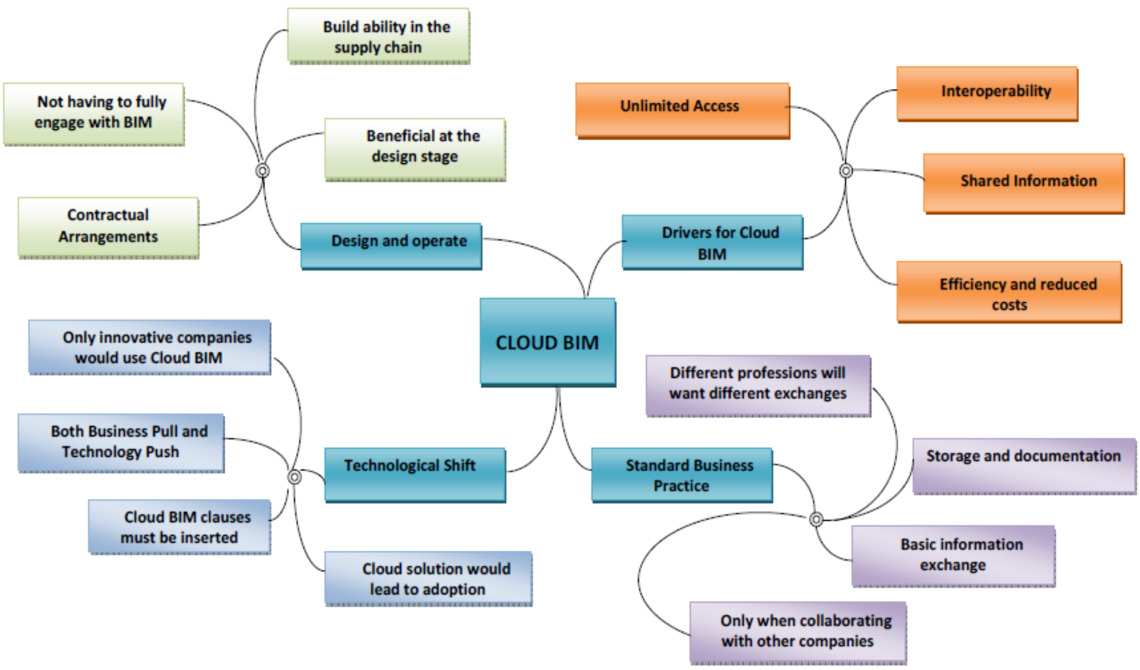


Figure 7.1. Key response to the four elements of the business process question

Question: What do you feel are the main drivers of Cloud BIM?

The key drivers for Cloud BIM were mostly associated with efficiency through reducing costs contributing to the integration of the various disciplines within the construction industry. In relation to user's experience, 'total information access' was viewed as an essential benefit by the respondents. However, some respondents did not believe that the main driver for BIM is having access to an integrated shared BIM through cloud computing because it does not currently exist nor does the technical ability to capture this information from a BIM model. Regardless of these points of view, the majority of the respondents identified that to have the technology to create interoperability between different disciplines and design tools, through the internet; enabling real-time sharing and re-use of information, can only be a benefit towards reducing waste and enhancing workflows. The high cost of initial fees of software and the investment charges associated with client-server technology (in comparison to having everything hosted on the same infrastructure and the ability to rent new applications) were also considered significant drivers towards the concept of Cloud BIM.

Question: Do you think there is a need for a standard business practice to address the information exchange requirements between design team and area specialists?

The need for having an industry standard business practice to address the information exchange requirements within the design team was clearly evident in the responses. However, some of the respondents identified that while having a standard business process in exchanging information when collaborating with other companies is essential, this should not influence the business process inside a company, as this will impede on their competitive advantage when working in a supply chain. The majority of the respondents referred to this standard level, as being a basic information exchange, as different professions will want different types of information, but that by having a standard business practice, it will contribute transparency and accountability between companies. In conclusion, one respondent stated 'the challenges are that there are so many different exchanges that can assist a new project and I completely support the need to document and identify these changes but I also do not want these standards to infringe on what I am presently implementing and deploying due to "plug and play" in the cloud environment.'

Question: Is BIM most suited to the Design and Operate procurement route?

In analysing if BIM is most suited to the 'design and operating' procurement route, the respondents indicated that it is but also acknowledged that it can be used for every procurement route. The major incentive for using design and operate was the fact that the same organisation is responsible for the design, construction and operation leading to significant efficiencies. In practice, relating to the design stage, the design team would input most of the information until the contractor became a part of the design team, then adding buildability knowledge before outsourcing to their supply chain (subcontractors) who would also contribute. Some respondents were of the opinion that the design stage gained most of the benefits from BIM. The prospect of being able to adapt to one's needs without having to fully engage in BIM via such exchange mechanisms as Construction Operation Building eXchange (COBie); where an excel spreadsheet containing building operations and maintenance data can be transferred into an open standard of IFC; is an attraction for implementation by non-BIM users.' The effect of the economic downturn within the construction industry featured in some of the responses, as interviewees recognised that a significant portion of the work will be provided by government departments and their specified contracts will have an effect on the procurement route.

Question: Is the construction industry ready for such a technological shift?

In assessing if the construction industry is ready to embrace Cloud BIM; based on the notion that it is a radical technological shift, the respondents had mixed opinions. The majority of the interviewees indicated that in general the industry is ready, with some respondents comparing BIM to manufacturing. However, this was more of a reflection on certain innovative companies, as there are still obstacles, such as, fragmentation, which are preventing change. There was a high percentage response identifying the fact that little innovation takes place when the economy is at its peak but, as the pace slows down, the need for re-engineering and creating innovative solutions becomes more prominent. However, some respondents did feel frustrated that, even with the success of BIM, there is still a reluctance to adopt it. In one instance, a respondent claimed that this was due to the senior executives who make purchasing decisions within firms not being actual users of the applications, thus slowing down the business process. Another cited problem was the issue of firms claiming to use the technology but actually only referring to certain aspects of BIM until being awarded the contract. The restricted use of a cloud solution was highlighted by a respondent who felt that, presently, companies are using BIM on internal servers and client technology but until cloud computing is used publicly, it will not be open to everyone to use. The main stakeholders of the business process, such as contractors, design team, governments and clients were all identified by respondents along with several different elements of business pull and technology push. The element relating to business pull was the fear being seen not to be involved and the potential loss of competitive edge. In relation to technological push; it was the benefit of reducing resources and increasing efficiency. The respondents also identified that until the use of technology, such as, Cloud BIM, is written into a contract, it will not be widely used; as stated by one respondent 'the construction industry, with the exception of a few very motivated companies, generally only deliver what is asked of them, so until the market demands a reduction in carbon, the companies will not be responsive.'

Summary of the results

In mapping the business process characteristics for using Cloud BIM (see Figure 7.1, which illustrates the mapping of the responses to the four key areas associated with the CLOUD BIM vehicle; driver for Cloud BIM, standard business practice, technology shift and design and operate), the main drivers highlighted where efficiency was gained namely through reducing costs, shared information through interoperability and unlimited access. The need for a standard exchange prompted responses, such as; it is only necessary when integrating with other companies as there are so many types of information, a basic standard would be adequate. However, the question of whether the industry is ready for such an adoption identified the need to have both technology push and business pull, in order to ensure success.

7.7 INFORMATION EXCHANGE

Introduction

In assessing the desire to have faster exchanges of data the questions in this section focused on investigating the need for implementing faster requests for information and which of the two main mechanisms for exchanging files 'IFC XML and IFC STEP' would best be adopted in practice.

Question: Why is the need for implementing faster requests for information such a significant issue to the construction industry?

The main requirement for having faster requests for information is the ability to reduce costs in relation to delays and increase efficiency by having more time to concentrate on the immediate tasks of the project. The need for rapidly setting up building sites and facilities, combined with wanting 3D models that provide all the essential information expected at the construction stage, has created a surge in developing solutions that can deliver faster key design decisions. The respondents were of the opinion that within BIM there exists a process that demands a more collaborative construction environment and that by improving requests for information this process will reduce the depth of information required. A significant feature of BIM is the amount of data that already exists within a model at a relatively early stage and, for some respondents the whole process of trying to meet unrealistic tender deadlines has pushed the need for having enhanced coordinated models at the design stage. However, a significant number of respondents also highlighted the financial risk for the design team with not having a contract in place, not getting planning permission, the project not having sufficient funding required and the design team failing to secure the tender. One respondent's solution was to acquire a 30% payment of fees before full completion of the model. The technological capability of exchanging certain items of information in real time was recognised as a catalyst for having faster and more accurate exchanges, thus reducing the time input of the design team for complex projects. In review of the following two respondents' statements ' faster is better and cheaper' and 'having all the information will speed up the process', the need for implementing faster requests for information is based on having to make faster decisions and using immediately available data to start projects in order to complete them earlier.

Question: Would you be in favour of using an IFC XML rather than an IFC STEP file format for exchanging information?

In focusing on the need to apply an integrated process, the respondent's opinions on using IFC XML or IFC STEP exchange mechanisms were examined. However, some of the interviewees had never used either exchange method and, as one respondent stated, 'we have never had the opportunity to work with firms using different IFCs; most of the companies that we have used collaborative BIM with were on the same platform as us.' This statement illustrates how the proprietary vendor tools are still the largest domain in the market and this is unlikely to change unless the industry implements Web-based services. Nevertheless, the majority of the responses did identify the need for enabling faster and cheaper information exchanges, with two respondents targeting different approaches but resulting in similar conclusions; as noted. One respondent emphasised the need for having an entity that can require the facility to transact within a relational database, permitting connectivity through a Web-service, thus allowing the end-user to interface with it. In further defining the process, the respondent envisioned an open IFC existing with relational dataset queries providing data-related requirements to the stage of the project that one is currently developing (object composition - combine simple objects or data types into more complex ones). In comparison with this idea Onuma (Onuma System), believes that IFCs are quite complex and exemplify the need for lightweight simple formats. Onuma perceived that the simple XML format had to be a very flat structure (implementations of simple databases) to enable anybody to develop it, or zone in on a part of the building or any part of the data to which one needs to connect. In conclusion, these respondents were in favour of reducing the IFC files through Web-based IFCs and promoting faster exchanges of information by extracting information earlier in the building cycle. In analysing the other respondent's opinions, several of them were in favour of XML. The responses highlighted the complexity of IFCs schema and acknowledged the advantages of using an XML structure; as one respondent stated, 'XML is ten times bigger than STEP (see Chapter 3 section 3.5) but with open source W3C tools it allows one to use XML - that means one can get to the data without using expensive proprietary tools; XML is an easier way to access data.' In summarising the responses, XMLs structure is mostly preferred especially in relation to having information when one requires it. However, when more complex analyses are required, IFCs will be needed.

Figure 7.2 shows the scope of Cloud BIM applications collaborating on an integrated platform. Each of the individual cloud depictions represent data (facts) collected from the semi-structured interviews, and transformed into a conceptualized model. This model demonstrates a new system architecture based on the authors key findings, such as, BPEA predicting the cost of energy consumption through the support of 5D BIM. The identified information exchanges; Open APIs, Web services and Plug-ins are used to provide the transformation of data between BPEA and 5D BIM applications.

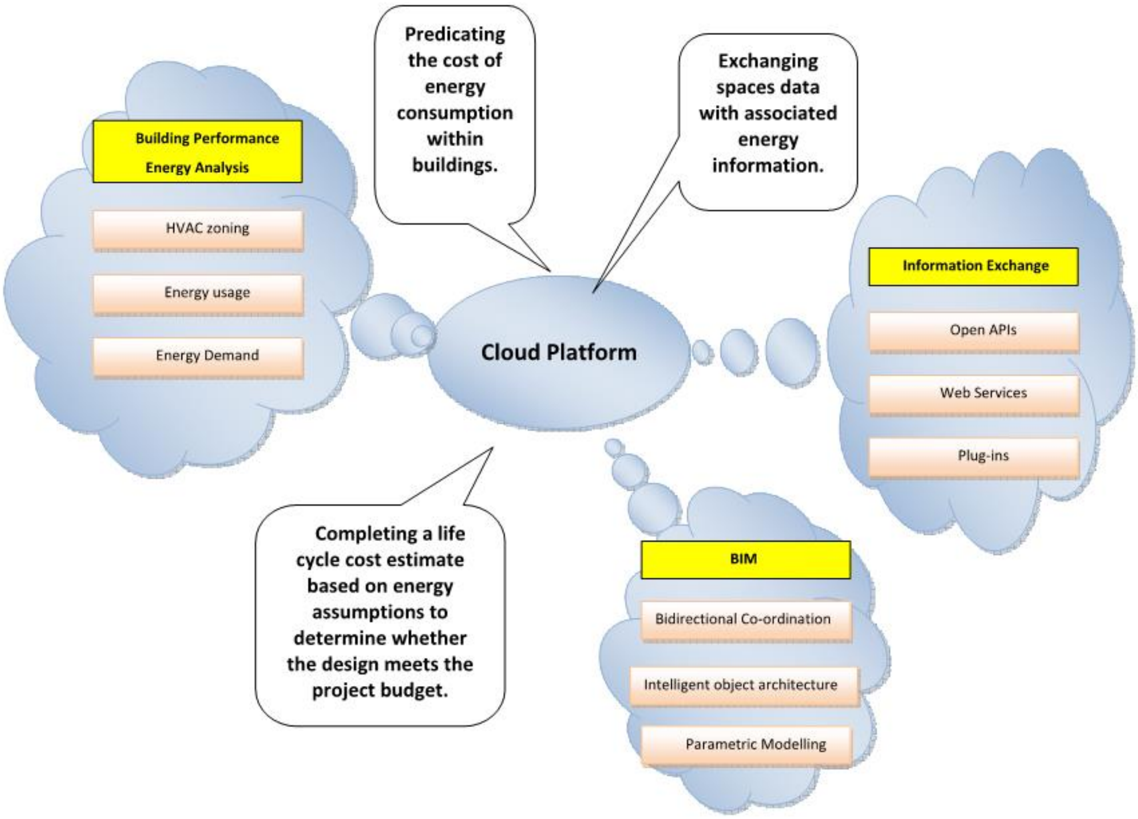


Figure 7.2. Scope of Cloud BIM application (author, 2010) [legend: bidirectional co-ordination – enabling virtual simulations of physical construction, parametric modeling - providing tabular views of components and characteristic interaction with elements]

Summary of the results

The information exchange mechanism for Cloud BIM is illustrated in Figure 7.2 which reflects the results of the semi-structured interviews. The nucleus of the concept is based on developing a cloud platform that can host Web-based BIM applications. Figure 7.2 shows such applications, as energy performance analysis directed at identifying energy usage and energy demand for HVAC zoning at an early design stage and applications in relation to using it for 3D, 4D and 5D BIM. However, in order to obtain full interoperability between the applications, a flat structured (relational database) XML would benefit the process. The industry's preferred solution to-date is to have an agreement on a common vocabulary for exchanging documents, such as Information Delivery Models and to use these to define Model View definitions – standard-based subsets of IFCs. Throughout the interviews, the design stage was highlighted as the key stage for exchanging information with design and operate as the preferred procurement route for implementing a standard exchange mechanism. Web services in Figure 7.2 feature as a basic standard for exchange of information. The anticipated procedure for using Cloud BIM would be to enable Web services to evolve with open standard exchange mechanism or SML hosted on a central repository that is the cloud platform and to define what is needed to be exchanged between the various applications at certain stages of the construction process.

7.8 A CLOUD-BASED BIM LIFE CYCLE MANAGEMENT SYSTEM

Introduction

The final section contained one question that focused on the measuring specific aspects of usability for a Cloud BIM service.

Question: Do you think there is value in using an internet platform such as a cloud to host 5D BIM, BPEA software for post-occupancy calculations, specifications and building performance?

The response to the concept that real value would be gained from using an internet platform, such as cloud, to host 5D BIM and BPEA data for post-occupancy calculations, specifications and building performance, was an overwhelming ‘yes’ from the interviewees. The respondents had several different reasons for wishing to implement such a service; for example, all of the applications would be connected, information would be retrieved with ease and there would be significant savings on using a Web-based energy performance analysis service in comparison to purchasing software that may have been only needed three times a year. The benefits of using the system to calculate the Life Cycle Costing in relation to the carbon footprint was highlighted many times, with one respondent acknowledging the efficiency of the system: ‘at the moment, almost unknown to the project, our mechanical engineers are collaborating with architects to identify if a certain amount of glazing is required by analysing the associated heating or cooling problems to achieve energy optimisation for the building. This system assists this process by producing more information with easier access.’ The respondents also recognised how end-users are comfortable with using applications on iPads and that this will “breed applications” for analysing the energy performance used in buildings. The respondent identified that the process could be undertaken similarly to a transaction where data is directly exchanged through a Web-service protocol and all that is required is publishing the connection. However, as another respondent confirmed ‘I think getting the internet platform and the [public] cloud understood and shared would be interesting because users will still want to use a private cloud while working out the design.’

In describing an example of how the system in Figure 7.2 could work; a respondent identified how the City Government of Washington D.C. publishes GIS data in multiple formats, such as, Google Earth’s Keyhole Markup Language, Zipped (KMZ) files, Environmental Systems Research Institute files, and Web-services. The respondent suggested that a file ‘building parcel information’ can be downloaded from the government’s Web-site and imported into this file thus creating a KML file which would then be compressed into a KMZ archive. However, the respondent acknowledged that the most efficient exchange procedure would be to support Web features that describes its capabilities, indicate its services and identifies the operations of each service. For instance; going directly to the government’s servers where they maintain the information and simply subscribe to it and if there were any changes they would be updated on the connecting server. Onuma envisions using this process to obtain energy data about existing building to assist in making key design decisions relating to similar buildings.

Summary

In summarising the LCC possibilities, one respondent stated ‘it would be of benefit to any project to undertake a simulation of the building before you build it as one can eliminate problems that would have originally being unforeseeable in the traditional way.’ The American Integrated Project Delivery model and NEC were cited as contracts that could be used as a preferred contract under this system. The notion of changing traditional contracts, so that information exchange and delivery were part of the contract was also identified as a possible solution.

7.9 CONCLUSION

The recognised problem with different BIM applications not communicating with each other has pushed the need to find a solution. The main feature of BIM is its ability to share synchronized information across multiple software applications. However, the main standard file exchange format IFC was not intentionally designed to carry all relevant data. IFC XML; a subset of the IFC schema mapped to XML; enables IFC files to be exchanged over the Web. The problem with IFC XML is that it is derived from the complex language of EXPRESS. The obvious proposed solution would be to create a super schema that would read various formats and combine them into a single format. However, as the results of the experts have indicated; there is a lack of understanding of the need to harmonize various XML schemas with equivalence mapping within the supply chain to create an open exchange model. Of those respondents who have actually exchanged files; the recipients' applications have always been IFC friendly. The prospect of developing a BIM central repository based on an integrated platform over the internet resulted in issues ranging from privacy to security and whether such a platform is technically possible. Other potential issues related to the industry lack of motivation of using new technology for sustainability without being influenced contractually in the same manner as Health and Safety.

However, the concept of the various disciplines only using the information that they required combined with the business process results emphasised the need for developing a 'Cloud BIM information exchange mechanism.' This type of exchange mechanism would enhance the possibility of many disciplines within the Architect, Engineering and Construction industry's environment collaborating on the same platform by sharing and exchanging data to provide more effective key decisions at the early design stage where most costs are estimated and upon which early investment decisions are made. Cloud BIM in conjunction with standard deliverables, developed into the main area of focus, as information can readily be exchanged between parties to a construction project team using BIM software on a cloud platform. Onuma System is one such cloud platform that hosts simple BIM data exchanges through plug-ins. The potential benefits of using Web service protocols has been cited by the respondents in reference to activating better information with easier access. The proposed solution extracted from the semi-structured interview process relates to not having to define a super schema but instead, focuses on using Web-based BIM exchanges on a cloud platform incorporating both IFCs and SML; which can lead to enhanced interoperability between different construction applications.

The following Chapter will measure an existing process that may possibly be re-engineered to feature some of the results stemming for the semi-structured interviews, in order, to identify the main component needed for combining three applications simultaneously. An existing SML exchange process for Cloud BIM will be investigated with the intention of measuring its development and capabilities in comparison to present industry practices in lieu of exchange mechanisms and FM costs at an early design stage.

Author's key findings in relation to the thesis objectives:

Objective 3: To investigate the potential of cloud computing and BIM in re-engineering early design processes - Figure 7.1 in section 7.6 illustrates the four key characteristics for using Cloud BIM; (i) driver for Cloud BIM – reducing costs, shared information through interoperability and unlimited access, standard business practice – only necessary when integrating with other companies as there are so many types of information, technological shift – the need exists for adopting both technology push and business pull and design and operate – the design stage will gain most of the benefits from BIM.

Objective 4: To establish expert opinion on advancing interoperability of data exchange through the use of Cloud BIM - In this chapter the use of the internet to host 5D BIM and BPEA was viewed as a positive benefit to any project as simulations of any building before it is built would eliminate traditional unforeseeable problems. The semi-structured interviews identified that with open source W3C tools it allows one to use XML as a means to get to data without using expensive proprietary tools, with easy access when one requires the information.

Objective 5: To identify the need for agreed information architecture framework that will create an interoperable layer of business processes – In section 7.5 the respondents viewed inadequacy of current contracts and the lack of clarity over ownership as the major barriers.

Objective 6: To measure the ability of advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform - Figure 7.2 'Scope of Cloud BIM application' illustrated the product functions of Cloud BIM with open APIs, Web services and plug-ins as the preferred exchange mechanism for BIM applications.

CHAPTER 8

CLOUD-BASED BUILDING INFORMATION MODELLING AND DATA EXCHANGE – CASE STUDY 2010

8.1 INTRODUCTION

This chapter describes a case study that refers to part (iii) 'Understanding and measuring an existing process' of the BPR methodology (see Chapter 1 section 1.3). The case study focuses on making implicit knowledge explicit regarding information exchanges between key supply chain members on a cloud platform. The key area to be improved was the exchanging of basic file-based documents at the feasibility stage. The use of a production function analysis technique was introduced to assess how the procedure for exchanging information could be advanced, in order to speed up key design decisions by involving the main disciplines at the earliest stage of a project.

The objective of the case study was to (i) estimate the cost figure difference between using a traditional order of cost estimate technique (New Rules of Measurement – RICS, 2009) and Cloud BIM, (ii) collaboration capability and (iii) key decisions scenarios (allowing one to use various tools to assist in informing decisions).

'Simplified XML' has been used by the ICT environment as a novel schema that only requires the extraction of partial data for exchanging information through an internet-based service. Within the construction industry 'knowledge' is difficult to capture. However, implicit industry knowledge (or belief networks) is typically created informally. Thus a recognised case study was applied to appraise specific contributions from implementing extracts of knowledge gained from using SML. The exchanging capabilities of partial BIM data on a Cloud BIM server, in order to produce an order of cost estimate report based on categorising, visualising designs and editing BIM features, demonstrated the efficacy of a simplified XML technology strategy.

By undertaking a case study to meet the author's objectives (to measure the ability of advancing key decisions at an early design stage through the use of exchanging partial sets of BIM data on a cloud-based platform), the knowledge produced provided a strategy for identifying the area to be improved. As identified by the production function analysis, the main critical point to be developed was a collaboration platform for exchanging partial BIM data through SML. The case study measured the key benefits of partial BIM, at the early design stage and assisted in understanding the main attributes to be reviewed, in order to create a new radical service.

8.2 PRODUCTION FUNCTION ANALYSIS

Otto and Wood (2001) emphasised that the difference between 'product development' and 'design process' was fixed on the notion that the product development process was an entire set of activities focused on market readiness. Initially this would include such activities as the inspiration of new product vision, business case analysis activities, marketing efforts, technical engineering design activities, development of manufacturing plans and the validation of the product design to confirm market readiness. In contrast, a design process involves sets of technical activities, as part of a product development that meets the marketing and business vision. Typical sets include new concept development and embodiment engineering of a new product. According to Otto and Wood, the design process essentially avoids business and financial management activities inherent in product development.

To *identify a process to be designed* (Cloud BIM), the new product concept would have to be based on how the products overall functions (primary performances) relate to its sub-functions (subsidiary performances). For example, a FAST technique assesses the function's critical path, in order to identify the key process to be designed and improved. According to Bartolomei and Miller (2001); FAST was invented during the Value Analysis (VA)/Value Engineering (VE) revolution of the 1960s. It has been defined as a rigorous method for investigating complex activities performed in a system to the functions performed for its customers. For example, a coffee percolator passes water through ground coffee beans, in order to give coffee its colour, taste and aroma. However, this procedure requires a user (customer) to boil water under pressure through the beans in a separate chamber until the coffee strength is reached. As part of this process the percolator may make a considerable noise. Through examining the activities (functions) involved, a more efficient technique may be identified that will alleviate the noise problem. Bartolomei and Miller perceived the system as a method for product improvement, process improvement, system design, and system architecture. However, Bartolomei and Miller did emphasize that the function is what the customer pays for. For example, the customer pays for security but the activity is what they get 'a document for improving security' which can become narrow and self-serving. Baxter (1995) defined product function analysis as a method for systematically analysing the functions performed by a product (as perceived by the user). Baxter asserted that all one requires for function analysis is to anticipate how the product will operate in use, coupled with the knowledge of how the functions will be perceived by the end-user and its relevance to their needs.

8.3 FASTER EXCHANGE OF INFORMATION

The initial step for identifying faster exchange of information through product function analysis was to list all the functions that the product serves in relation to the customer. In order to complete this task; all the functions were arranged into a 'tree function.' The primary function of this task was 'faster exchange of information for managing data related to buildings.' With regard to the customer's requirement of advancing key decisions at the design stage, the product (software process) under review would need to be improved. This function was placed at the top left of the diagram (referring to Figure 8.1). The following functions relating to the prime function were grouped logically and hierarchically under it, such as:

- sharing and exchanging with other programs,
- information exchange between different applications,
- open standard integration on a single platform,
- for identifying cost, carbon and value (ideas shared by users of what is good or desirable) information.

The functions listed under the prime function are the subsidiary 'basic functions.' The functions of sharing and exchanging with other programs are essential for managing information data related to buildings. Without exchanging diverse information (data collected from a range of software packages) the data obtained would be limited. The information exchanged between different applications (as highlighted in Figure 8.1) is a direct consequence of sharing and exchanging with other programs. The sub-function sequence of 'open standard integration on a single platform' is a result of 'information automated between different applications' for example, if automation between different applications was not possible then there would be no need for open standard integration on a single platform.

The listed functions to the right of the main function, 'information for managing data related to buildings' are a result of questioning 'How is this function achieved' but also incorporated into each question is 'why this basic function is being performed.' Otto and Wood (2000) view this structure as the backbone of the function of the product and the sub-functions listed below are critical to achieving the product function. The more a function is listed to the right of the primary function, the stronger the indication that this function needs to be achieved. The activities to the right of the primary function are identified below:

- Information for managing data related to buildings
- Integrated energy performance programs

- Integrated platform to predict life-cycle costing
- Data storage capabilities
- Full access and sharing

‘Integrated energy performance programs’ is listed on the critical line next to the primary function, highlighting the need for extracting this information, in order to fully obtain information related to buildings. The sequence of basic functions listed beneath ‘integrated energy performance programs’, is a similar process as previously identified for ‘information for managing data related to buildings’ where an activity cannot be performed without the sub functions underneath it. As illustrated on the second column in Figure 8.1 the sub functions of features adaptable for integration, structure data for FM, and COBie standard, are all required to achieve an integrated energy performance program. The following functions listed on the critical line: integrated platform to predict LCC, data storage capabilities, and full access and sharing are a repeat of the process as used before; however one will notice that the hierarchy level of sub-functions contributing to the critical line has been reducing. This sub-dividing technique of FAST clarifies the dependency structure of the basic function to the primary function and highlights the main product to be designed. The sub-function positioned on the right-hand side of the dashed line at the end of the primary list of functions, is the process to be designed entitled ‘Simple flat files’ for exchanging information instantly on a collaborative platform.

The results of the FAST technique identified the process to be investigated ‘assess more detailed information at a faster rate’ this would enable advancements in key design decisions at the earliest stage of a project. In order for this idea to be validated, it required a case study to be undertaken in a controlled environment. This situation afforded the author the opportunity of examining an existing Cloud BIM server ‘Onuma System’ as the selected case study, due to its ability to exchange data through SML ‘BIM XML.’

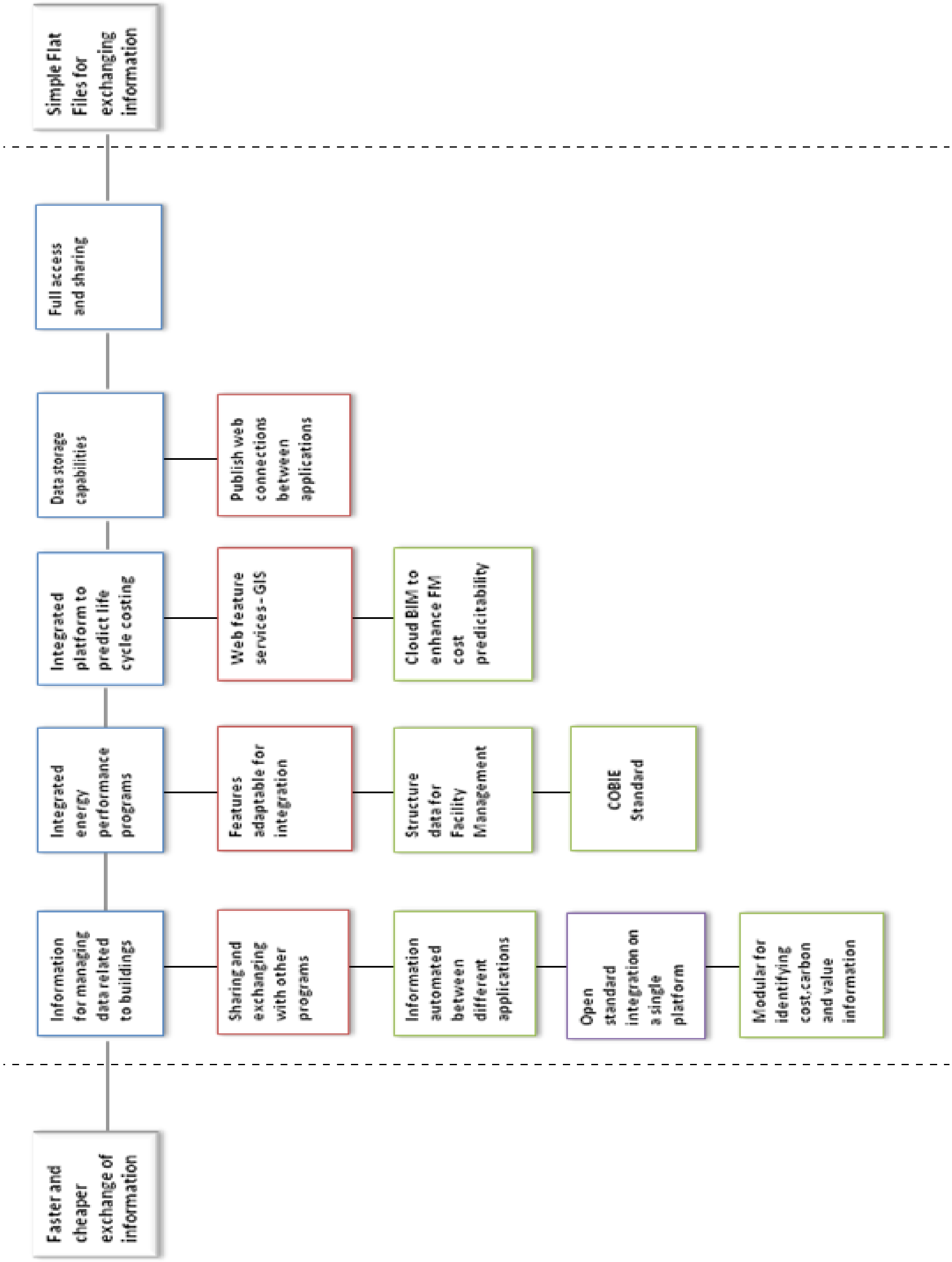


Figure 8.1. Function Analysis System Technique for faster exchanges of information

8.4 THE CASE STUDY

Emblemsvag (2003) identified that studies have concluded that up to 85% of production cost is committed before a single unit of the product is manufactured and suggested that new approaches were needed. Construction cost accuracy (difference between cost predictions and actual costs at project completion), varies between plus and minus 40% (Antohie, 2009). Thus the value of improved information is high. Vendors of tools for built environment design are increasingly involved with BIM-oriented infrastructure designs which may or may not be innovative, open, and relevant to appropriate decision makers. With regards to understanding the decision-making environment, McDaniel and Gates (2002) are of the opinion that the better the researcher understands the industry and its products or services the more likely it is that the problem will be defined correctly. They refer to this step as conducting a 'situation analysis.' This analysis provided the background to why the author used a case study to review information from a similar process to identify the research goal 'exchanging data to advance the making of key design decisions' (to measure the use of exchanging partial sets of BIM data on a cloud-based platform).

8.4.1 BIMStorm

The 'BIMStorm' is an international open Web platform scheduled event which takes place internationally and is organised to demonstrate new innovative design processes. Any event can be attended virtually or physically with attendees participating in either environment. The participants use innovative tools such as, Web-enabled multi-user platforms to access BIM applications. Images of buildings are visualised through Google Earth, via a network link, to the Onuma System open BIM model server. The structure of the event encourages individuals or teams to use their preferred BIM tool of choice. This enables multiple studies on various tools for LCC, curtain wall systems, energy analysis, constructability, interior design, mechanical and electrical plant systems and structural systems. The BIMStorm projects are not real-world projects but are driven by real-world needs. For example, participants can interact with peers sitting next to them at the conference or log in virtually using desktop BIM or even iPhones. The main concept of this collaborative event is to enable easy access to BIM applications and make decisions from the data that is exchanged. This is why partial BIM data representing specific information becomes a priority. The usage of a BIM model server eliminates e-mail communication (file transfer protocols, FTP) and traditional documentation, as communication is channelled through the open server, forcing the user to access BIMs sharing capabilities in real-time, through cloud computing. This type of collaboration allows changes to be made in design at the very early stages, as various disciplines can graphically visualize the design decisions, based on feasibility studies and construction costs (Onuma, 2009).

Figure 8.2 is a diagram of a ‘adapted swim lane’ process designed and produced by the author at BIMStorm 2010, specifically for the case study. The three phases of the case study are categorised as design team, exchange and outline cost plan.

Model developed route (see Figure 8.2)

- Step 1: The process begins with the design team (professional architects, surveyors, engineers etc.) being questioned as to whether or not the concept design is BIM complete. This question refers to whether or not a 3D model has been developed with the need to add further information or whether the design team has only availed of basic essential information, such as, building size, room sizes and storey height. If the answer is ‘yes’ then one must proceed to Step 2 moving in a horizontal direction (referring to Figure 8.2).
- Step 2: Open Revit (BIM software developed by Autodesk) file and click on Onuma Plug-in (an application programming interface, API).
- Step 3: The Onuma Plug-in exports the model into a BIM XML file. Objects such as furniture can be exported as an addition to the document file.
- Step 4: This step involves exchanging data through importing the BIM XML file back into the Onuma System. At this stage the process has reached milestone A which must be considered as a ‘design freeze’ by all disciplines, in order to review the steps taken.

Alternative route (see Figure 8.2)

- Step 1: If ‘no’ is the answer then the alternative path of moving vertically is undertaken.
- Step 2: Without the model being previously developed, one can insert the areas of the building with associated room sizes via Onuma Template based on Excel.
- Step 3: This step involves creating the projects identity. The Excel template takes into consideration generic space setting requirements based on such open

standards as the Consortium for Real Estate for example Code 1100 represents ‘exterior wall’ and 1140 signifies mechanical circulation.

- Step 4: Figure 8.3 illustrates how the template is used to import tagged (ID) areas, quantities, room names and furniture fittings into the model. Once the Excel file has been loaded into the Onuma System, a geometric visual representation of the building has been created. The users can now start to re-configure the footprint shape of the building and insert items such as, staircases. Furniture items can also be imported from the Revit model through the BIM XML exchange procedure but would require the model being imported back into Revit.

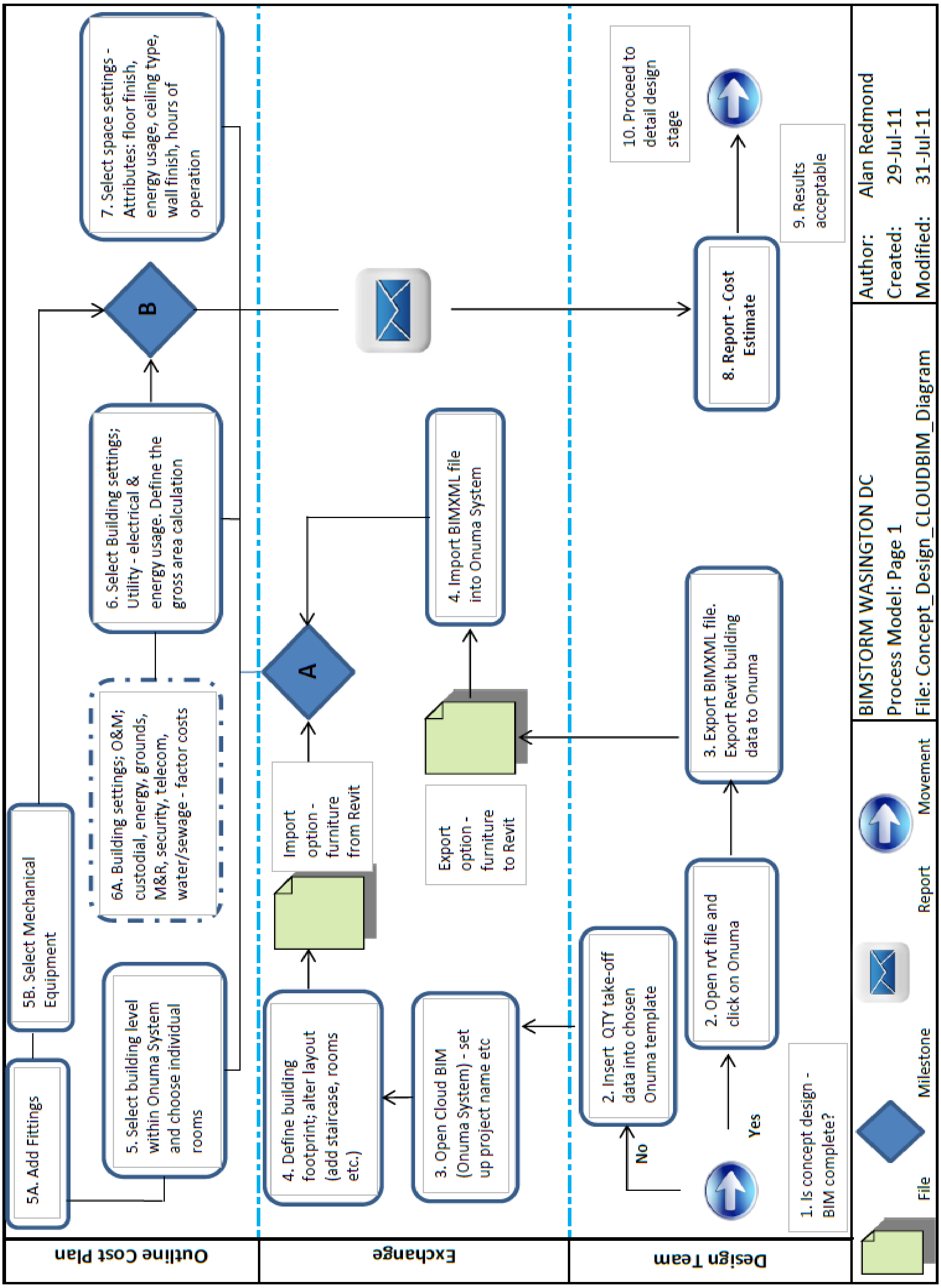
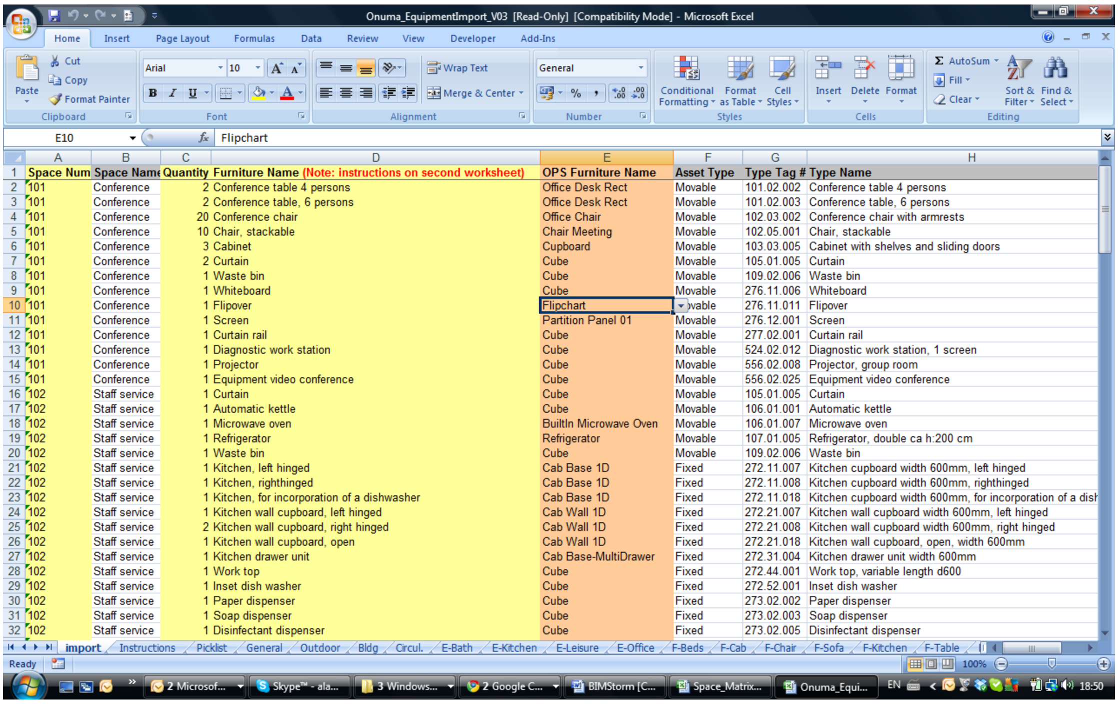


Figure 8.2. BIMStorm 2010 Case Study Swim Lane Process

At this point both routes have reached the target milestone before the final phase 'outline cost plan.'

Both routes

- Step 5: The Onuma system has several different virtual building levels within a model and each level depicts the amount of information that can be added for example, certain building levels can enable one to add and select mechanical equipment such as Air Handling Units.



	Space Num	Space Name	Quantity	Furniture Name (Note: instructions on second worksheet)	OPS Furniture Name	Asset Type	Type Tag #	Type Name
2	101	Conference	2	Conference table 4 persons	Office Desk Rect	Movable	101.02.002	Conference table 4 persons
3	101	Conference	2	Conference table, 6 persons	Office Desk Rect	Movable	101.02.003	Conference table, 6 persons
4	101	Conference	20	Conference chair	Office Chair	Movable	102.03.002	Conference chair with armrests
5	101	Conference	10	Chair, stackable	Chair Meeting	Movable	102.05.001	Chair, stackable
6	101	Conference	3	Cabinet	Cupboard	Movable	103.03.005	Cabinet with shelves and sliding doors
7	101	Conference	2	Curtain	Cube	Movable	105.01.005	Curtain
8	101	Conference	1	Waste bin	Cube	Movable	109.02.006	Waste bin
9	101	Conference	1	Whiteboard	Cube	Movable	276.11.006	Whiteboard
10	101	Conference	1	Flipover	Flipchart	…vable	276.11.011	Flipover
11	101	Conference	1	Screen	Partition Panel 01	Movable	276.12.001	Screen
12	101	Conference	1	Curtain rail	Cube	Movable	277.02.001	Curtain rail
13	101	Conference	1	Diagnostic work station	Cube	Movable	524.02.012	Diagnostic work station, 1 screen
14	101	Conference	1	Projector	Cube	Movable	556.02.008	Projector, group room
15	101	Conference	1	Equipment video conference	Cube	Movable	556.02.025	Equipment video conference
16	102	Staff service	1	Curtain	Cube	Movable	105.01.005	Curtain
17	102	Staff service	1	Automatic kettle	Cube	Movable	106.01.001	Automatic kettle
18	102	Staff service	1	Microwave oven	BuiltIn Microwave Oven	Movable	106.01.007	Microwave oven
19	102	Staff service	1	Refrigerator	Refrigerator	Movable	107.01.005	Refrigerator, double ca h:200 cm
20	102	Staff service	1	Waste bin	Cube	Movable	109.02.006	Waste bin
21	102	Staff service	1	Kitchen, left hinged	Cab Base 1D	Fixed	272.11.007	Kitchen cupboard width 600mm, left hinged
22	102	Staff service	1	Kitchen, righthinged	Cab Base 1D	Fixed	272.11.008	Kitchen cupboard width 600mm, righthinged
23	102	Staff service	1	Kitchen, for incorporation of a dishwasher	Cab Base 1D	Fixed	272.11.018	Kitchen cupboard width 600mm, for incorporation of a dish
24	102	Staff service	1	Kitchen wall cupboard, left hinged	Cab Wall 1D	Fixed	272.21.007	Kitchen wall cupboard width 600mm, left hinged
25	102	Staff service	2	Kitchen wall cupboard, right hinged	Cab Wall 1D	Fixed	272.21.008	Kitchen wall cupboard width 600mm, right hinged
26	102	Staff service	1	Kitchen wall cupboard, open	Cab Wall 1D	Fixed	272.21.018	Kitchen wall cupboard, open, width 600mm
27	102	Staff service	1	Kitchen drawer unit	Cab Base-MultiDrawer	Fixed	272.31.004	Kitchen drawer unit width 600mm
28	102	Staff service	1	Work top	Cube	Fixed	272.44.001	Work top, variable length d600
29	102	Staff service	1	Inset dish washer	Cube	Fixed	272.52.001	Inset dish washer
30	102	Staff service	1	Paper dispenser	Cube	Fixed	273.02.002	Paper dispenser
31	102	Staff service	1	Soap dispenser	Cube	Fixed	273.02.003	Soap dispenser
32	102	Staff service	1	Disinfectant dispenser	Cube	Fixed	273.02.005	Disinfectant dispenser

Figure 8.3. Template for Onuma system

- Step 6: This step allows the user to stipulate individual settings to be used for the cost report, such as utility and energy usage based on certain factors; energy, telecom and water /sewage etc.
- This final step within this phase 'step 7' captures space setting attributes such as finishes and hours of operation (see Figure 8.4).

Upon completion, the users will have reached the second milestone B. Here, all the information that has been assembled, such as the areas and objects added with associated costs, are accumulated and processed to the report cost estimate. Following a review, if the costs are accepted then the design will proceed to a more detailed feasibility phase.

For the actual case study, an Excel cost estimate was compared with the Onuma System's general estimate. The type of estimate was very basic, as it was based on the Gross Internal Area (GIA). The GIA for the Excel estimate was 3,583 m² (square metre) with a fixed cost of $1,250 per m². The case study tested both routes, however, for the Onuma System estimate comparison, the Revit model was favoured (alternative route). The total cost of the building by Onuma System was $8,688,025 in comparison with $8,448,653 as calculated by manually using Excel (cost/m² ($4,478,750) plus preliminaries/overhead and profit at 23% ($1,030,113) plus contingency at 10% ($550,886) plus construction inflation ($515,079) plus design team fees ($986,224) plus other costs such as 'VAT' ($887,601)). The Onuma System had allocated $811,146 for intangible costs such as inflation and risk, which was only evaluated at $515,079 in the Excel estimate.

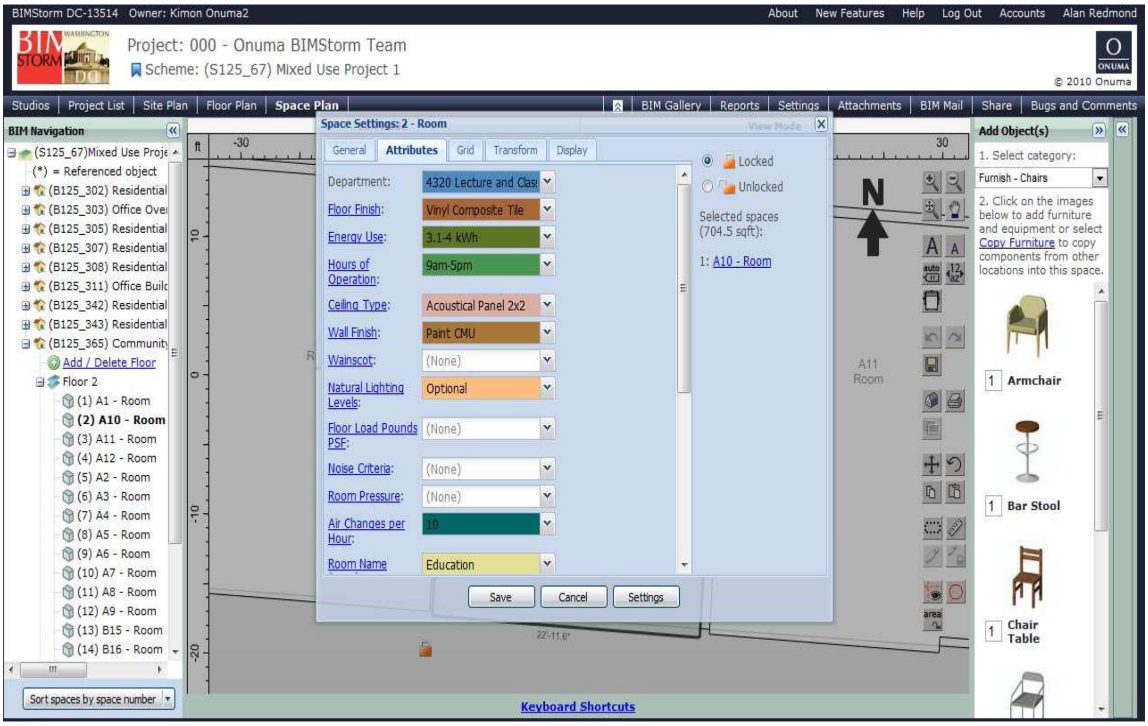


Figure 8.4. Screen print space settings for the Onuma System

The Onuma System had also automated costs (based on the author's template) of $29,050 for basic furnishings that were specified – this was not measured in the Excel estimate. In relation to cost associated with the life cycle of the building, the Onuma System produced a building report based on the following information provided: the energy usage, materials and sensors that were virtually attached to each specified room. The total cost of the basic life cycle fittings was estimated at $463,154.

8.5 RESULTS AND DISCUSSION

The case study investigated whether BIM applications could be used collaboratively to exchange information rapidly and allow all design team members to access the model through their Web browsers, via the Onuma System cloud platform. This case study highlighted the productivity benefits of exchanging partial subsets of XML and further validated Nour's (2009) findings (see Chapter 3 section 3.1)**,** such as exporting data from Revit and importing it into Onuma System and then exporting the data from Onuma System to other applications.

The case study also reviewed the comparative sizes of exporting an IFC file from Revit into Onuma System and compared it with a BIM XML file. The Revit IFC file; which contained all of the information about the model; was 7,368 Kilo Bytes (KB) in comparison with the BIM XML file size of 34 KB, which only comprised of the basic information needed. The BIM XML schema only exchanged information using approximately two hundred lines of a programming code, in contrast to IFC's estimated two hundred thousand. This meant that BIM XML exchanges related to specific data that was required where IFC inherited all of the data. The idea of using relational databases to retrieve information relates to Chapter 3 section 3.6, where Nour (2009) had previously highlighted that flat business objects contained data that did not reference objects or any inheritance hierarchy classes. These simple flat relational schemes used predetermined queries for aggregated information, thus speeding up the process of siphoning the main information that was required.

The exercise also compared a typical traditional manual Excel cost estimate process with that of an internet-based Cloud BIM cost estimate process, in order, to identify the duration and the amount of rich data achieved from using the latter.

The Onuma System software allows the user to produce an order of cost estimates based on specific chosen fields, such as general mechanical, floor finishes, and ceiling types, in order to evaluate the potential LCC of a building. The most significant attribute of using the Onuma System is its ability to plug-in with other applications. The Onuma System essentially provides a Cloud BIM platform for exchanging information with other applications, based on open planning data. However, if a standard mechanism based on a simple XML was designed to allow interoperability between Web-based applications, such as 5D BIM and Energy Performance Analysis software, it would increase the accuracy of data being exchanged by reducing the errors from manually inserting information into programs, and the cost of re-entry.

The challenges of defining the key criteria are listed in the matrix Table 8.1.

FACTORS or Decision CRITERIA	Current Practice Gross Internal Area (GIA).	DELTA (difference between Current and Cloud BIM)	Internet / CLOUD BIM
Context estimate the Life Cycle Cost of a building	Solo Estimator using Standard Proprietary data and a Spreadsheet 3,583 m2 fixed at $1,250	No difference	Collaborative process between design team through BIM Model Server.
Technical Feasibility?	No doubts	a) Some basic introductory training required for BIM. b) Cloud BIM service fee = $40 per month	Some questioned if technically feasible; and if technically feasible, was it as easy to accomplish by semi-skilled generalists or does it take "deep knowledge" to apply?
Reported ESTIMATED COST --- Inflation Cost --- Basic furnishings --- Life Cycle fittings	$8,448,653 (including design team fess, OH&P, preliminaries, contingency & VAT) $515,079 --- Ignored --- Ignored	$239,372	$8,688,025 $811,146 $29,050 $463,154 (not included in overall cost)
Duration of Exercise	One working day	One working day	Two working days
Number of ITERATIONS (i.e. number of times the model was updated and significant changes in assumptions were made, likely changing the Go – No Go decision by Manager-Owner	What If Scenarios in Microsoft Excel 2010 can show… but this feature is not well understood in industry.	The true value associated with having all disciplines viewing the document in real-time for assessment can only be estimated.	As a CLOUD BIM, the Information Model was always in a "Current State" Because any change was reflected at once. Report versions showing scenarios are available.
Accuracy of Process	Only as good as previous data libraries and the estimator providing the cost.	More rich validated data produced by Cloud BIM	Data library essential – however information can be contributed by all design team members and stakeholders.
Number of "Artifacts" involved; number of "cycles" --- XML --- IFC --- Simplified XML --- BIMxml	NOT RELEVANT for this exercise	Not required	In future exercises against IFC, and Novel XML problems… these criteria require explanations

Table 8.1. Factors or Decision Criteria (author)

The main factors or decision criteria

- The technical feasibility of using either Excel or Cloud BIM is obviously more expensive for Cloud BIM, as Excel is a part of the Microsoft Windows package. However, Cloud BIM is certainly more technically advanced and requires basic BIM training. The software packages fee is modelled on a pay-as-you-go basis fixed at $40 per month.
- There was a significant difference in cost ($239,372), however, as previously stated, this was due to the significant amount of rich data added to the Cloud BIM model.
- The order of cost estimate produced traditionally was one day faster than Cloud BIM. However, Cloud BIM tested two scenarios using more advanced data than originally anticipated, due to the amount of data being sourced and exchanged.
- As the case study was a participant observation by the author, the conclusion that decisions were enhanced due to real-time input from several disciplines, can only be presumed at this stage.

- The number of times various schemas were used (as part of the workflow operations), was not examined at this stage.

8.6 CONCLUSION

The FAST technique used in this chapter identified that access to more detailed information at a faster rate may advance key design decisions at the earliest stage of a project. The technique highlighted the main critical and sub-functions involved in supporting this task. ‘Simplified XML’ was identified as the main function to be investigated, in order to achieve faster design decisions, which would lead to improvements in the process of exchanging data.

In view of the notion that a process cannot be redesigned before it is understood; the use of a novel XML ‘simplified XML’ was investigated, with results illustrating that SML is evolving into a very well-defined subset of XML. The case study examined the ability to use such a mechanism in the construction environment. The results of the case study demonstrated the benefits of exchanging information through SML on a cloud platform. The case study section showed how BIM applications such as Revit can be used to exchange information through BIM XML, and allow all design team members to access the model through their Web browsers via the Onuma cloud platform. The ability to simplify the file relational structure of exporting and importing partial BIM data files through BIM XML led to a significant increase of data knowledge, which in turn advanced decision making based on the required information needed for an order of cost estimate.

The factors or recommended decision criteria in Table 8.1 examined key values of using Cloud BIM for producing an order of cost estimate, in comparison with the traditional Excel method in a working industrial context (a trade association ‘Controlled Test Environment’). The qualifications of Cloud BIM have prompted the possible design of a framework model based on new empirical evidence entitled ‘case sensitive analysis.’ The case study indicates that BIM applications need to work with a wide range of software solutions across the internet and that the use of SML can make decisions faster which can benefit the building’s life cycle cost predictions due to better information.

The opening of the next chapter will focus on the chosen semantic methods and tools for enhancing the ICT capabilities of Cloud BIM, to be tested once again in similar environment to the previous case study. The purpose of this test is to review the case studies contribution towards developing a mechanism for exchanging partial sets of

BIM information between facility management data on a cloud-based service featuring geospatial technology.

Author's key findings in relation to the thesis objectives:

Objective 3: To investigate the potential of cloud computing and BIM in re-engineering early design process - The case study in this chapter tested the workflows of Cloud BIM cost estimate in comparison with a traditional order of cost estimate. The findings proved the potential to re-engineer the design process based on BIM XML and Cloud computing as a large amount of data was sourced and exchanged with several options being tested in a short period.

Objective 5: To identify the need for agreed information architecture framework that will create an interoperable layer of business processes – The case study demonstrated the communication and productivity benefits of Cloud BIM with the results showing the potential of all disciplines working together with more rich data in comparison with traditional techniques.

Objective 6: To measure the ability of advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform – As part of BPR methodology, 'understanding and measuring an existing process,' the product function analysis of Cloud BIM was examined in this chapter taking into consideration the information derived from the previous chapters. The functions listed on the critical line were as follows; information for managing data related to buildings, integrated energy performance programs, integrated platform to predict life-cycle costing, data storage capabilities and full access and sharing. The result of the FAST technique clarified that Simple Flat files needed to be investigated and tested in relation to assessing more detailed information at a faster rate for advancing key design decisions. After establishing the main function that would increase product value, this chapter tested the properties of exchanging data through BIM XML with results demonstrating that decisions were enhanced due to virtual real-time input. The BIM XML schema used in this case study highlighted through the file's size exchanges the size difference between IFC and the subset XML was 217 KBs. BIM XML comprised of only basic information to be exchanged whereas IFC files inherited all of the data. The case study supported the need for predetermining queries for aggregate information, thus speeding up the process of siphoning the main information that was required.

PART 3:

DEVELOPMENT AND EVALUATION OF A FRAMEWORK

CHAPTER 9

DESIGNING A CLOUD BIM BUSINESS PROCESS MODEL – CASE STUDY 2

9.1 INTRODUCTION

In October 2006, the productivity numbers released by the U.S. Bureau of Labor Statistics, showed the slowest growth rate since 1997. The rapid productivity growth of the previous 5 years had suggested that the investment in Information Technology would have an infinite increase in productivity. However, these findings prompted a review of the process of measuring productivity for the digital age with concepts such as 'organizational capital' being developed (Baker, 2007). In review of the construction industry Teicholz (2004) highlighted that the construction industry's productivity had declined by approximately 40% over 40 years and Smith and Tariff (2009) reiterated these findings but insisted that BIMs cost benefit analysis, to that of structured information that is organised, defined and exchangeable (with these key characteristics computer programming object architecture can be exchanged more successfully) will enhance productivity.

Erik Brynjolfsson, director of the MIT Center for Digital Business, coined the term 'organisational capital' based on the theory that companies in the 1990s were not just investing in ICT but also in new business processes. These investments were rewarded with gains in 2001-2002 but when ICT spending dropped, so did the investments in organisational capital, which created the downward slope for 2006 (during which, the software productivity output declined). Brynjolfsson insisted that in order to achieve returns in three to five years, organisational capital must be a part of a company's structure. The theory of organisational capital requires both business managers and computer programmers to collaborate in developing applications; whereby business managers outline their work tasks through a business process flow diagram and computer programmers develop software to suit (Baker, 2007).

Davenport and Short (1990) recognised that the benefits of using ICT include transferring information rapidly across long distances (thus reducing the need for manual human intervention), supporting the co-ordination of tasks and work flows, capturing and publishing knowledge to improve the process, and simplifying communication, in order to improve the transfer of data. By investigating the benefits of such capabilities, Davenport and Short acknowledged that the procedure for *designing a prototype* is built upon successive iterations and key activity stages, including selecting the preferred design, creating a prototype for the new workflows and developing a strategy for using the new process.

This chapter demonstrates a business process model 'Cloud BIM' based on exchanging early design stage data to optimize productivity. Novak and Canas (2008) emphasised that in order to efficiently analyse knowledge (a collection of facts interpreted in light of the concepts, such as beliefs, methodologies and know-how) for which their concepts are being applied or considered, it is best to construct concept maps (graphic tools for organizing and representing knowledge) with reference to some particular question one seeks to answer. The question this chapter focuses on is; 'Are semantic (relationships between common content) methods and tools capable of supporting a Multi-Attribute Decision (MAD) Model (see section 9.3.3) with which to benchmark a CLOUD-BIM case study productivity.' The semantic reference relates to the use of Web service architecture applications and the MAD model aspect correlates with the key decisions to be undertaken with regard to implementing the workflows. The benchmarking of a case study's productivity will provide evidence from a direct observation of the benefits of exchanging partial sets of BIM information on a cloud-based service.

9.2 BIM ISSUES (IDM) BUSINESS PROCESS MODELLING NOTATION (BPMN)

The existing building industry standards of data storage, information delivery and data directory (IFD - a standard for terminology libraries or ontology's for example an open BIM model can be linked to data from many sources, improving interoperability) all have semantic content. IFC standards provide an old, but accepted, open data model for construction project data that has been borrowed from the auto industry (STEP). The majority of construction vendors back IFC, using an API or similar interoperability solutions between proprietary applications (see Chapter 3 section 3.5). In May 2004, the Business Process Management Initiative (BPMI) drafted the Business Process Management Notation 1.0 specification. The primary objective was to eradicate the productivity bottleneck in writing software code. By using a simple set of flow chart symbols, business managers could describe a process in a flowchart (as a Business Process Diagram - BPD), and software developers could implement these workflows into an executable code. This procedure would enable managers to monitor largely automated practices through reports or electronic dashboards. The main purpose of undertaking a BPD is to create a standardised structure between the business process design and its implementation. A BPD should be based on a Universal Modeling Language (UML) standard. The outline procedure refers to a business process model, as a network of graphical objects, such as, activities and flow controls that are defined in a sequence of performances. The value of modeling tools and notations has been identified but technical gaps still exist between businesses and programs. Ideally a process management should support a set of object attributes that have been mapped to the Business Process Execution Language for Web services (BPEL4WS v1.1 - specifies actions within business processes with Web services. Processes involves exporting and importing information by using Web service interfaces – see Figure 9.1) the process execution standard (White, 2004; OMG, 2011).

In order to develop a heterogeneous network platform for exchanging Web services, the case study required a BPMN based on 'Cloud BIM' services. The following section briefly analyses the methodology used to develop the process maps (BPMN) for 'Cloud BIM' services and the chosen semantic applications to benchmark its productivity.

9.3 METHODOLOGY 'PROCESS MAPS' FOR DATA FLOW INTEGRATION

According to Anumba et al. (2010) the Building Information Modeling Execution Planning Guide, a product of the BIM Project Execution Planning buildingSMART alliance™ (bSa), was developed to provide a practical manual to be used by project teams to design their BIM strategy and develop a BIM Execution Plan. The guide highlights that there is no one strategic plan for how to implement BIM on every project, so each team must design a plan based on an understanding of the project's goals. In designing a BIM project execution processes maps are created to identify information exchanges criteria (IDMs) that will be shared between multiple parties and to clearly define the various operational tasks to be performed. The initial step outlined in the guide is to map the BIM process, which requires that the project team develop an overview map (see Figure 9.1 for the Author's overview map), showing the different BIM processes to be performed. The next stage involves placing the potential BIM uses into the BIM overview map. In order to achieve this task, the guide has provided templates in a Microsoft Visio (http://visio.microsoft.com) file containing the process maps. The traditional process maps used by the NBIMS project committee (see Figure 3.6) entailing structured horizontal swim lanes identifying actors such as the various activities were not favoured by the author in his approach to specify exchanges of data. This decision was not based on a technical orientation but rather simply on graphical representation.

With reference to the case study and testing the re-engineering performance of BIM XML, the author created individual BIM process maps to define when Web services should be imported and exported using BIM applications.

For convenience and ease of usage; the software chosen to develop the BPMN for Cloud BIM services was Microsoft Visio 2010. The chosen operational tasks were; (i) cost estimation, (ii) 4D modeling, (iii) design authoring, (iv) energy analysis and (v) design co-ordination. These tasks were chosen because design '3D,' planning '4D,' costing '5D,' and life cycle management '6D' individually represent the feasibility study phases associated with the author's BIM overview map.

9.3.1 Identifying the component parts of a process map

In designing a BPD for graphical representation, a major aspect of the maps is the flow objects which usually consist of the event, activity and gateway (decision node). An *event* is usually defined by a circle; depending on where the process happens. For instance, at the beginning it is represented by a circle, at the intermediate stage by two concentric circles and on completion by two concentric circles with the outer ring in black. The *activity* is a network of performing operational tasks depicted by a rectangle. The content of each task box identifies the responsible party to undertake the named assignment and the system associated with delivering such a procedure. For example, 'Process Name' will be inserted in the largest box accompanied with two smaller boxes identifying the responsible party and the chosen tool, such as 4D, to undertake the operation. The *gateway symbol* of a diamond relates to the decision making aspect of the flow model. It is used to control the sequence flow and divert the process if the decision suggests that it will not fulfill its obligations. Figure 9.1 demonstrates the flow objects and sequence flow arrows.

The sequence flow arrows represent the order of the sequence for the activity process that is being performed. In addition, depending on the direction of the dotted line an arrow extracted from the critical path can be deemed as either exchanging information or references and vice versa for inserting data. In analysing the sequence of events, the core processes' 'rectangular boxes' are positioned to represent the activities scheduled to be undertaken.

The main feature of Figure 9.1 is to create the modelling of the sequential process flow, as indicated through the heavy lined arrows. The dotted arrowhead lines refer to the flow of exchanging information.

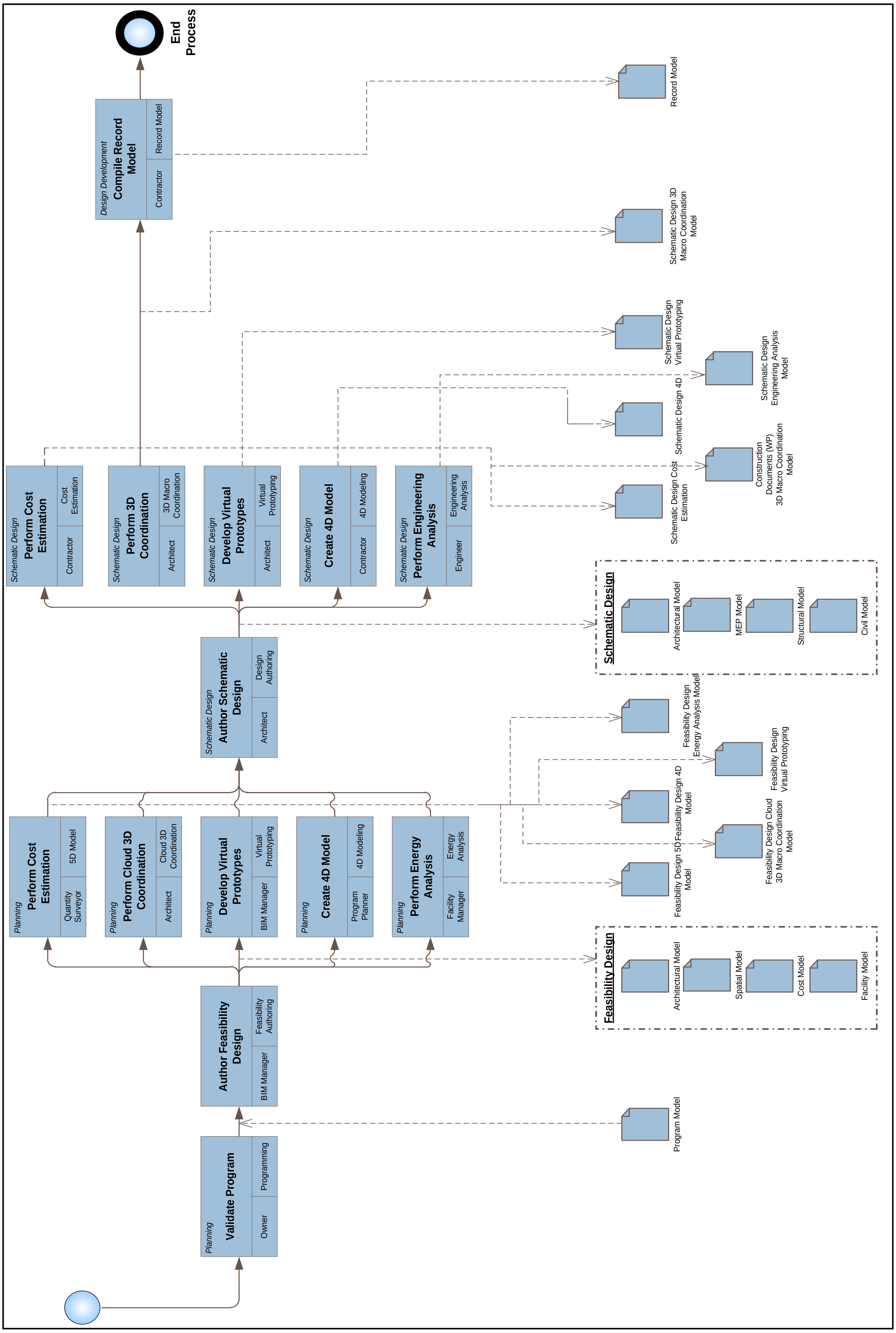
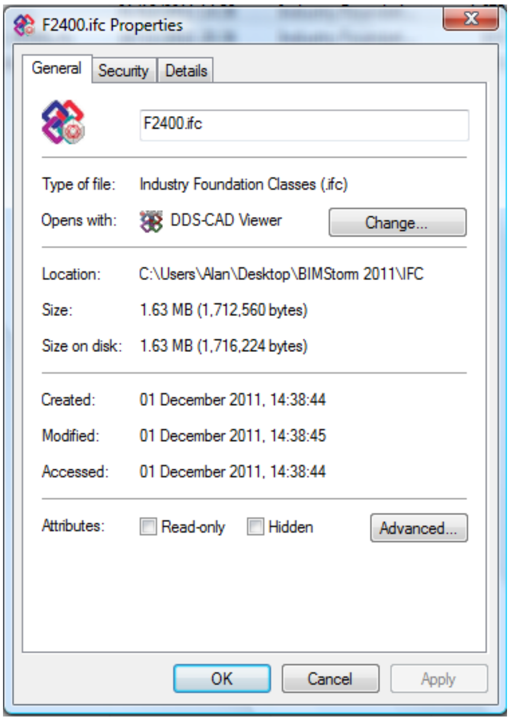


Figure 9.1. The author's chosen BPD for exchanging partial sets of BIM data

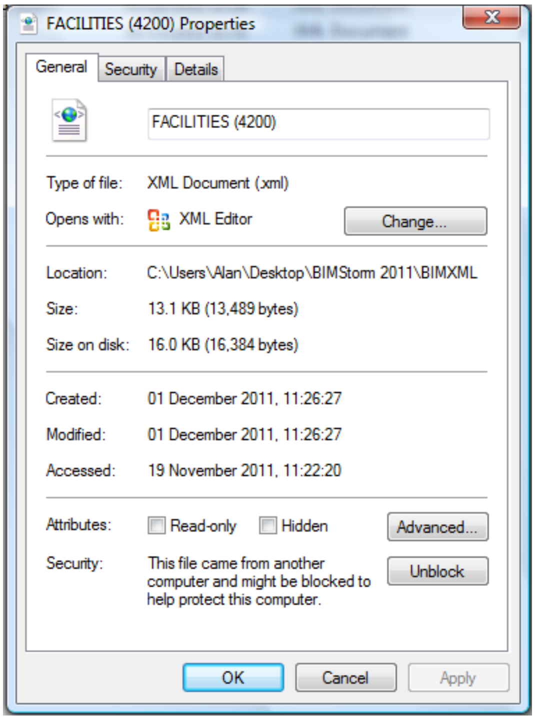
A data object is illustrated in Figure 9.1 as a folder with its upper right-hand corner folded. A data object symbolises data produced by activities or inserted into an activity. The annotation mechanism provides the modeller with the opportunity to include additional text, such as tagging (assigning a piece of information) energy software to be used for the energy analysis virtual model. The grouping of certain data objects, as illustrated in Figure 9.1 (feasibility design) shown as a dashed line surrounding documents is used for signifying the production of documentation or analysis of such documents.

9.3.2 BPD 'Flow Chart' for Benchmarking IFC and Partial IFC Data on a Cloud Platform

A Process Map reflecting BIM exchanges on a cloud computing platform was developed, in order to successfully implement a Cloud BIM service, at the earliest possible stage of the planning procedure. Figure 9.2 shows the properties details of the IFC file size (1.63 MB) and BIM XML file size (13.1 KB) files for exchanging information. The IFC files are 127 times the size of BIM XML but BIM XML represents the simple BIM virtual objects that were required. The logic of this refers to the question whether total information is required or simply partial information at various levels of detail exchanges?



'Properties of IFC'



'Properties of SML'

Figure 9.2. Property differences between IFC and SML

9.3.3 Multi-Attribute Decision Models

Multiple criterion decision making is a technique that relates to identifying problems, constructing preferences, evaluating alternatives and determining the best alternatives. It falls into three categories:

1. Descriptive analysis –concerned with the problems that the decision makers (DM) actually needed to solve,
2. Prescriptive analysis – determining the methods that DM ought to use to improve their decisions and
3. Normative analysis – focusing on the problems that DM should be addressing.

The format is strategically structured to attempt to identify the problem, before selecting the information to be considered which leads to building alternatives. The final outcome of this process will seek to determine the best alternative. In order to assist this, an analytic process is used to model subjective decision-making based on multiple attributes in a hierarchical system. It is widely used in corporate planning, portfolio selection and cost benefit analysis. The highest level of the hierarchical structure is the overall objective and is decomposed into several criteria which can be divided into other sub-criteria (Tzeng and Huang, 2011).

The MAD Model design objective for assisting the decision-making process for implementing a Cloud BIM service, features the benchmark properties of a simple markup language for exchanging data on a cloud platform. The BPD model in Figure 9.1 is a generic overview for which several other models have been developed, based on choosing the most appropriate BIM tools to optimize the cost benefits of a feasibility design. The BIM overview map illustrates the main activities; cost estimation, 4D modeling, design authoring, energy analysis and design co-ordination all used for identifying a business process in which the ICT programmer can map to the Process Execution Language for Web services.

9.3.4 Design authoring of process activities

The process flow defines the discipline that is associated with the activity, for example, 'design new architecture model' is the responsibility of the BIM manager. Each of the tasks induced from the design model highlight the two definitive roles of the architect at the feasibility stage, namely creating a spatial model and designing an architectural model. The quantity surveyor is typically associated with cost comparison models. However, in relation to reinstatement (refurbishment of a building), a facility manager governs an existing model, as using their expertise at this stage can only benefit the life cycle of a project. The sequence flow advances with the introduction of a decision diamond 'gateway' conditional upon either a "Yes" or "No" answer. If the answer is yes, the process continues. Alternatively, if errors are found, the model will be corrected and redesigned to suit. Figure 9.3 shows the exchanging of reference information provided by a parametric modelling component (the ability to co-ordinate changes and maintain consistency at all times) which is illustrated in the process flow between analysing the existing data and designing new architecture model. In relation to creating occupancy models and evaluating existing models, data can be obtained from existing buildings and used to assist the redesign modelling process.

9.3.5 Design co-ordination of the process

Prior to starting the design co-ordination process flow, the main opening activity relates to defining the required information from a Cloud BIM server. In order to achieve this activity, a company's supply chain standards must be taken into consideration. The mechanics of obtaining information through a Cloud BIM server is largely based on all sub-process activities being identified, such as, creating a cloud model sharing system, defining the mechanisms for exchanging information, establishing a protocol for accessing data and developing a strategy for the feasibility study. At this stage three information exchange mechanisms, BIM XML, IFC and WFS can be used to exchange data before inserting the basic design model and starting the co-ordination process. The benefits of using BIM XML for exchanging files on a cloud platform demonstrated the speed and accuracy to enable key decisions to be made at the feasibility stage. For example, the model did not need to be updated because it was always in a current state and any changes were immediately recognised in real-time. Upon agreement of the different model tasks to be designed, for example how to implement 3D and 4D practice, the process proceeds to identify the solutions (file exchange format to share information) to form a collaborating service (Figure 9.4).

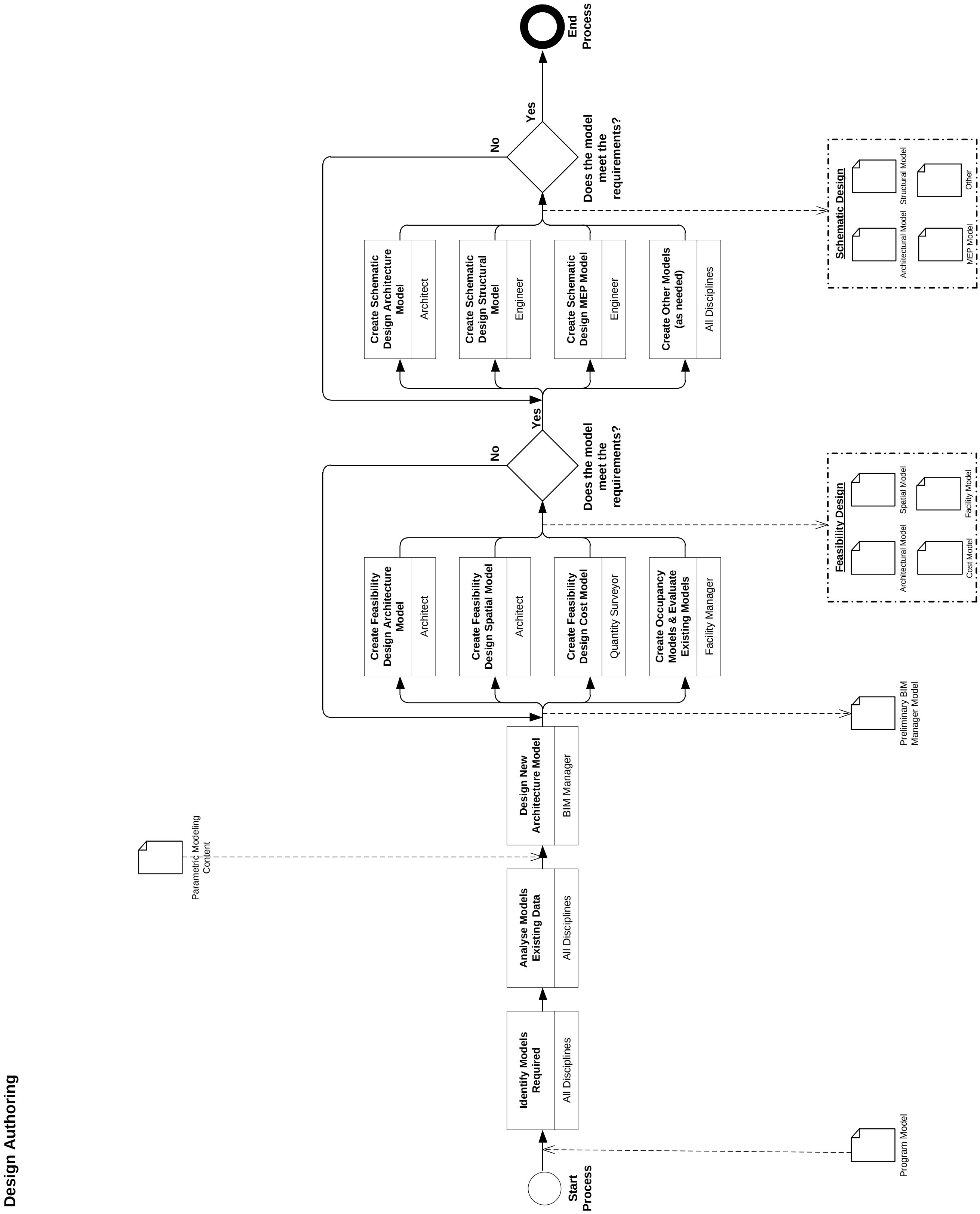


Figure 9.3. Design authoring - disciplines responsible for the process activity

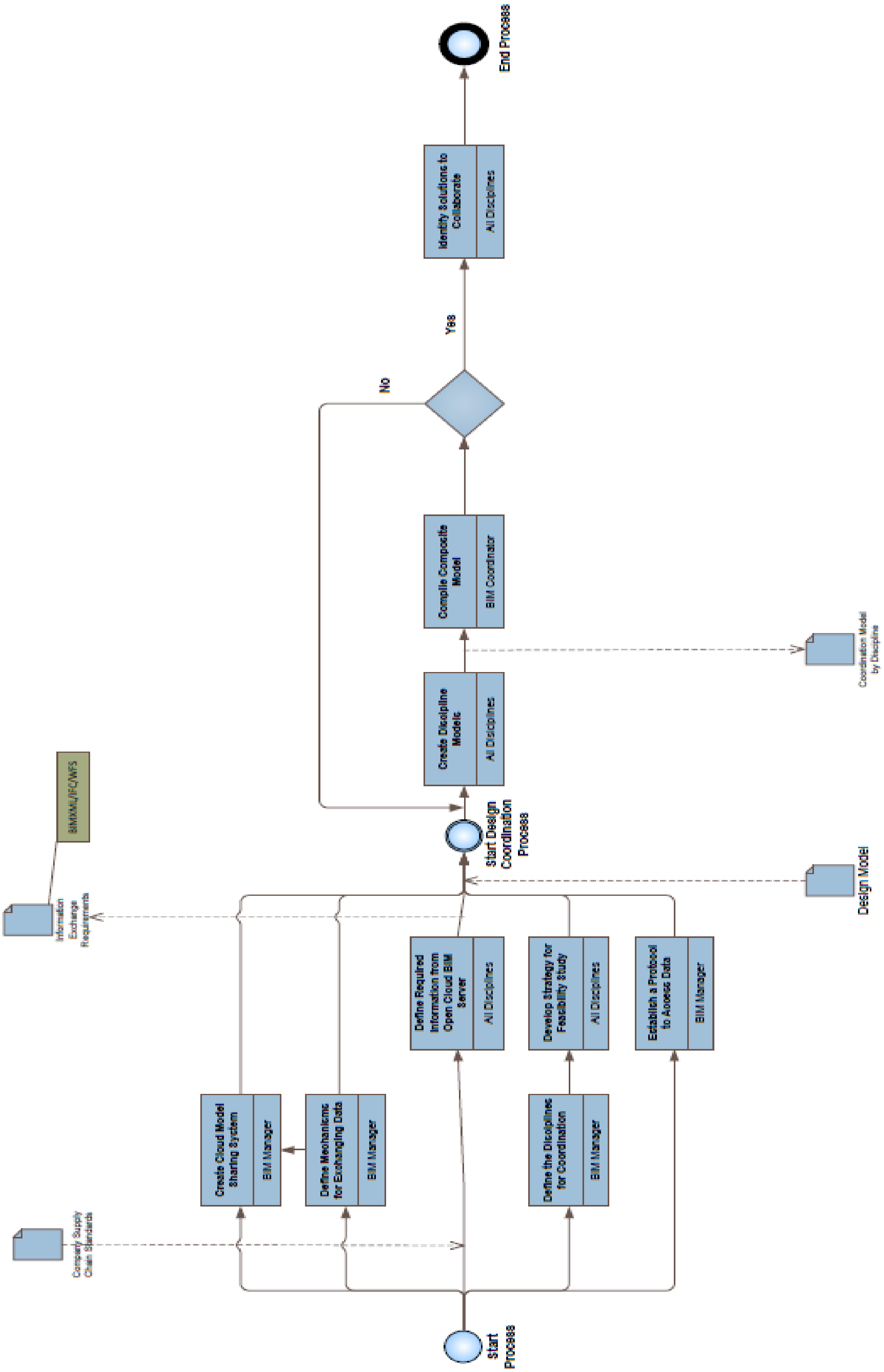


Figure 9.4. Design co-ordinations BPD

9.3.6 Cost estimation process flow

The sequence flow established for a cost estimation process relates to the remodelling of a building, incorporating information from an existing facility report (see section 9.6.1, dilapidation report) based on existing buildings data, to predetermine the budget cost. The next data model inherits the 3D model design, from which a quantity surveyor can import the design into a 5D model for quantity take-off/cost analysis. On deciding that the model is deemed ready for progressing to linking to the 3D component elements to the quantities, the critical path requires the exporting of this data into a spreadsheet for review by the quantity surveyor. In accepting the results; the technique for evaluating how the construction process will be undertaken is reviewed, in order to map the sequence of the cost schedule. Figure 9.5 shows the initial tasks associated with the cost estimating process flow. The costs that are assigned to the quantities can be obtained from an external or internal cost database. The possibility exists to exchange library data obtained from online resources; such as, Building Cost Information Services (BCIS) via Web services using SOAP or REST (www.bcis.co.uk/xml/indices_v10.xsd). The rejection of any cost forecast at this stage may result in a full evaluation of the quantities and their associated rates in an elemental breakdown analysis. If the projected costs are not within the target budget, then certain elements may be redesigned. The significance of having real-time cost information has been highlighted by Kirkham (2007), who alleges that, on many projects, the official documentation is merely trying to catch up with real and informal site communications.

9.*3.7* *Program modelling process flow*

The 4D modelling process flows are dependent on the exchange of information from numerous object architecture (file, documents represented as a data structure) documents, such as an XML file created from Microsoft Project Manager, and an IFC file representing the design model. Information relating to resources is obtained from previous project data. The immediate tasks comprise of developing a project program and adjusting the schedule depending on the resources (man hours/plant) available. The procedure involves importing both the XML program project file and the IFC file into the 4D Model application. The sequence of the process flow involves linking the 3D visual elements to the 4D program. If the program is acceptable, a 4D model draft schedule file is created for all disciplines to review and to identify if the program has been optimised. If the program is rejected at this stage it will be referred back to the preparing/adjust scheduling task to be analysed by all disciplines involved (Figure 9.6).

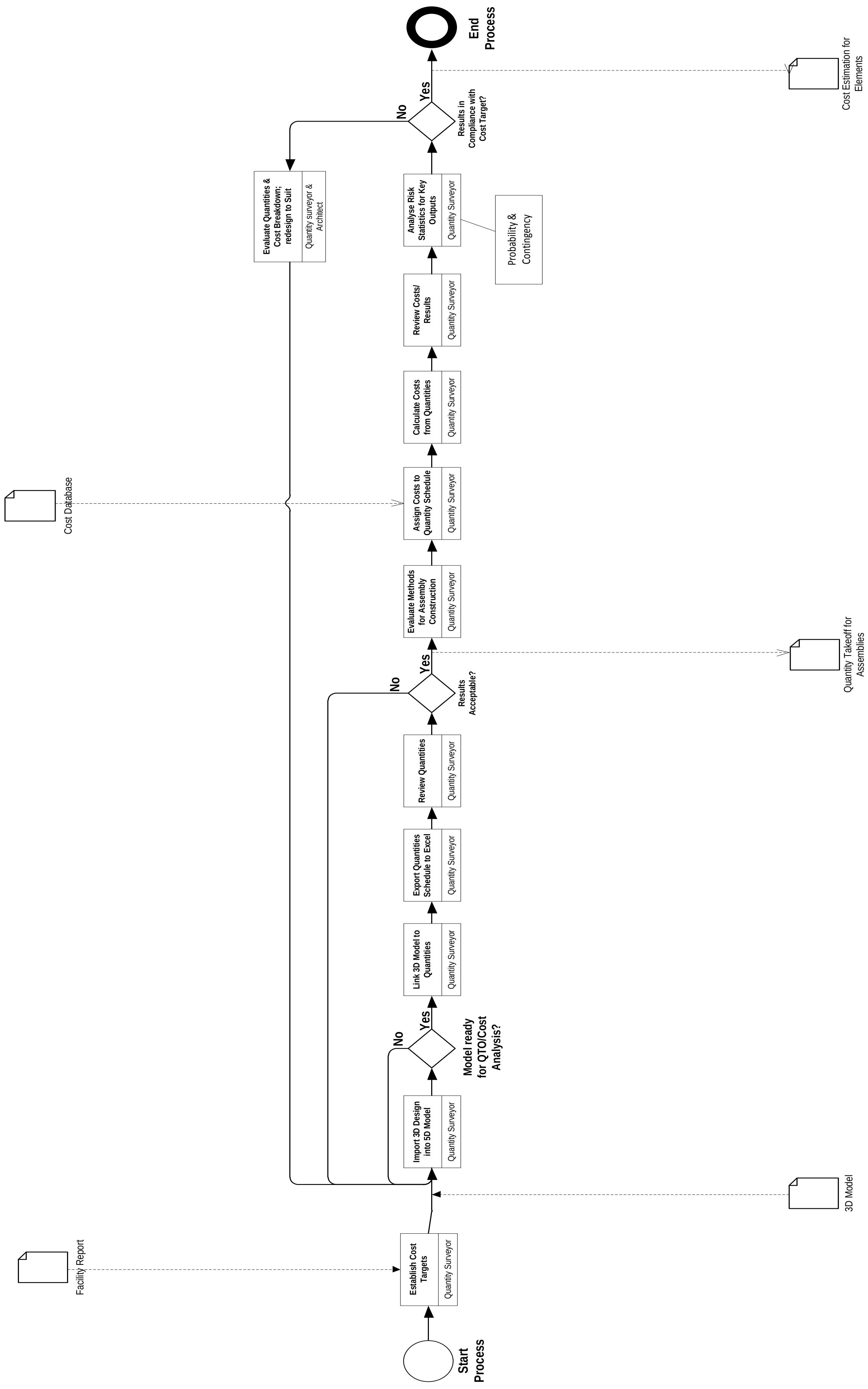


Figure 9.5. Cost estimation process flow

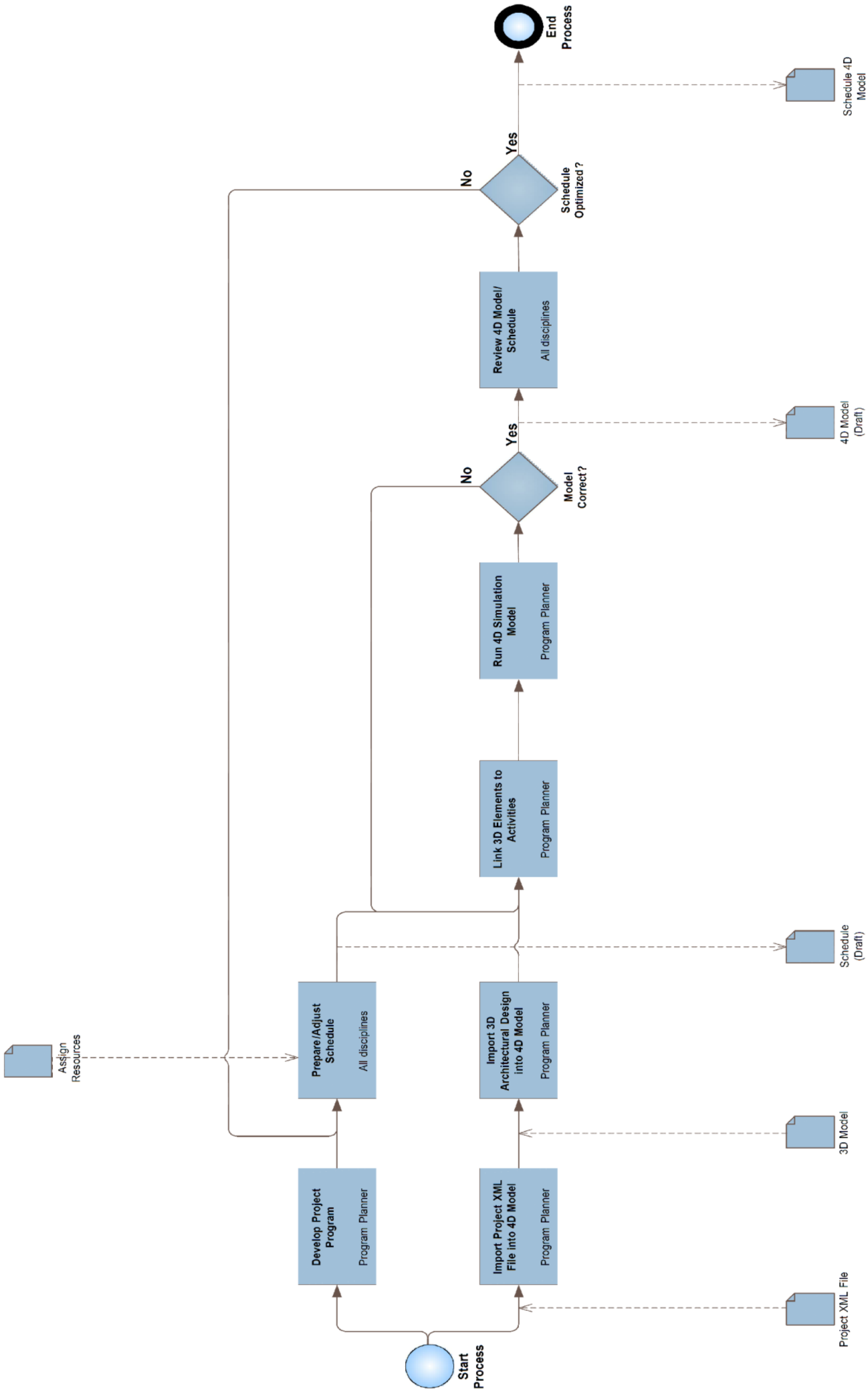


Figure 9.6. 4D process model flow BPD

9.3.8 Energy analysis process flow

The main benefit of conducting an energy analysis for 'feasibility design' is to provide an approximate measure of the life-cycle energy use/cost of a building over 30 years. The process should start with configuration of a Cloud BIM model incorporating the occupancy of the room layout data. Taking into consideration that the prototype would be conducted on virtual level relating to the State of California, the CALGreen specification was analysed. This specification states that before the design phase of a project begins documents must include such items as; environmental and sustainability goals, energy efficiency goal, facility functions and hours of operation, and building occupant and O&M personnel expectation (CALGreen Non-Residential Commissioning Guide, 2010). The BPD includes tasks such as developing a lighting schedule that requires reference data. For instance, hypothetically the data relating to a faculty building class time schedule could highlight when the associated rooms are being occupied thus projecting the energy usage. By determining the thermal zones based on existing libraries; the energy content can specify the most suitable types of materials; for example the percentage of glazing for an external envelope. At this stage, the BPD questions whether the model is ready for simulation. Upon acceptance, the procedure involves analysing the energy demand consumption based on specified energy tariff legislation and a mechanical engineer reviewing the results before issuing a report. If the results are acceptable the process is complete; if not, the entire process starts again. Figure 9.7 illustrates the process flow of an energy analysis BPD.

9.3.9 Summary of BPMN proceedings

The methodology presented for the 'generic overview of the BPMN for exchanging partial sets of BIM' was based on using multiple simple BPDs to achieve the required sequence flow. The novel concept represents the process of utilising both IFCs and SML on a cloud platform. Each of the task flows were fully analysed and represented visually via individual BPDs based on complementing the Building Information Modeling Execution Planning Guide. The five main tasks are, cost estimation, cloud 3D co-ordination, developing a virtual model, creating a 4D model and performing an energy analysis. These are the chosen exchange flows related to designing a process flow notation for the feasibility design stage. The use of WFS (connect individual Web services together) and cloud network (modular interactivity and inter applications communications) provided a strategy for managing and improving business performance through optimising business processes coupled with the technological solutions of subset XML.

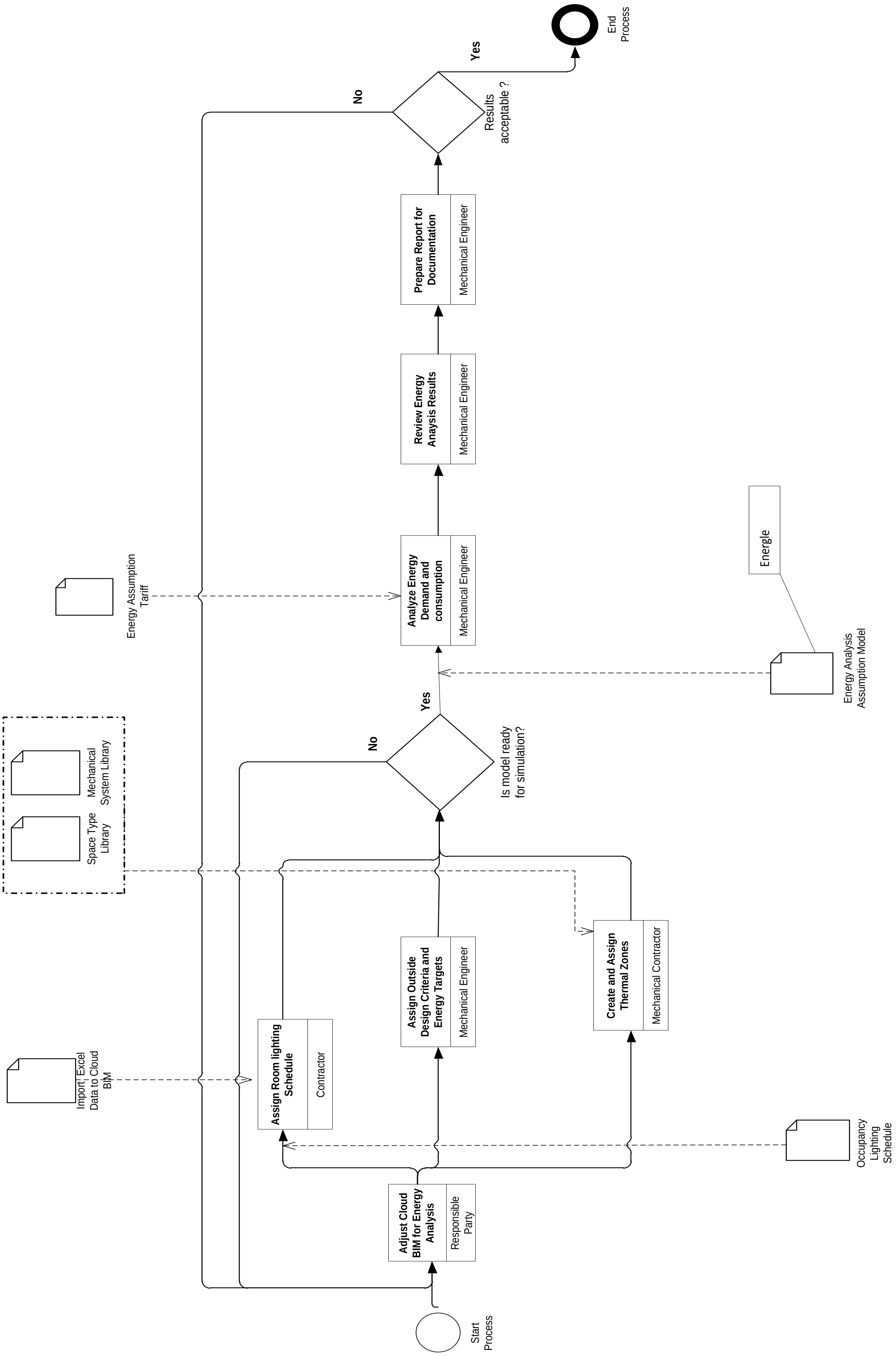


Figure 9.7. The process flow of an energy analysis BPD

9.4 SYSTEM ARCHITECTURE

The system architecture designed for Cloud BIM services provides a usability vision of how the BPMN process would work. The core issue of cloud computing, being a big data system (data that exceeds the processing capacity of conventional database systems), coupled with BIM, shows how to provide a system that can enable various disciplines to work collaboratively. The component architecture of Figure 9.8 refers to the overall system, as a manageable subsystem which enables open access for all construction design disciplines. The FUSION+GIS+ONUMA Systems architecture (a potential integration of three independent services) based on exchanging IFC and SML information seamlessly between FUSION's 'facility management system chosen from California,' GIS 'geographical location,' and Onuma System's 'Cloud BIM.' The following layers outline the components of the system architecture based on the to-be-implemented services of FUSION+GIS+ONUMA System.

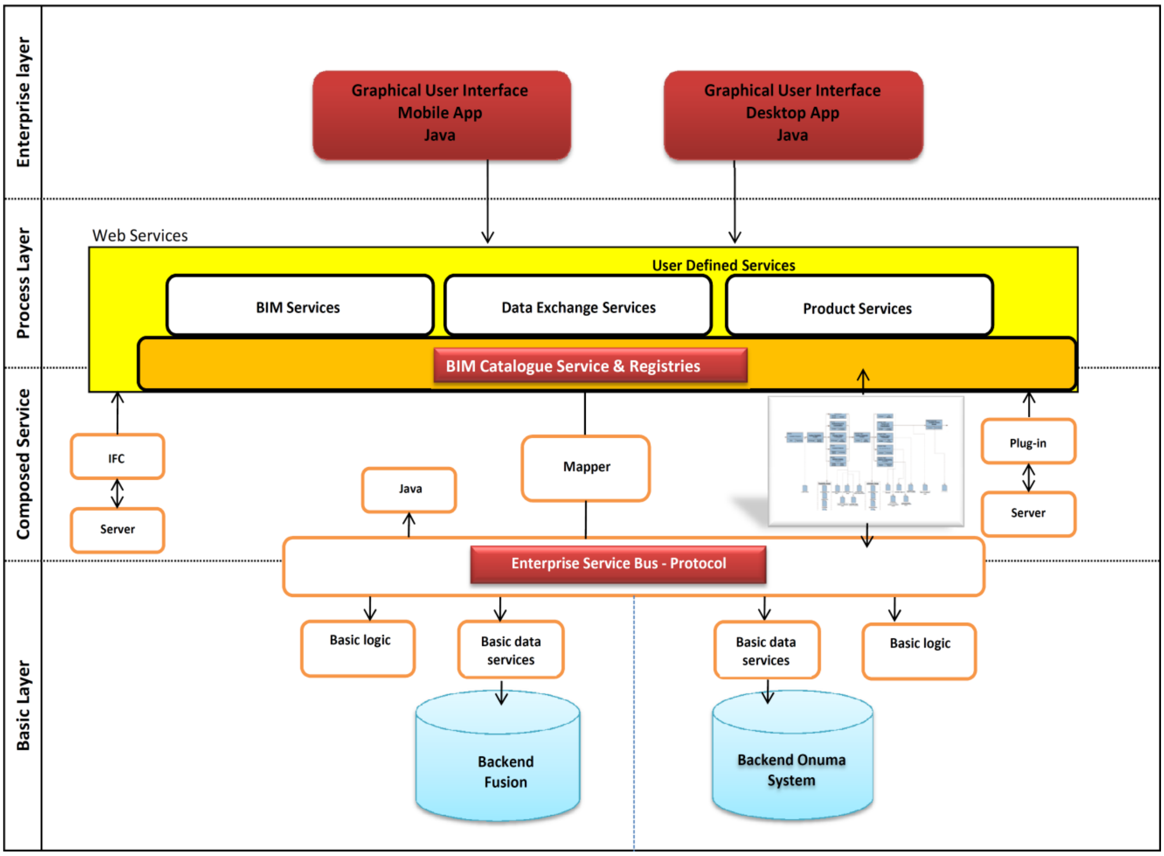


Figure 9.8. Designed solution approach architecture (author)

Basic layer: the systems basic layer for FUSION+ONUMA contains backend and basic data services and logics. Data services are services that read or write data from or to one backend system. Typical examples include, create a new customer, creating new account and the address of the customer. Data logic service processes input data and return correspondence, such as defining a product catalogue and price lists. Basic services adaptors provide a common service API, so that the backend/database can be accessed through SOA (Josuttis, 2007).

Composed services: the most important concept of SOA is the utilising of Web services information through business processes. The composition of services allows one to provide support for business processes. The dedicated language and engine of the business process is BPEL (Business Process Execution Language) (Matjaz, and Kvizevnik, 2010). The purpose of this central processing layer was to use BPEL to specify the exporting and importing of information through Web service architecture between companies. By achieving this objective the business flow diagrams would highlight the benefits of either creating IFCs or plug-ins based on XML schemas; particularly SML, in reference to being uploaded to a Web repository (manage services and their artifacts from a business point of view).

Process layer: the concept of the BIM catalogue services and registries (managing services from a technical point of view) hosting the user-defined services, BIM services, data exchange services and product services was based on Open Geospatial Consortium (OGC, 2007) BIM interoperability through a service interfaces approach. The usage of the registries and repositories is to simply search the services maintained on the registry. Usually a UDDI directory service is used to look up XML schemas and other standard Web service interfaces. However, WFS can retrieve requests using URL strings, avoiding the need for XML Metadata Interchange (XMI) tags. XMI tags are used for storing object instances (describes a relationship not a thing, for example; X *is an instance* of type Y meaning X is a member of the set of values that is the type Y); it extends XML to make it object-oriented.

Enterprise layer: this layer provides the end users with the required information to perform their tasks. It is the responsibility of this layer's manager to meet the needs of the users at a fair cost with a high quality. The Graphical Users Interface (GUIs) will enable multiple users to connect to the cloud platform through their Web browsers. The ability to achieve this connection relates to the architecture of the previous layers referred to as a Web application server.

9.5 ANALYSING ICT PERFORMANCE CAPABILITIES IN A CASE STUDY

The main contributing factor of this section relates to whether or not the assembled technology works and how it meets the short-term challenges. Fuchas et al. (2010) emphasised that IFCs do not and are not intended to store and carry all relevant data for all multi-featured construction processes. Furthermore, not all relevant data can be structured in a single super schema. Fuchas et al's approach was to take existing models, as they are, and treat them as one interoperable multi-model space, thus allowing for information to be assembled in a straightforward manner by composing relevant model data and extending the building process information by using alternative models.

Fuchas et al. main objectives are: (i) an extension mechanism to contribute the client software modules, (ii) modularity by itself and for the client modules to allow subset distributions, (iii) a common user interface, (iv) a possibility to load, hold and provide data of the single-model instances and (v) an implementation of the multi-model container (open source Web server and servlet container) format for persistence and data exchange.

The FUSION+GIS+ONUMA System case study illustrates the benefits of obtaining intelligent building object data and exchanging information freely using 'BIM XML' through a central repository 'cloud platform.' This case study 'BIMStorm 2011' is a progression of the previous case study 'BIMStorm 2010' (see Chapter 8) where an existing schema was used to export and import data onto a cloud platform. The re-engineered simplified XML structures of the original schema 'BIM XML' used at BIMStorm 2011 exchange partial BIM data openly through SOA based on the author's research.

9.5.1 Evaluating an information exchange mechanism for BIM

The case study involves using WFS standard http request syntax for fine-grained data access. The notion of using WFS to exchange information between FUSION and Onuma relates to CAD-GIS-BIM. The Open Geospatial Consortium Web Services, Phase 4 (OWS-4) Testbed was originally an initiative of the OGC interoperability program to demonstrate geospatial interoperability. The major technical achievements included the development of the first Web service implementation of a set of CAD-GIS-BIM requirements, establishing an OGC workflow using BPEL, and to demonstrate the process in several scenarios, such as, profiles of the Web Processing Service, for example Topology Quality Assessment Service and Model Output Processing Service (OGC, 2007).

The technical approach for FUSION+GIS+ONUMA Systems is based on a similar technique of using Web services to exchange information. The GIS aspect had been previously used via KML. However, the FUSION+GIS+ONUMA System format provided the capability of extracting facility management information from FUSION and using this accessible data hosted on a cloud platform to alter the design decisions of the BIM model.

The basic WFS used for FUSION+GIS+ONUMA System was READ-ONLY but comprised of (i) GetCapabilities: a Web feature must describe its capabilities, indicate its services and identify operations each service will support, (ii) DescribeFeatureType: upon request the feature type structure that it can service must be described, and (iii) GetFeature: servicing a request to retrieve feature instances and specify which feature properties can be approached.

In contrast with using SOAP, the WFS used in the case study are based on REST. Josuttis (2007) defined REST as “a collection of network architecture principles that focus on simple access to resources.”

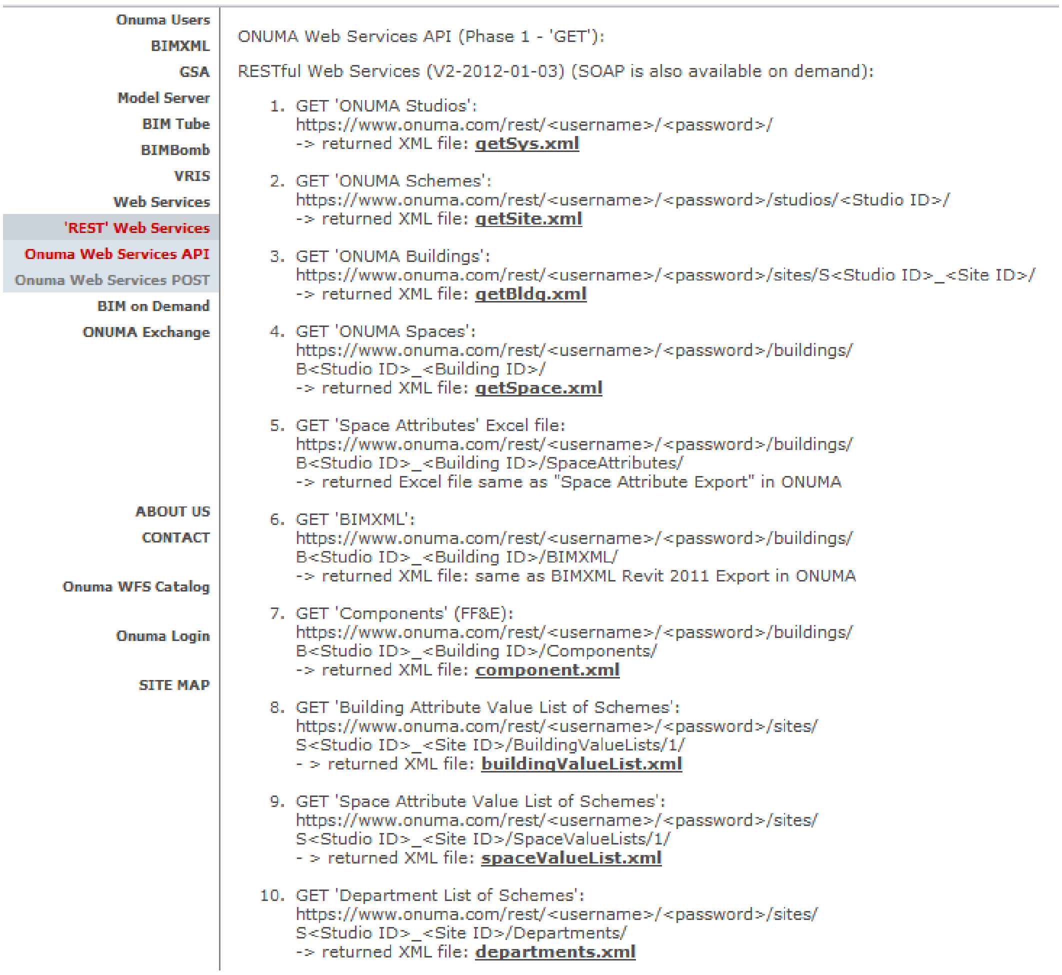


Figure 9.9. Onuma Web service APIs (Sourced from www.onuma.com)

It uses the four fundamental HTTP methods: GET, PUT, POST and DELETE, to stateless read, write, create/perform and delete resources identified by URLs. Figure 9.9 lists the various Web service API that were used for FUSION+GIS+ONUMA System case study. The technical structure of a Web service API comprises of CURL (command line for getting files using Syntax) string for posting API, in order to return requested fields, as indicated in Figure 9.9 buildingValueList.xml. The notion of using RESTful Web services was to advance the capabilities of retrieving real-time information asynchronously from FUSION+GIS in order to make decisions on cost implications relating to facility conditions.

The author's research up until this point had identified the need to use an enhanced BIM XML for exchanging subsets of BIM data between applications on a cloud platform, which prompted the use of WFS. In order for this to be achieved Onuma's developers produced new XML documents based on the existing schema by creating Extensible Stylesheet Language Transformation (XSLT – a declarative XML-based Language used for transforming XML documents). Figure 9.10 illustrates the process:

- The XSLT processor takes two input documents a) the original XML- an XML source document and b) the new sub class XSLT codes – an XSLT stylesheet. From this a new output document is produced.
- The XSLT stylesheet contains a collection of templates rules that guide the processor in the production of the output document. The output document is used to convert data between different XML schemas.

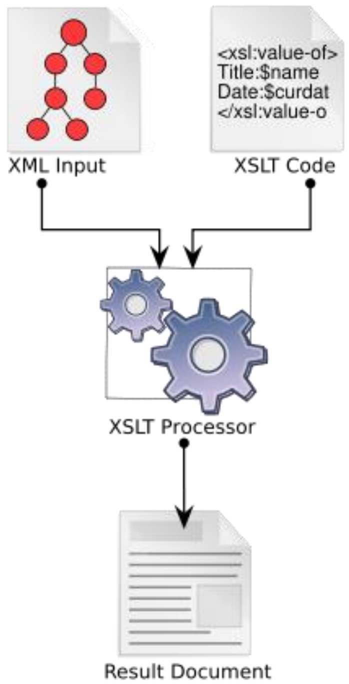


Figure 9.10. Basic elements and process flow of XLST transformations (Dreftymac, 2007)

The idea of the system architecture, which led to the designing of the case study, was based on the diagrammatic representation of the theory test shown in Figure 9.11. The sequence flow of the diagram starts with the GUI, before proceeding to the Onuma System, FUSION and the image of the combined system FUSION+GIS+ONUMA. The query cubes associated with FACT tables in Figure 9.11, are; location, time, sensing device and HVAC equipment. FACT tables relate to Chapter 3 section 3.7 were OLAP for relational databases were referred to as ‘cubes’ (a set of data, organized in a way that facilitates non-predetermined queries for aggregated information). The process uses MDX to exchange aggregate components of XML.

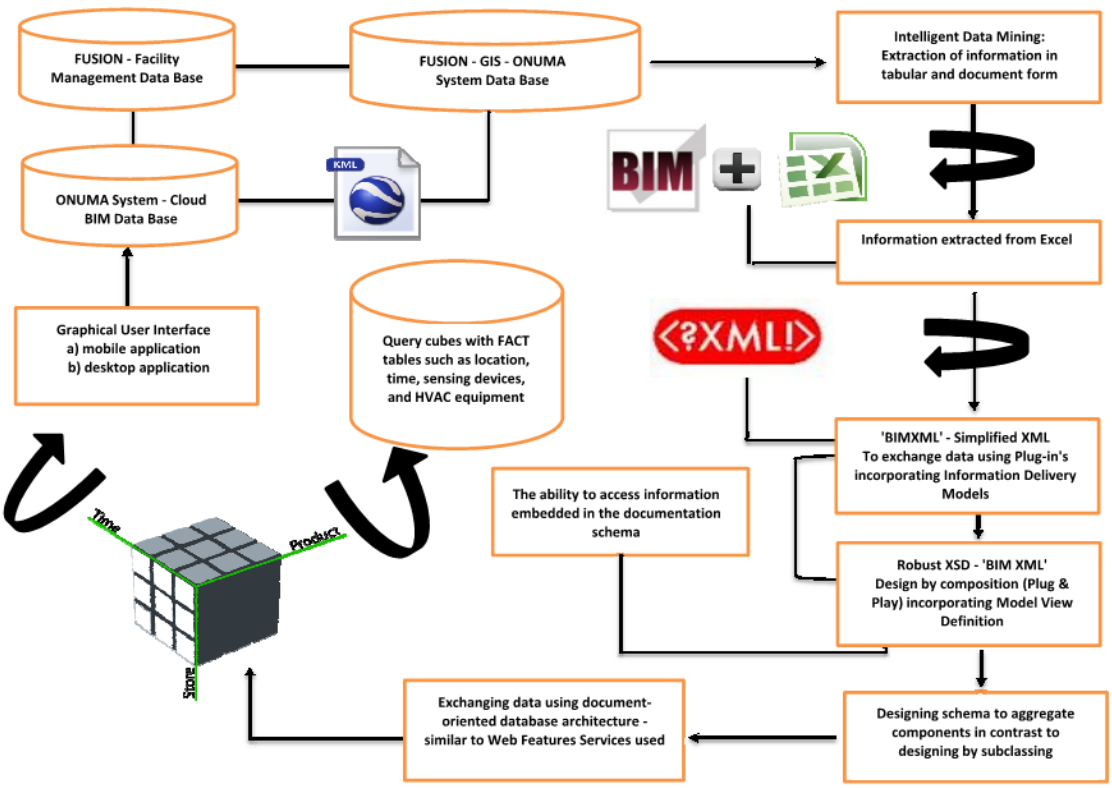


Figure 9.11. Diagrammatic representation of the theory test for FUSION+GIS+ONUMA System case study

Figure 9.11 Diagrammatic presentation of the theory test for FUSION+GIS+ONUMA System case study as follows:

- Stage 1: Merging FUSION (FM) + GIS (geospatial information connected through KML files) + Onuma System (Cloud BIM data base) in order to create FUSION+GIS+ONUMA System.
- Stage 2: Extracting machine learning data (such as that from sensors or databases) from FUSION+GIS and importing this data into Onuma System.

- Stage 3: Importing excels spreadsheet template information (such as Consortium for Real Estate) into Onuma System.
- Stage 4: Extracting partial sets of data via the abstraction layer of the systems architecture (without touching the applications code) for example; Revit and import information through APIs plug-ins.
- Stage 5: Designing sub sets of XML in order to use WFS to create connections between external applications, for example, exchanging data between FUSION+ONUMA.
- Stage 6: Incorporate query cubes for extracting HVAC information.
- Stage 7: Access software via mobile or desktop devices.

Figure 9.12 shows a snippet of the simple XML file, ‘BIM XML’ used to exchange subset data of BIM files on a cloud platform by creating XSLT style-sheets to produce new XML documents.

```
<?xml version="1.0" encoding="iso-8859-1"?>
<xs:schema elementFormDefault="qualified" targetNamespace="http://www.bimxml.org/xsd/001"
xmlns="http://www.bimxml.org/xsd/001" xmlns:xs="http://www.w3.org/2001/XMLSchema">
	<xs:element name="BIMProject">
		<xs:complexType>
			<xs:choice minOccurs="0" maxOccurs="unbounded">
				<xs:element maxOccurs="1" name="BIMApplication">
					<xs:complexType>
						<xs:attribute name="Name" type="xs:string" use="required"/>
						<xs:attribute name="Version" type="xs:string" use="optional"/>
						<xs:attribute name="Developer" type="xs:string" use="optional"/>
					</xs:complexType>
				</xs:element>
				<xs:element maxOccurs="1" minOccurs="1" name="BIMSite">
```

Figure 9.12. Snippet of a simple XML file ‘BIM XML’schema (sourced from Onuma.com)

9.6 BIMSTORM 2011 CASE STUDY 2

Case study 2 was conducted in the same environment as case study 1 Washington D.C (see Chapter 8), but using a new project ‘California Community Colleges (CCC).’ As with the initial case study, the author led his own test observation (see appendix F). A list of buildings belonging to MiraCosta College Oceanside Campus in California was sent to the author for review, in order to choose the most appropriate building for his virtual case study. The building chosen for the case study was a Facility Building with a code reference ‘4200.’

The Facility Building 4200 at MiraCosta College Oceanside Campus is one of 6,000 buildings in the CCC facility condition assessment program. The Facility Condition Index (FCI) is a deficiency tool (for facility management) used to measure the percentage gauge of a building’s condition when determining whether or not the building is worth maintaining. The results of the last assessment, conducted in November 2010, indicated graphically on a facility GIS condition map that Facility Building 4200 had a FCI of greater than 10% (suggesting that it should not be maintained). The FCI ratio is the ratio of the cost of addressing all of the facility's deficiencies versus that facility's replacement value (MiraCosta CCC Comprehensive Master Plan, 2011).

The overall objective of the case study was to show the key benefits of Cloud BIM through its capability of exchanging partial sets of BIM data between applications, such as; improved communication and collaboration among project participants, enhanced project decision making, more accurate planning and scheduling, greater process standardisation, cross-discipline co-ordination / virtual issue resolution and an understanding of the construction environment through visualization from the beginning.

9.6.1 Sequence of a lifecycle process – the case study of Facility Building 4200

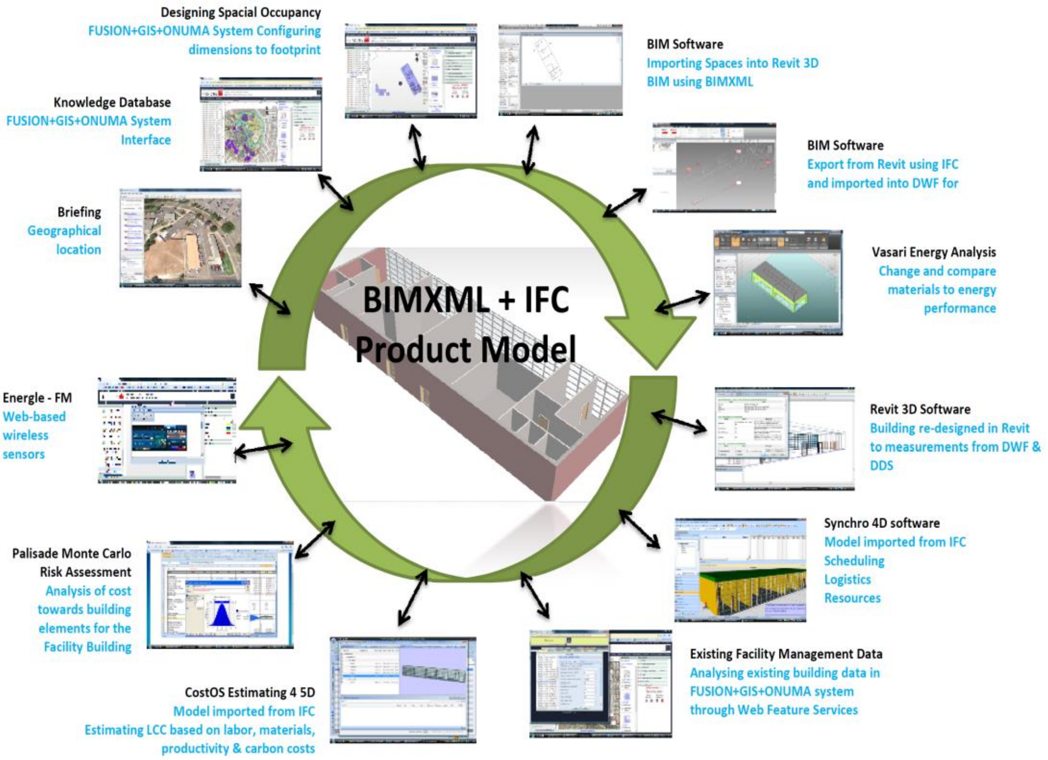


Figure 9.13. BIM XML + IFC product model

Each of the screen prints in Figure 9.13 represent the stages of the case study's life cycle that tested the system architecture design of Figure 9.8, structured to a similar outline of the theory test as illustrated in Figure 9.11. The WFS associated stages of the case study: briefing, knowledge database, designing special occupancy, existing facility management data and Energle-FM, were all based on using Web service APIs to exchange partial sets of BIM data through the internet. The remaining stages involved a combination of using BIM XML for importing and exporting files onto the cloud platform and IFC for proprietary file exchanges. All of the following stages listed in sequence were designed and tested by the author to demonstrate the benefits and limitations of the FUSION+GIS+ONUMA System case study.

Briefing: The published information derived from FUSION via WFS showed that the total repair cost for the Facility Building was calculated to be $288,666 in comparison to the total replacement value of $1,930,960, which yields an overall FCI of 15% (5% above the tolerance figure). Thus, the reason why the Facility Building was chosen for the case study was because FUSION had specified that the building was obsolete. FUSION's data on the building excluded drawings but did include a list of rooms with dimensions (a layout of the building with estimated dimensions is included in appendix F). The initial task was to view the building via Google Earth and take into perspective the existing building's environment.

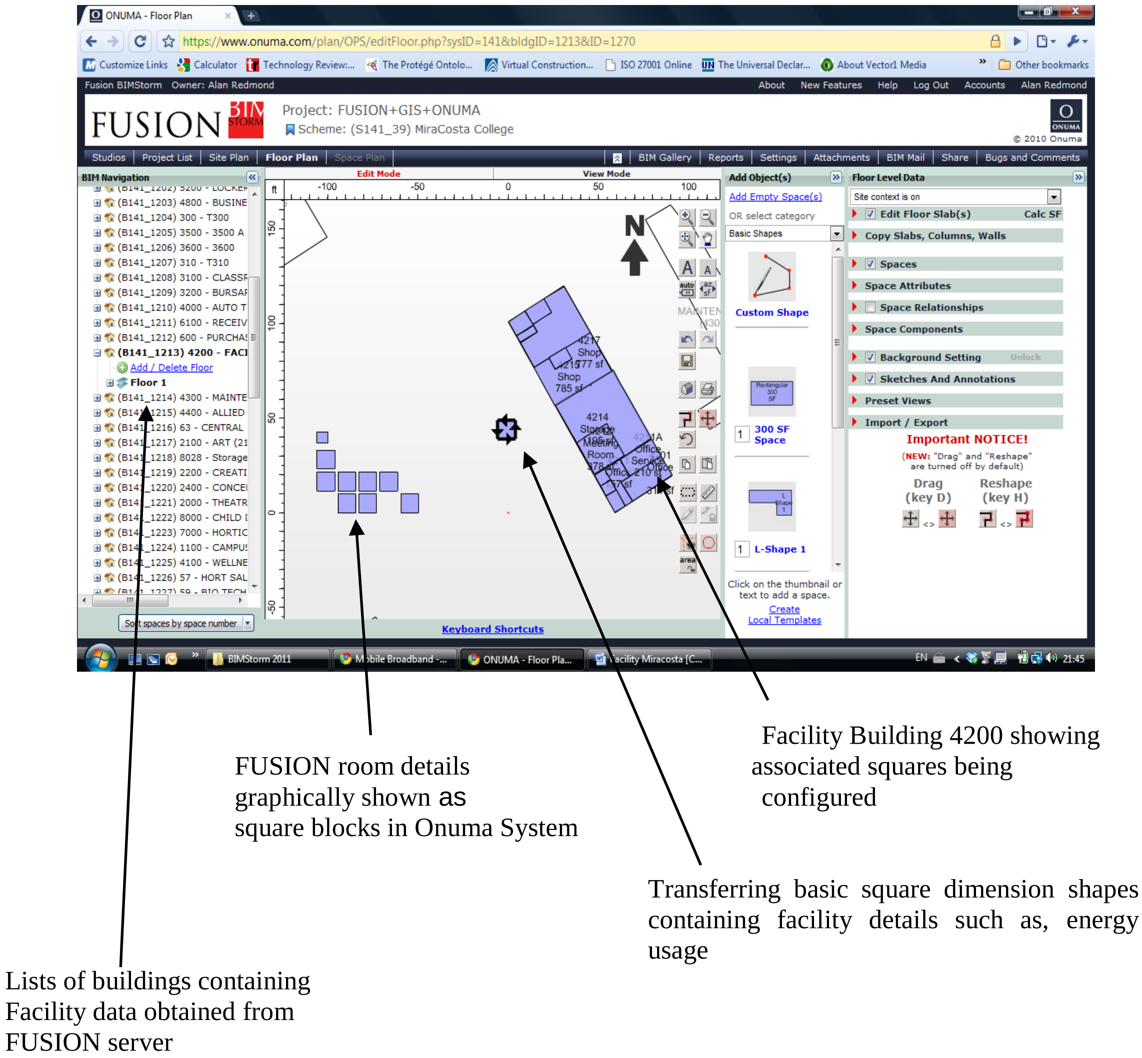


Figure 9.14. Configuring FUSION detail into existing building's footprint

Knowledge database: The interface of the Onuma System provided the rich facility management data of FUSION in a tabular form. By using the Onuma System command tools this information was converted into a 2D drawing coupled with KML ability to illustrate the building in basic 3D; located precisely in its intended position on the MiraCosta campus. The service allowed the author to open his project on a Cloud BIM server (Onuma System) and extract the facility management information from FUSION, without having to leave the interface of the Cloud BIM server. This procedure demonstrated the exchange capabilities of client to server architecture (Web-based APIs) through cloud computing (see Chapter 2 section 2.4; 'characteristics of cloud computing productivity software').

Design Spatial Occupancy: The spatial design of the building was configured to the dimensions and layout of the existing building's details (as extracted from FUSION). Figure 9.14 demonstrates how FUSION information was converted from a basic square with all its associated data (with reference to level of model detail 'basic design' – building footprint, building use, floors and occupancy); is transferred and designed to meet the existing layout plan (level of model detail 'medium' – rooms, partitions, open space and access).

BIM Software: At this stage the basic layout of the building had been positioned in Onuma System; the proceeding process involved exporting and importing this data into a 3D model (at this stage WFS was substituted with desktop applications). The software chosen for this was Revit. The procedure requires exporting the basic Facility Building floor plan, via Onuma plug-in. This BIM XML file was then imported into the Revit model (in order to advance the geometry) and export as an IFC file. The IFC file was then imported into an Autodesk's Drawing Web Format (DWF) viewer to enable measurements of the building to optimize volume (length, width and estimated height projection).

Vasari Energy Analysis (http://labs.autodesk.com/utilities/vasari/): according to Liu et al. (2011), Heating, Ventilating and Air Conditioning accounts for approximately 40% of the energy consumed in buildings. The reason for implementing a basic generic energy simulation for feasibility design of a project, relates to the fact that any improvement on energy performance is a benefit to the life cycle of the building. The Vasari Energy Analysis uses a subset code of Revit and accepts both BIM XML and IFC files. The Revit IFC file was imported into Vasari where simulations were carried out based on two options; option 'A' featured glazing at 40% and option 'B' 36%. The use of glazing, as a key test feature, was based on Selkowitz' (2011) statement that windows are responsible for 10% of total building energy use (approximately 4 to 5%

of total U.S. energy consumption). The results conveyed that option ‘A’ would produce a life cycle energy use of approximately 1,411,538 kWh, a life cycle fuel use of 88,886 Therms, and a life cycle energy cost of $110,813.00. In comparison with option ‘B’: approximately 1,041,874 kWh, 68,577 Therms, and $82,810.00 based on a 30 year life cycle of 6.1% discount rate for costs. This comparison was a basic demonstration and logically option B was chosen but Vasari can also calculate other external wall material changes, such as, block work in comparison to glazing.

Revit 3D model (http://usa.autodesk.com/revit-architecture/): the Facility Building was re-designed taking into consideration the energy analysis based on the volume and glazing associated with the initial design. The IFC file associated with this design was imported into a Data Design System (DDS) viewer. DDS viewer features include; powerful navigation functions, transparency, material mapping and analysing object properties. It also supports both IFC and DWF files. Figure 9.15 illustrates the transparency capabilities of DDS.

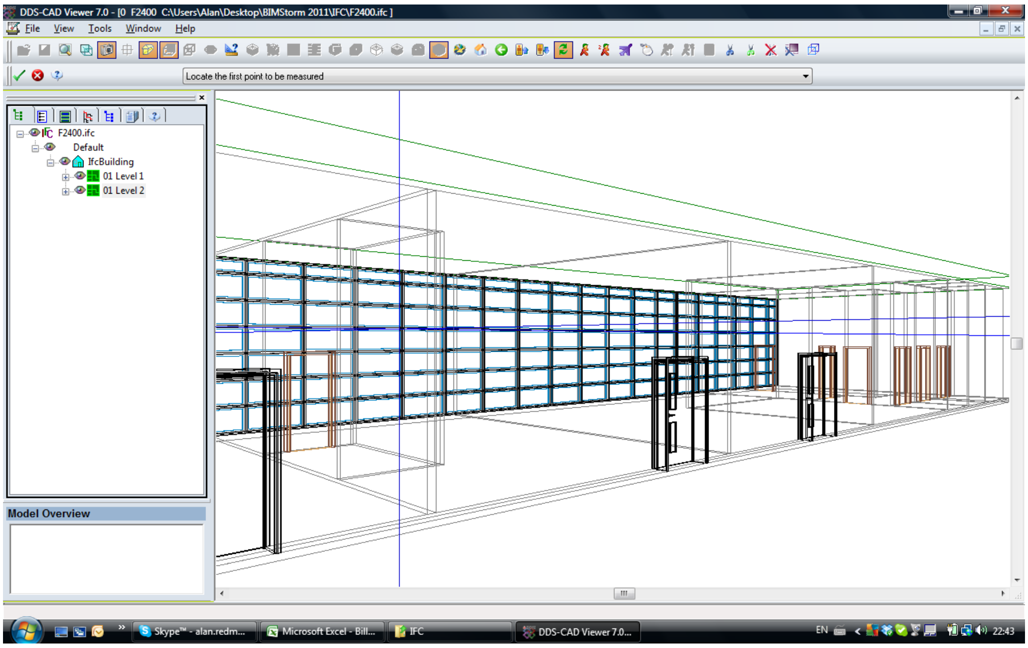


Figure 9.15. DDS transparency view

Synchro 4D software (http://www.synchroltd.com/): the interdisciplinary collaboration capability of BIM to easily manage change while transporting information about a building, from one life-cycle phase to the next harnessed the integration of virtual prototypes (Guo et al. 2010).

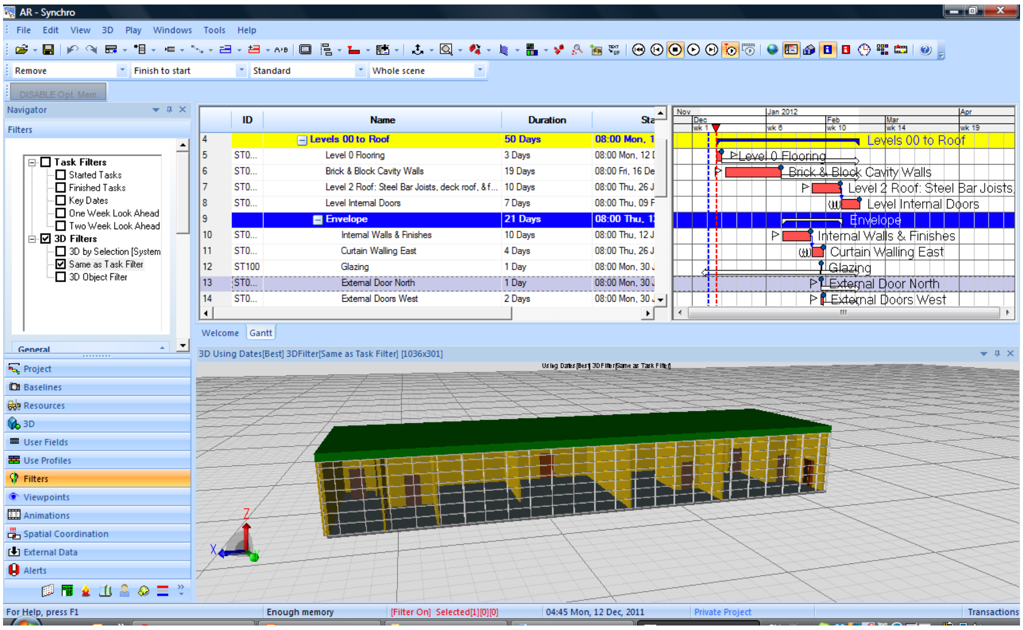


Figure 9.16. 4D planning model

The original project management program created by the author for the re-development of Facility Building 4200 was initially prepared in Microsoft Project Manager and saved as an XML file before being imported into Synchro 4D. The visual image of the model came from the Revit IFC file. The main procedure was to assign the project management program to the associated model tasks. Synchro software provides the simulation ability to show a movie representation of the scheduled program's development stages of the building. This process enhances the decision making capabilities in relation to analysing time-frames, cash flow and allocating resources.

CostOS Estimating 4 (http://www.nomitech.eu): This 3D estimating software allows the user to directly create a cost estimate based on an imported IFC file with an option of adding or changing elements assigned to the cost model or alternatively inserting an Excel spreadsheet and combining this table of quantities with the 3D elements. The characteristics of the BIM visualiser embedded within the estimate enables the associated 3D elements to be displayed individually. For example, clicking on a 3D element on the visual screen will highlight the element's quantity and cost. The reverse procedure separately displays the visual entity of the element. Figure 9.17 shows a screen display image of the Facility Building and its associated cost estimate.

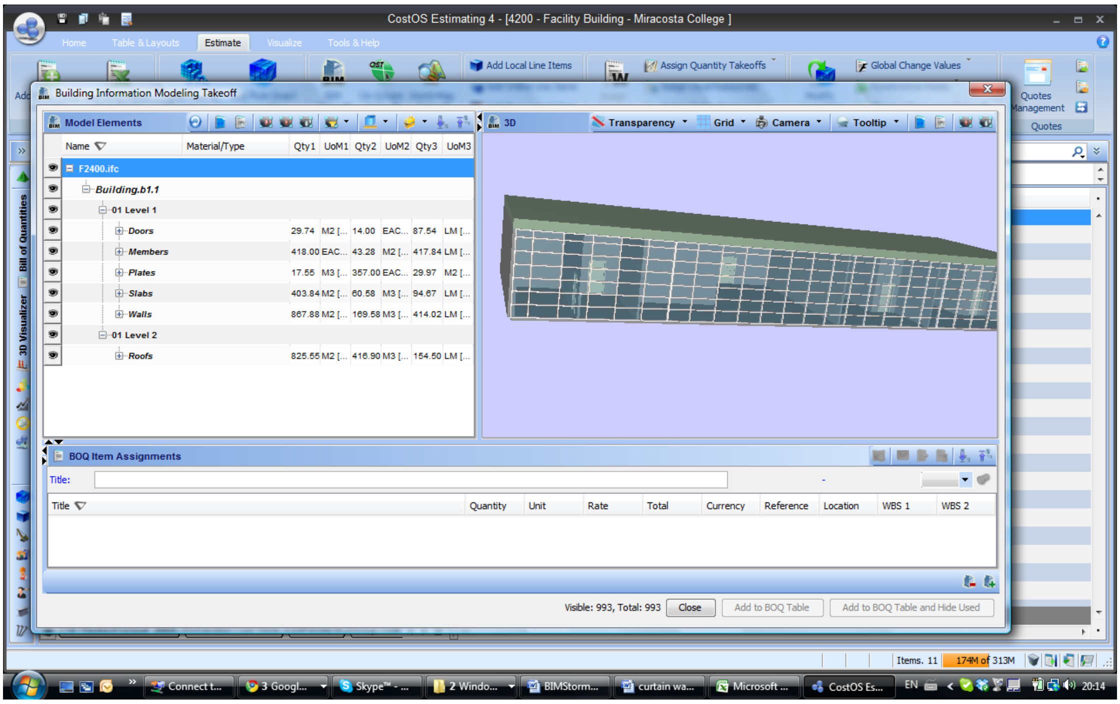


Figure 9.17. 5D Cost Estimating 'Facility Building'

The Excel cost estimate was formulated from exporting the initial 5D take-off and inserting rates based on location 'California.' The author's total estimated figure of $1,708,205 for the new Facility Building was based on demolition, sub-structure, super-structure, utilities and services. The projected cost was $222,755 within the parameters of the initial target cost. However, intangible costs, such as insurance, design fees, inflation and contingency were not included in this estimate.

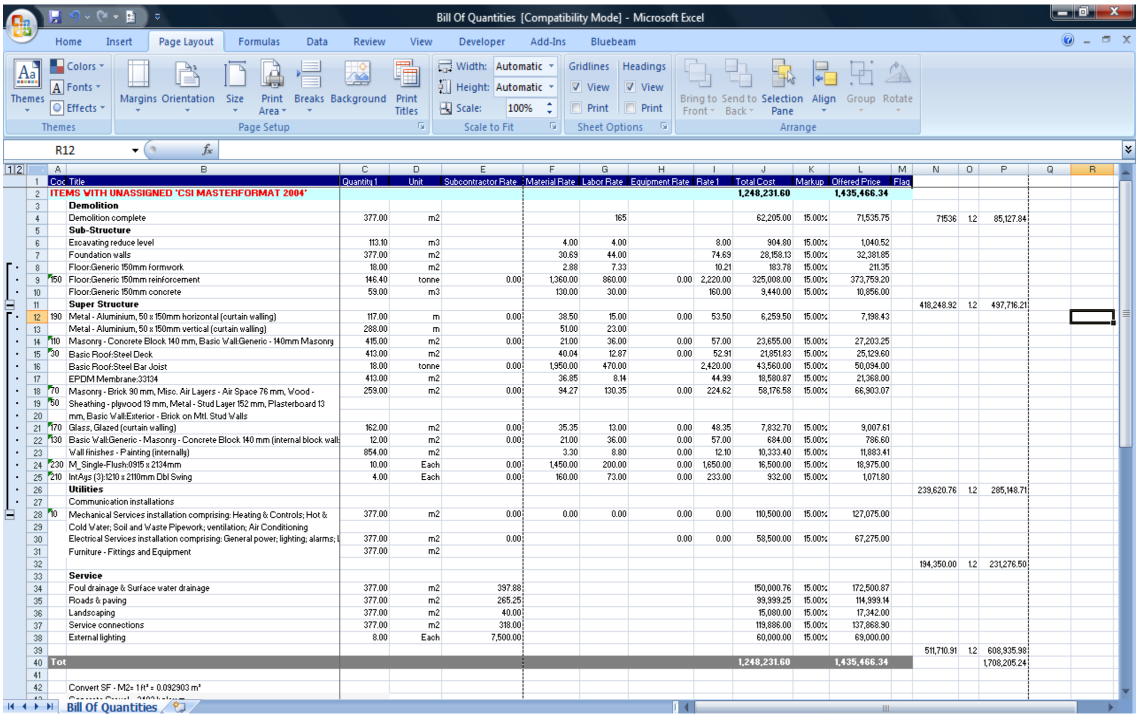
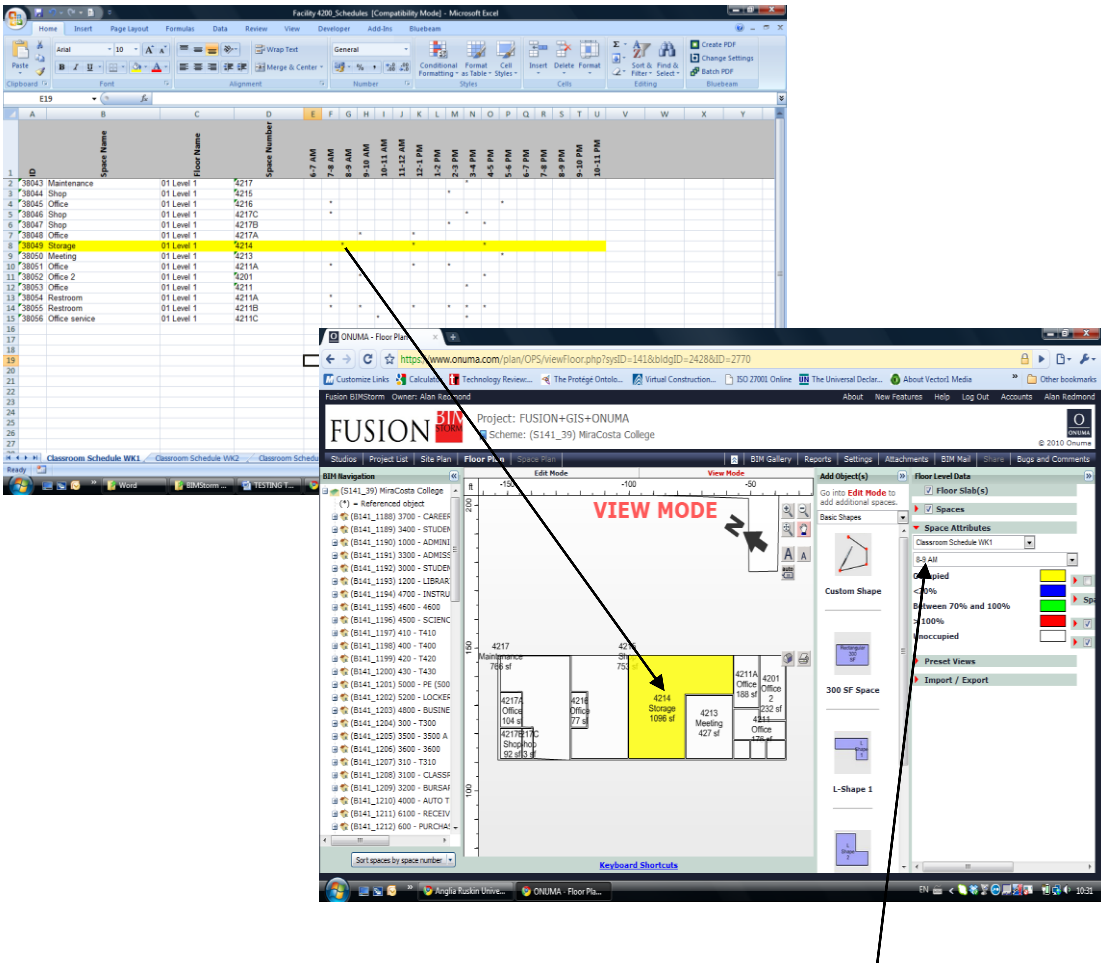


Figure 9.18. Facility Building cost estimate produced by CostOS 4

Palisade Risk Analysis (http://www.palisade.com): The Monte Carlo method concentrates on examining uncertainty analysis, consequently risk management, and cost management under three simple structured parts; definition, what is the hypothesis to test and results and discussions (Emblemsvag, 2003).

These three parts were examined by Palisade Risk Analysis software. The overall budget cost relates to Emblemsvag's conept of a *definition* which was tested against a Monte Carlo simulation at random from the input probability distributions. The Monte Carlo simulation analyses each set of integer a thousand times (in reference to the *test*). The determined value of $1,856,248 represented the probability cost of the finished project. This extra cost of $148,004 added an additional risk contingency to the original budget figure of $1,708,205 (stimulating the *discussion*).

Onuma System (www.onuma.com): The spaces attributes template provided by Onuma System contains a digital object ID code and references, such as; space names, floor names, space numbers and time schedule.



Onuma Systems interface schedule box displaying 8-9am

Figure 9.19. Displaying Onuma templates graphically in the Onuma System

The information is inserted into the template columns and imported into the Onuma system via XML. The result is a list of rooms that will be highlighted to a hypothetical class time schedule, indicated by such colours as yellow if they are over 70% occupied by people. The concept of using this tool for the life cycle was to show which rooms of the facility building would be engaged during a weekly period. This timetable would be repeated for the duration of a semester thus portraying a room schedule representing the lighting usage. By scheduling the classes being used one could potentially estimate the generic lighting/energy costs. Figure 9.19 demonstrates how the Onuma template in tabular form is graphically represented in the Onuma System.

Energle – FM: Is a Web-based wireless sensor connected to the Onuma System interface via Web service APIs. This application was not actually used during the case study. However, the application has the capacity to monitor as-is conditions, such as, energy usage based on temperature, humidity, CO_2, and Lux Level.

9.7 RESULTS AND DISCUSSIONS

Figure 9.13 shows the life cycle model of the participant observation case study undertaken at BIMStorm 2011 by the author. The model is a replicate figure of the BIM relationship; NBIMS (2007) but redesigned based on a BIM XML and IFC exchanging format mode. The original BIM XML schema for Cloud BIM is a subset of XML, which is itself a subset of the Standard General Markup Language. BIM XML was developed into several different subclass XMLs in order to connect FUSION+GIS+ONUMA System through WFS. The overall procedure for developing the feasibility design involved using new XML documents, such as Microsoft Project Manager and importing both SML (BIM XML) files and IFCs into such applications as Autodesk and Synchro, as identified in Figure 9.9.

<u>Case Study Limitations</u>

The problem associated with Synchro and Autodesk not having developed individual XML documents for Web service connections meant that a large amount of data exchanges were not achieved through cloud computing, such as designing and analysing the energy efficiency required for the building. The 4D and 5D services of the life cycle required plug-ins and IFCs for exchanging data. However, if it was not for these two software products the whole cycle of the case study would not have been completed.

Overall each individual application assisted in delivering an efficient schematic/design development cost model based on feasibility information within 3 days that possibly would have taken on average a month. The potential exists for using a Web service architecture to exchange data seamlessly and provide the end-user with the capabilities of activating Web applications through their Web browser. This procedure would allow the user to locate all the required tasks, on one interface, or alternatively a category of interoperable applications, thus reducing time and storage and increasing the speed of exchanging information between BIM applications. Table 9.1 identifies the objectives of the case study and its findings.

Performance metrics	Traditional Standalone Model for exchanging data	Cloud BIM featuring subset of XML for exchanging data
Improved communication and collaboration among project participants	The traditional techniques of using stand-alone or proprietary data exchange mechanisms have been consistent. Projects to date have achieved their required performance indicators. However, the industry recognises that the supply chain is fragmented, as entry barriers for SMEs exist due to the lack of technical ability (not having the required software).	As the author was the project's only participant, this benefit is hypothetically measured. Certainly the aspect of using WFS to instantly share and use facility data without leaving the BIM server model allows for open and instant collaboration via Internet.
Enhanced project decision making	Ethernets already exist but these collaborative hubs require the building design to be undertaken through stand-alone applications before being uploaded to the hub.	The ability to analyse information at the earliest stage through the Internet enabled assumptions with a higher amount of detail to be reviewed earlier, such as, deciding on the spatial and design content based on data derived from FUSION.
More accurate planning and scheduling	The actual main software for developing the work and schedule program with a simulation movie was based on a stand-alone application that used the open exchange schema of IFCs to transfer information.	The ability to have instant data allowed the author to have more time when considering certain scenarios. The BPEL work flows had already advanced the planning and scheduling of the project and the level of model detail required for exchanging data.
Greater process standardisation	The majority of the stand-alone applications used in the case study was to IFC 4x2 standardisation, which does indeed streamline the exchanging of documents (noted not as fast as Cloud BIM).	Both BIM and cloud computing characteristics are based on standards for data interchange – options for saving data or for importing data that is standardised.
Cross-discipline co-ordination / virtual issue resolution	Co-ordination between cross disciplines through the traditional technique happens at a slower pace than Cloud BIM. However, some disciplines prefer to only share information when they are ready, as opposed to the instant alternative.	With access to the project in virtual real-time through the internet, the potential exists for stakeholders and design disciplines to co-ordinate on an open platform at any stage of the project.
Understanding of the construction environment through visualisation	3D and 4D BIM is used regularly in the Built Environment but not in collaboration at the feasibility stage and certainly not asynchronously.	The FUSION+GIS+ONUMA Systems use of three services, facility management, geospatial data and BIM collaborating simultaneously enabled the feasibility and design briefing stage to be visually analysed.

Table 9.1. Performance metrics of the case study and its findings

9.8 CONCLUSION

The IDMs (not in the traditional context as identified in section 3.5.1 but under the presumption to be used as a definition to what building information is required; these specifications are commercially sensitive) and Process Maps were designed to provide clear-cut guidelines for exchanging Web service applications. Cloud computing and BIM enables standardisation of data interchange between multiple levels of a building model's virtual development such as, basic and medium detail. Thus cloud computing and BIM are two ICT programs that influenced the development of a semantic engine based on a heuristic model engaging with corporate and social responsibilities (referring to the stake holders business intentions) to interact and to be collaborative.

The ICT oriented models of 'Cloud computing and BIM' required a process that would enable software developers to implement business processes, identified by mangers, into an executable code. This chapter demonstrated the development aspects of individual flowcharts supporting simplicity, in order to eradicate the productivity bottleneck (barrier) in writing such codes. The business process models used for supporting a Multi-Attribute Decision Model were able to identify a system architecture based on exchanging Web service APIs and IFCs. This benefit allowed the Author to activate programs without having to manually manipulate the source code, which in turn facilitated a mash-up of data. The basic WFS of Onuma System, based on REST, defined a simple access to resources, thus enabling data exchange services between BIM and facility management services. The developer's use of XSLT to create numerous, subclasses of XML documents, based on BIM XML, originates from the author's research on combining three individual applications on a cloud platform. REST provided a communication mechanism between services with XSLT offering a uniformed method for describing services to other programs and WFS located searchable Web services registries.

The capable benefits of transferring nD information through subclasses of BIM XML for Web services and plug-ins exchanges, enabled the case study to be tested successfully. The results demonstrated the interoperable capabilities of Web service APIs for exchanging partial sets of BIM data with real–time constraints at the feasibility design stage. The case study findings highlighted the enhanced decision making capability of using Cloud BIM for the spatial and design content of a building that can factor all of the design team and stakeholders' inputs from the very beginning. Having a service that contributes to sharing information asynchronously, with access to rich data, will assist the design team in making educated assumptions on more cost options than previously undertaken within the industry.

The ability to produce a model for subset distributions, with a common interface on an open platform containing diverse application files for data exchange, proved to be positive through a Cloud BIM service. However, stand alone applications were still required to complete the full life cycle costing model.

Author's key findings in relation to the thesis objectives:

Objective 5: To identify the need for an agreed framework that will create an interoperable layer of business process - The use of IDMs and MVDs in this chapter assisted in designing Figure 9.8 designed solution approach architecture tested in 'case study 2.'

Objective 7: To develop and validate a prototypes ability to exchange partial sets of BIM data by use of simplified XML between differing applications on a cloud platform - The results of the BPDs in this chapter created several different subclass XML documents from BIM XML in order to connect FUSION+GIS+ONUMA System through WFS. The final strand of the methodology 'applying strategic frame work to case study' tested the key concept of BIM XML for exchanging partial sets of BIM data which evolved into the BPDs identified in this chapter.

Part 3: 'Developing and evaluating a case study,' focused on analysing and testing ICT capabilities through designing BPDs and developing and building a prototype of the new process (system architecture design and case study 2).

The use of WFS was first identified in the research with OGC (2007) highlighting how CAD-GIS-BIM integration through GML was used to display 3D buildings in a larger spatial context. The use of ONUMA System based on SOA provided a platform for exchanging not just Web space with published information but actual BIM and facility applications to connect and exchange data asynchronously 'FUSION+GIS+ONUMA System.'

The Web services used had to be prescribed to the SOA platform. The case study tested the communication of the services using REST as the protocol and the several subclass XMLs of BIM XML to connect and exchange data. Figure 9.12 'BIM + IFC' outlined the LCC of the case study. The various services that were combined using WFS performed exceptionally; facility data was analysed and used without leaving the BIM server, thus creating open collaboration. However, in order to achieve the full cycle IFC-STEP files were needed.

CHAPTER 10

SUMMARY AND FURTHER STUDY

10.1 SUMMARY

The author's research on cloud computing and BIM highlighted the need to combine both vehicles together 'Cloud BIM' in order to provide the transferring of nD (3D, 4D, 5D, and 6D) BIM applications through Internet exchanges (via Web services APIs and plug-ins) in real-time. The research successfully itemised the potential of combining three applications asynchronously in order to utilise the social capacity of the design team and stakeholders and to be collaborative during the 'feasibility phase' when key cost-benefit analysis and decisions are invoked.

However, the construction industry requires standard exchange methods for BIM over the Internet, and the current use of IFCs makes the structure too complex and difficult to form SQL queries to receive pertinent data.

Chapter 6 reviewed the exchanging difficulties associated with using IFC–STEP and IFC-XML, which lead to the solution identified in Chapter 7, 'creating a simple and flat relational schema.' In Chapter 8 the flat file of BIM XML was tested in a controlled environment to the author's workflow criteria (the feasibility and design brief stage of a project). The findings highlighted BIM's potential benefit of working across the Internet (via cloud computing) using SML for exchanging data between a wide range of applications, in order to efficiently make decisions that would contribute to the LCC of a building.

This thesis research demonstrated that e-business protocols, such as REST, can be beneficial to the feasibility design phase of a construction project, by using a subset of XML ('BIM XML') to increase the interoperable capabilities of sharing BIM files on a cloud network. The use of XSLT in creating subset XML documents, based on the BIM XML schema, produced the connection between FUSION, GIS, and the ONUMA System. REST supplied the communication mechanisms between the services, and WFS identified the Web services registry to invoke collaboration simultaneously.

In Chapter 9 the testing of a cloud computing infrastructure based on the original attributes of a SOA enabled the component parts of the Facility building to be modelled in disparate software programs. The traditional method of exporting a file from one server and then importing it into another was superseded due to the SOA, as the Facility data remained in FUSION while being modified in the ONUMA System. SOA provided the underlying context for the Web services. The key difference between generic SOA and Web services for the FUSION+GIS+ONUMA System was that specified technologies were prescribed for each system SOA.

The results of the second case study (Chapter 9) demonstrated benefits of sharing information between standard Web service interfaces on a cloud network to achieve cost-benefit analysis, such as *using WFS to instantly share and use facility data without leaving the BIM server model*. The overall cost model did however, require both data exchange techniques, traditional 'desktop application' and Cloud BIM 'Web service APIs' in order to complete the cost estimate. In defining the significance of the research three individual services were combined together on an Internet platform based on the BPEL4WS workflows of when to export and import Web services. The BPDs identified the subsets of BIM XML to be developed that provided the mechanism to exchange data within the FUSION+GIS+ONUMA System.

10.1.1 Review of Main Findings

Chapter 2 – Literature Review 'Cloud Computing'

The potential for increasing productivity in the construction environment by using ICT to reduce poor communication, inefficient processes, and general fragmentation and to support a distributed workforce has been slowly recognised. However, the industry does acknowledge that in order to make key decisions organisations must be centrally connected. In this chapter the characteristics of cloud computing, which are similar to those of BIM, were highlighted, such as standards for data interchange (standardised options for saving or importing data) and modular interactivity communications (the ability to allow one application to interact with the other). However, one of the noted key drivers of cloud computing turned out to be the instigation of the research on 'inter-applications communications' (the ability of an application to use the service features of another). This chapter also identified several benefits of cloud computing and some of the obstacles (which were further investigated in the primary research).

Similar research conducted in Ireland on cloud computing indicated strong support for the availability of pay-as-you-go service. In relation to SMEs, it was recognised that their business productivity would increase while their ICT capabilities were advanced. Other benefits included linking organisations with customers and suppliers through the use of Web 2.0 tools. The benefit of ICT and its role in re-engineering was seen as a driver behind the changes in the design and construction process. The desktop case study of Bechtel highlighted the cost-benefits associated with high-performance computing that would adopt the architecture of loose coupling between infrastructure and applications, thus reducing legacy infrastructures. The majority of the literature in Chapter 2 was investigated in Chapter 5 (drivers, barriers, and benefits), Chapter 6 (benefits of BPR and obstacles of cloud computing), and Chapter 7 (capabilities of cloud computing).

Chapter 3 – Literature Review 'BIM Standard Exchange Formats'

The importance of standardised exchange mechanisms to advance interoperability was highlighted in this chapter as a major challenge for the construction industry. The prospect of utilising interoperability within the industry would require an open standard data format. The most successful data information exchange format for hosting construction data that connects to a building virtually prior to it being built physically is IFC. The three main identified exchange formats were direct links (incorporating APIs to extract data), proprietary exchange formats (interfaces developed solely for a company's applications), and public product versions (IFC, text file and XML).

However, the problem with IFC is its use of the language EXPRESS, as its coding rules are too complex and difficult to compile (this would be further investigated in Chapter 6 and Chapter 7). A key observation by the author was the industry's use of XML in using Web services to exchange data ('pertinent BIM data') to increase interoperability across the Internet. One such Web standard was WFS based on CityGML for exchanging proprietary BIM data. This standard had a profound effect on the direction of the research, as it identified a domain that existed in the geospatial industry that could possibly change the construction industry with the assistance of a SOA for 'inter-application communications,' thus providing accessibility, integration, and the use of several different services asynchronously and all relating to the life-cycle relationships of BIM. Another major finding from the secondary research was the idea of using IDMs and MVDs to decide when and how exchanges would be made. IDMs and MVDs were used in Chapter 8 to develop the swim lane diagram workflow and in Chapter 9 for creating BPEL4WS. The findings from the literature review also recognised the benefits of SML, a subset schema of the XML language, as the solution to freeing complex exchange structures and barriers.

The desktop case study of France (2010) demonstrated the cost savings of two million U.S. dollars by reducing expenses associated with workstations and laptop hardware through virtualisation of GPUs.

Chapter 4 – Methodology 'Formal Belief Network – Knowledge Mapping Process'

The author's chosen survey strategy was a full hybrid methodology based on both qualitative and quantitative survey techniques aligned with triangulation of data ('observation from multiple positions'). The series of techniques, a main survey questionnaire, focus groups, two Delphi techniques, structured interviews and a case studies were formulated into two separate categories: (i) formalizing domain knowledge, and (ii) applying a strategic framework for the case study based on the philosophical orientation of the mixed methods and the theory and practice tension relating to 'grounded theory.' This structure was used to investigate the first three parts of the thesis strategic plan relating to BPR: (i) development of a business vision – examining questions extracted from the literature review relating to ICT adoption, collaboration, and cloud computing; (ii) identifying the process to be designed – investigating information extracted from the *formalizing domain knowledge* surveys; and (iii) understanding and measuring an existing process – reviewing an existing SML schema and *applying a strategic framework to a case study*.

Chapter 5 – The Online Survey and Focus Groups 'Development of a Business Vision'

The author presented the findings of a 2010 questionnaire survey based on a sample of 40 international vendors and 50 Irish construction firms/SMEs. The objective of the survey was to examine the use of cloud computing in the construction industry. The survey was designed to illustrate the drivers, barriers, and benefits of cloud computing as a central repository vehicle for hosting and exchanging data. The technique of the 'focus groups' used the information obtained from the online survey to identify whether the Irish market required the benefits of cloud computing.

The online results showed that BIM/CAD, document management, estimating and costing, and project management were the main applications being used in the construction market. The survey identified that the driving force for using cloud computing was value-added service and sales. Speed, agility, accelerated information access, communication in real-time, and assisting collaboration through streamlining information were deemed as the main benefits. Lack of knowledge about cloud computing, lack of typical construction Web applications that could be used on a cloud computing platform, and security were recognised as the highest barriers. The focus groups comprising 10 vendors from Ireland supported the need for a virtual operator to host a portal window to connect all vendors in the market and identified disaster recovery and business continuity as the main barriers.

Despite the issues associated with cloud computing, one Irish vendor in particular, highlighted the benefits of using open data storage for HVAC, such as ease of access through a Web browser from any location and a reduction in inefficient paper-based hand reports.

Chapter 6 – Delphi Questionnaires 'Identifying the Pprocess to be Designed'

The findings of the initial Delphi questionnaire established a practice for developing a cloud-based construction service, through identifying standardised deliverables, obstacles, and opportunities for growth. However, the possibility of providing an interoperable process based on binding three focused construction applications through a single repository platform (cloud computing) required further analysis.

The results of the second Delphi questionnaire demonstrated that BPEA, 5D, and request for information were the most favorable BIM applications to be tested for advancing interoperability at the early design stage. The need for the construction industry to have software interoperability through exchange definitions was connected to the possibility of developing an open exchange model with a common interface. The process of using IFC-STEP, in comparison with IFC-XML, favoured XML because of its Web services integration ability with BIM. However, the survey did show that aspects of FM, such as BAS and SWE, through Web services were considered very complex.

The results of the second questionnaire determined that the market is increasingly demanding that open standards be applied to BIM and that by having multidisciplinary project teams that work together with data-sharing tools, a common information model can exchange information faster than standard legacy systems can, possibly through the use of Web services.

Chapter 7 – Semi-Structured Interviews 'Identifying the Process to be Designed'

The findings of the 2010 semi-structured survey emphasised that the main standard file exchange format of IFCs was not designed intentionally to host all relevant data. However, ifcXML was recognised as a potential solution, considering that the IFC content is still derived from the complex language of EXPRESS (a cumbersome exchange mechanism). Initially the alternative solution of creating a BIM central repository based on an integrated platform, over the Internet, found opposition with issues ranging from privacy to security to whether such a platform was technically possible.

On the positive side, the results did identify a need for a Cloud BIM exchange mechanism, in contrast to developing a super schema. The ability to exchange data between the various different AEC disciplines by collaborating on the same platform advanced the concept of conducting key decision making at the early design stage. The use of standard deliverables and the capability to utilise Web service and plug-ins by incorporating Web-based BIM exchanges using both IFCs and SML highlighted the potential to access faster information more quickly.

Chapter 8 – Case Study 1 'Understanding and Measuring an Existing Process'

The 2010 case study tested the value of using BIM XML in a working industrial environment. The test analysed Cloud BIM's ability to export and import a arrange of specified data files, through a model server, activated by a Web browser, in contrast to the existing stand-alone exchange method of transferring completed BIM model files. The swim lane workflow designed for the case study demonstrated how BIM XML's original strategy of exchanging files could be enhanced and redesigned to achieve faster decision-making capabilities. The major contribution of the case study was highlighting Cloud BIM's ability to obtain rich data at the feasibility stage of a project through exchanging partial BIM data in order to aid key design decisions. This case study provided enough evidence to conduct another test (Case Study 2), which would embrace the concept of using Web services to combine and exchange application data on a shared platform while utilising both novel XML and IFC to test a full LCC model.

Chapter 9 – Case Study 2 'Designing a Cloud BIM Business Process Model'

The 2011 case study emphasised the innovative technique of developing IDMs and process maps, based on semantic methods, and tools to support multi-attribute decision modelling. The MAD models determined the decision-making process for implementing Cloud BIM services using SML for exchanging data on a cloud computing platform. The case study illustrated that a combination of nDs can be transferred through Web services and plug-in exchanges. This practice was only achievable through creating subset XML documents of the existing novel XML, based on several workflow designs that incorporated IDMs and MVDs to a basic, medium, and high model level of detail.

Six metrics were used for the performances in the Cloud BIM case study 2:

- Improved communication and collaboration among project participants: The use of WFS created instant sharing capabilities across the Internet while staying in one application.
- Enhanced project decision making: Rich data was utilised at the commencement stage of the project.

- More accurate planning and scheduling: The ability to change information from a basic to a high model level of detail in real-time generated the capacity to analyse various design project programs.
- Greater process standardisation: Options for saving and importing data are standardised.
- Cross-discipline co-ordination: Potential exists for all disciplines and stakeholders to collaborate on a single Internet platform.
- Understanding the construction environment through visualization: Three independent services were integrated on one domain, which allowed 2D facility data to be graphically viewed in a BIM model connected to real-world images of the environment.

The result demonstrated the benefit of the Cloud BIM SOA case study by enhancing the interoperable capabilities of sharing BIM files on a cloud computing network - 'predicating 80% of the life-cycle costs within 3 days at the feasibility phase.' Figure 10.1 is a synopsis of the thesis main points as identified through each of the chapters.

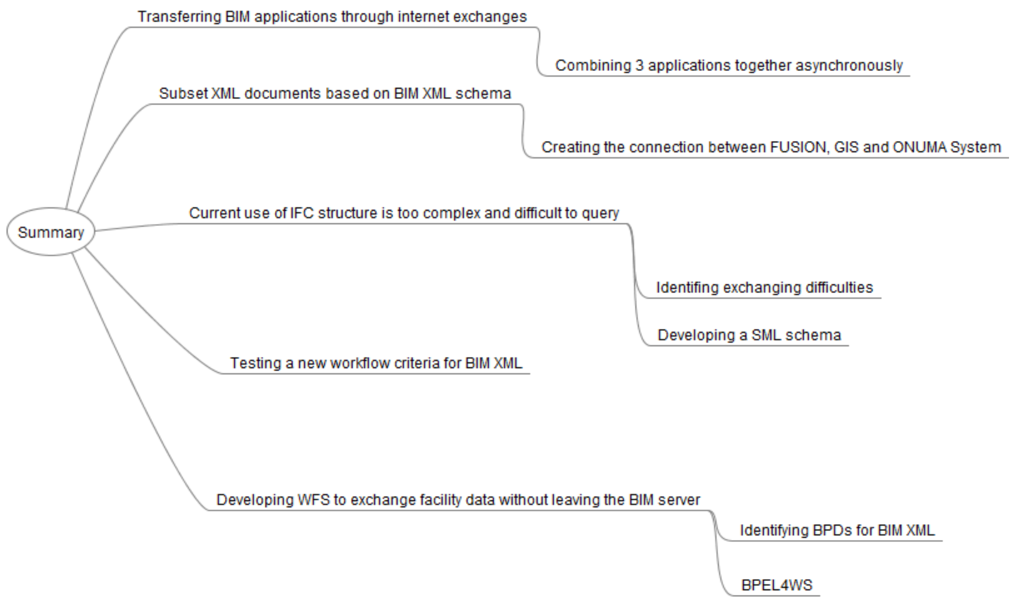


Figure 10.1. Summary of the thesis main points

10.2 BUSINESS PROCESS RE-ENGINEERING SOLUTION

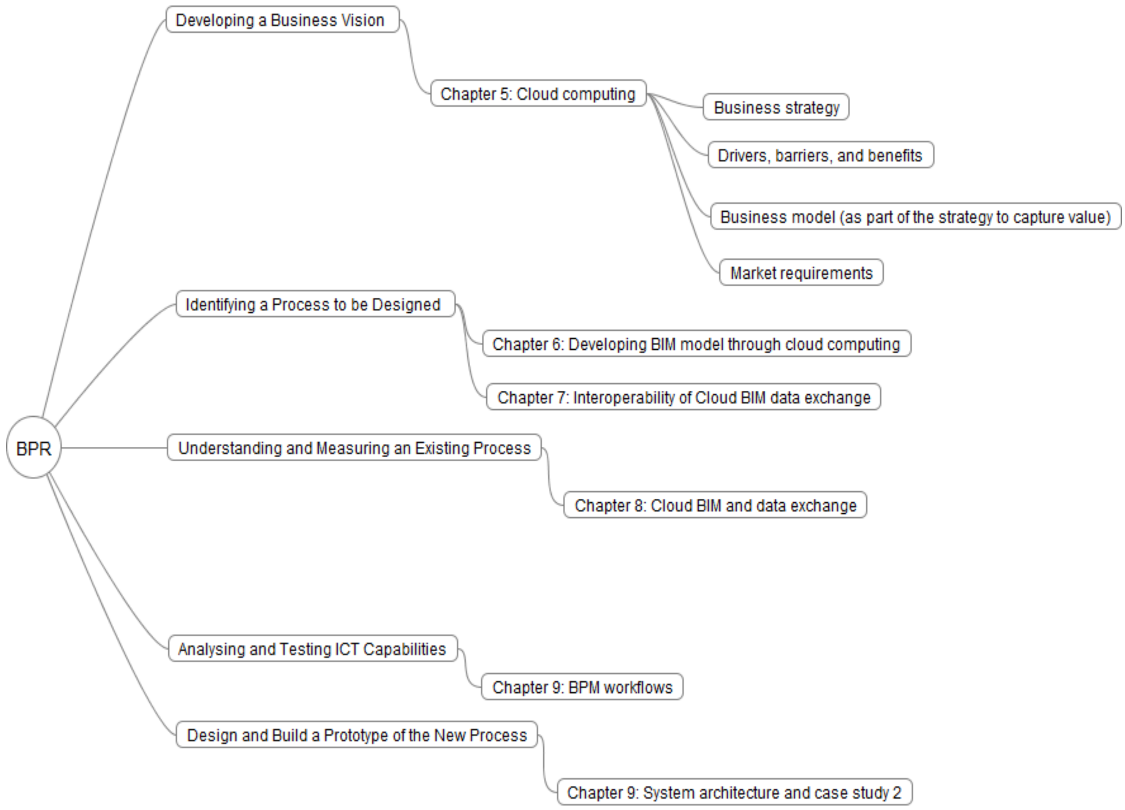


Figure 10.2. BPR flow diagram (adapted from 'Thesis Roadmap') [see Chapter 1 section 1.4]

The author adapted the Business Process Re-engineering methodology identified by Avison and Fitzgerald (2003). The initial stages involved investigating the challenges of interoperability for construction using ICT software. The solution identified was Web collaboration technology, and the initial vehicle was cloud computing - 'a network platform capable of reducing transaction costs, for creating reliable information flows for enhanced online collaboration tools.' The construction industry's main bottle neck for exchanging building object data resided in the traditional proprietary file-based exchange methods. The industry's recognised solution was BIM, as its characteristics graphically detail a building virtually prior to building it physically, in order to work out problems and perform cost-benefit analysis, using structured information that is organised, defined, and exchangeable. These two ICT levers ‘cloud computing’ and ‘BIM’ were effectively used as drivers for redesigning the current construction practice.

Chapter 4 outlined a formal belief network that was incorporated into the BPR process to represent knowledge in the form of conceptualisation ‘analysing the results of surveys in order to define the relationships between them.’ The relationships as previously indicated in this chapter summary were investigated and analysed for the model to be designed (Cloud BIM). In reference to redesigning the construction industry process for exchanging data, Chapter 8 tested the existing exchanging mechanism of IFC (borrowed from the auto industry’s STEP) in comparison with BIM XML.

The key aspect to identifying the need for developing a mechanism for exchanging partial sets of BIM information on a cloud platform relates to the properties of BIM XML. Evaluating this existing schema to facilitate decisions that can contribute to the building’s life cycle and significantly reduce costs supported the solution previously recognised in Chapter 6 ‘combining three individual applications together through Web services.’

The semantic methods and tools, such as MAD, as indicated in Chapter 9, contributed to developing BPMN that was used to test the Web service collaboration case study of BIM applications on a cloud computing platform. With incorporation of the BPR stages identified by Avison and Fitzgerald (2003), the end result successfully created several subset XML documents based on the novel schema BIM XML, in order to exchange data openly through SOA. This practice provided a rich store of data to the potential decision makers (design team and stakeholders) when required thus advancing the exchange process in virtual real-time and utilising best practices during collaborative work that can readily be transferred to project teams using Cloud BIM software.

10.3 ACHIEVEMENT OF THESIS OBJECTIVES

The overall aim of this thesis was to design and test an integrated process for exchanging partial sets of BIM information on a cloud-based service. Through re-engineering an existing method, the developed Web-based model (Cloud BIM) provided more rich information exchanges during collaborative work at the feasibility phase of a project when key decision are to be made. This practice prompted the need to provide readily transferable and available data for project teams when they most likely require it leading to exchange of small portions of data on a collaborative accessible platform (the Internet) to generate faster design decisions.

Thesis Objectives	Performance metrics	Correlation between objectives and performance measurements
Objectives – 1, 2 and 4	Improved communication and collaboration among project participants.	Objective 1 – to describe the importance of design interoperability: communications were improved. Objective 2 – utilise the data interchange benefits of Web services: WFS instantly shared and used facility data. Objective 4 – advancing interoperability of data exchange through the use of Cloud BIM: facility data was used without leaving the BIM server model allowing for open and instant collaboration via Internet.
Objective – 3	More accurate planning and scheduling.	Objective 3 – investigate the potential of cloud and BIM in re-engineering early design: this objective was measured through BPEL work flows which advanced the level of model detail required for exchanging data at the early design stage.
Objective – 5	Greater process standardisation.	Objective 5 – create an interoperable layer of business processes in a software form common to a building project that will require information exchanges between specialised software packages: the developed subset of XML invoked and received queries based on the standard interchange of BIM XML.
Objective – 6	Enhanced project decision making.	Objective 6 – the ability to advance key decisions at an early design stage: the ability to analyse information at the earliest stage through the Internet enabled assumptions with a higher amount of detail to be reviewed earlier.
Objective – 6 and 7	Cross-discipline co-ordination / virtual issue resolution.	Objective 6 – the ability to advance key decisions at an early design stage through the exchange of partial sets of BIM data on a cloud-based platform: the prototype allows stakeholders and design disciplines to co-ordinate on an open platform at any stage of the project. Objective 7 – develop and validate a prototypes ability to exchange partial sets of BIM data by use of simplified XML between differing applications on a cloud platform: the real-time open platform enabled design disciplines to co-ordinate at any stage of the project.
Objective –7	Understanding of the construction environment through visualisation.	Objective 7 – optimize productivity and performance at the early design stage of a construction project: the FUSION+GIS+ONUMA Systems use of three services, facility management, geospatial data and BIM collaborating led to the producing of a schematic design stage estimate at the feasibility stage within 3 days.

Table 10.1. Correlation of thesis objectives with prototype performance metrics

10.4 FURTHER STUDY

The issue of contract had produced discrepancies between various answers throughout the research techniques such as, being ranked as both a low driver and barrier in the postal questionnaire but highlighted a disputed issue by the focus groups. Contractual issues were identified in the Delphi techniques as a problematic area but it was not until the semi-structured interviews did the author fully appreciate the potential to eliminate the barriers associated with electronic exchange of BIM information. Chapter 7 highlighted that The American Integrated Project Delivery model and NEC conditions of contracts would be the most preferable types to be used for facilitating exchanges of BIM data. The author proposes that further advanced research should seek to develop swim lanes and analysis on how BIM data exchanges can be legally incorporated into specific contracts to establish the role and responsibility of a designated professional required to manage the information system of a data repository and ownership of BIM models.

Walton (2006) recognizes the classical problem of information versus knowledge citing that what currently exists on the Web at present is information (‘a large collection of facts’). The process of converting facts into knowledge is achieved by means of interpreting the concepts, such as truths, beliefs, perspectives, judgments, methodologies, and know-how. These types of concepts had been previously demonstrated in Chapter 4, such as using belief networks for the methodology of the thesis, thus leading to the development of a Cloud BIM Web service network. This concept together with the facts defined the relationship between them and formed the basis of conceptualization.

The process for creating a specification for conceptualization is defined by ontology (a set of objects and the relationships among them). The future vision of the Web will be based on semantic principles, enabling applications to retrieve, comprehend, and exchange data using automated techniques. Walton establishes the question: ‘How do we compose knowledge services into applications that can accomplish specific tasks?’ As shown within this thesis, SOA can be used to underpin the entire architecture by providing connections between the resources of existing network nodes with other nodes as independent services. The ability to access these independent services is vital to the structure of the semantic Web. Chapter 9 identified how Web services are made available by registering with a specific directory through WFS. The development of Web service architecture is advancing the development of a computer-oriented Web. Deitel et al. (2003) predict that XML will become the universal technology for representing data passed between Web applications. This practice will allow all applications employing XML to communicate with each other, without regard to OS and hardware platforms.

In essence, the future of developing software will be less structured in the formal format of the waterfall model, in reference to Horner (1993), and more inclined to represent Web service architecture. By creating Web services access to resources that perform computation on the provided data will be transformed instantly - for example, performing a design-related task based on the inference of knowledge, such as a building type, or using Web-based BIM agent programs to provide and transform data. The possibility now exists for various Web-based BIM services to form a multi-agent system utilizing existing ontologies (such as OWL for BAS) to develop a centralized Web-based system architecture automatically transforming data into knowledge output.

10.5 LIMITATIONS OF THE RESEARCH

The participant observation method of data collection was used to measure the volume of output in contrast to the volume of input. However, labour productivity is the amount of services that one produces in a given amount of time (labour productivity norm) and is dependent on a number of factors: type of work, discipline, and location. In both case studies 1 and 2, it was not possible to be detached and record how other design disciplines, such as architects and engineers, may have utilised the workflows because the practice of using novel XML was not the industry norm (however, each sequence of work was validated by an industry representative in real-time). This meant that in regards to the efficiency of the case studies (the ratio of planned volume of output to the actual volume of output), the author's expertise and experience was the only real qualitative version of the technique that could be measured.

As noted in case study 1, the real-time input benefits of a Cloud BIM model for the other design disciplines at the feasibility phase could only be measured hypothetically. Several issues were associated with case study 2 because the model was not developed completely using Web service architecture. The 3D rendering of the design was through Revit and the 4D project program required the use of Synchro. This meant that in order to finish the LCC estimate, the model needed IFCs to transfer information. The overall rationale of the research was that *not all relevant data can be structured in a single super schema*. This would imply that both IFCs and XML or novel XML would be required, but it was the author's intent to demonstrate that a complete model of Web services could be used up until and possibly beyond the schematic stage (the point where detailed exchanges of information would be essential).

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