THE IMPACT OF BUILDING INFORMATION MODELLING ON ESTIMATING PRACTICE

Analysis of perspectives from four organizational Business Models

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STATEMENT OF ORIGINALITY

The thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying subject to the provisions of the Copyright Act 1968.

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ABSTRACT

This study aims to explore the impact of 3D CAD and BIM on estimating practices based on the notion that both paradigms, in varying degrees, improve the cost performance of projects compared to the use of conventional design tools such as 2D-CAD. The objectives are: (1) to explore the activities required to develop workable estimates in different estimating practice domains and represent them in the form of process models; (2) to establish the degree of association and reliability of the identified activities; (3) to compare 3D CAD and BIM estimating processes across different practice domains (using discriminant analysis); and (4) to suggest how the process models can be implemented and further strengthened for application development.

The theoretical framework of the study was based on Kagioglou et al.'s (1999) process re-engineering model - to define the forms and goals of estimates in the different phases of the development of construction projects. Further review of literature shows that there are several estimating methods that are applicable to the various project development stages, which are ontologically stratified across the various construction business domains. Consequently, different perspectives of estimating practice in construction businesses are developed from four business structure models viz. the MModel (representing client organizations), the DModel (representing contracting organizations), the FModel (representing consulting practices) and the NModel (representing specialist project delivery systems such as IPD).

Mixed and plural research methodologies were used to explore the stages and activities that are involved in 3D CAD and BIM estimating. Firstly, products of four software development organizations were investigated to ascertain how the applications were used for 3D CAD and BIM estimating. Data was also explored from 5 presentations on 3D CAD and BIM estimating by the software development companies to 77 subject-experts who offered their views on estimators' expectations of BIM applications. Secondly, participants, 17 in total, were sourced from the 4 business models indicated above to discuss their 3D CAD and BIM estimating processes. Data were captured through focus group sessions and individual interviews.

The estimating themes for 3D CAD and BIM were garnered from the aforementioned qualitative data using a combination of direct observation, focus group discussions and interview sessions. Through these methods, the stages and activities involved in the preparation of estimates based on 3D CAD and BIM across the four business structure

models were identified and rated. These ratings were statistically analysed to test whether the variables were sufficiently robust to be used to create process models, which the different practice domains can deploy to generate workable estimates with 3D CAD and BIM. The data were normally distributed and were analysed parametrically. First scoring factor analyses showed that the views of participants from DModel and FModel practices were highly correlated in both 3D CAD and BIM regimes. In addition, multiple comparisons using Fisher-Hayter and ANOVA procedures showed the key characteristics of the variations between how participants from the different practice domains viewed the importance of activities leading to estimating outcomes.

Additionally, reliability tests (Cronbach's Alpha) were used to measure the internal correlation of the estimating activities that were identified in both 3DCAD and BIM. In 3D CAD, 16 out of the 31 themes were discounted for lack of internal consistencies. The resultant process model has an Alpha value of 0.96. In BIM regime, analyses show the Alpha value to be 0.95, while only four themes (estimating activities) were discounted for lack of statistical consistencies. The themes retained after the reliability tests formed the centroid (group representative) process models for the 3D CAD and BIM estimating. However, the derived variables in the centroid models apply differently to the practice domains. Consequently, both ad-hoc and post-hoc data were analysed to determine the discrimination of the centroid models across the four practice domains.

Implementation of the process models was also discussed. First, illustrations were made on system architectures for the process models. Second, indicative EXPRESS-G structures were provided to show how the process models can be advanced for implementation in the form of applications, training and for future research. Third, indicative integrated definition formats (IDEF0) were developed to illustrate how the outcomes of the process models can be strengthened with case-based control measures.

This study has established that estimators still use conventional methods to estimate 3D CAD projects, and more than 50% of activities leading to estimate outcomes in this domain do not add value to estimating outcomes. This study also presented the key characteristics and enablers of opportunities for estimators in BIM. Recommendations were also drawn on how to develop change management models for dealing with operational issues when transiting from conventional practices to digital systems.

SUPPORTING PUBLICATIONS (SELECTED)

The research work reported in this thesis is supported with nine articles published by the author of this dissertation. These include four journal articles, three conference papers and two book chapters. The contents of the publications are summarized below:

Journal articles

- In (Olatunji, 2010c)[1], the author explores the relationships between macro-variability and construction costs. Analysis in the study shows that construction costs are impacted by varying economic indicators such as variability in the relationship between construction GDP and other activities in the main economy (e.g. balance of trade, government policies and cost of finance). It is also found that, more usually than represented in project drawings, and largely unpredictable so, these indicators pressure construction cashflow through hard-to-control changes in resource costs and stochastic conditions in cost of finance.

- In (Olatunji, 2011c)[2], the author reviews the legal implications of model ownership in project implementation with BIM. The overriding argument in this study is that the process integration triggered by BIM involves substantial trust in the integrity of data that have come from different disciplines. The study concludes that the repercussion of this perception is significant to project economics. This is because the methodology for valuing intellectual property in BIM is yet undefined, and existing legal frameworks in the industry promotes fragmentation.

- In (Olatunji, 2011b)[3], the author explores the cost implications of corporate implementation of BIM in construction SMEs. It emphasizes that BIM implementation in construction business requires strategic actions which involves changes to resource utilization and corporate philosophies on business behaviours. It presents a validated regression model for predicting the cost of BIM implementation in construction SMEs in Australia.

- In (Olatunji et al., 2010b)[4], the authors review the relationship between quantity measurement, estimating and (mis)conception about the integrity of BIM data. The study reports that workable estimates are not promoted by putting superficial costs into model objects or by simply applying costs to quantity data that are auto-generated from BIM models; rather by conscious engineering of model data and resource data in ways that best meet project goal.

Book Chapters

- In (Olatunji and Sher, 2010b)[5], BIM is presented as a novel platform for storing data on project lifecycle processes. The study relies on past studies in facilities management (FM) processes to explain a framework for utilizing BIM for FM. Conclusion were drawn in the study on how BIM supports data and process integration and automation of FM processes.

- In (Olatunji et al., 2010a)[6], the authors argue that BIM requires effective collaboration to drive satisfactory project outcomes. The three primary components of gaming theory – Pareto optimal, hawk dove and prisoners' dilemma – were used to explain the practical implications collaboration in null, partial and full forms. Different collaboration scenarios were used to outline potential outcomes when BIM project teams do not collaborate, when they collaborate partially and when they collaborate fully.

Conference Papers

- In (Olatunji, 2010a)[7], the author developed a conceptual model to explain the implication of BIM-triggered changes to the business structure of estimating practices. The model covers the varying requirements that estimating businesses and their different levels of staff need to implement in order to fulfil their goal with BIM.

- In (Olatunji and Sher, 2009)[8], the authors make predictions about the potentials of BIM in 2020. The paper covers the chronicles of advancements in CADD and CAD since the 19th century with conclusion on the potential of BIM in conjunction with mobile computing, remote site access technologies and laser scanning.

- In (Olatunji et al., 2010c)[9], the authors explore BIM and its impact on construction estimating. The paper argues that estimators' views about model objects are not the same as designers', and for model data to meet estimators' requirements, they must be structured in ways that promote probity and accountability.

List of Publications

Olatunji, O. A. (2010a): BIM adoption: a conceptual model for managing practice changes in estimating organizations. *Proceedings, 6th International Conference on Innovation in Architecture, Engineering and Construction.* (June 10 - 11) Penn State University, United States of America.

Olatunji, O. A. (2010b): The impact of oil price regimes on construction costs in Nigeria. *Construction Management and Economics,* 28**,** 747-759.

Olatunji O. A. (2011a): Modelling the costs of corporate implementation of building information modelling. *Journal of Financial Management of Property and Construction,* 16**,** 211-231.

Olatunji, O. A. (2011): A preliminary review on the legal implications of BIM and model ownership. *Journal of Information Technology in Construction (ITcon),* 16**,** 687-696.

Olatunji, O. A. & Sher, W. (2009): Building Information Modelling (BIM) System in construction in 2020: Opportunities and Implications. International Postgraduate Research Conference (IPGRC-09), The Lowry, Salford Quays, Greater Manchester. University of Salford, UK, 429 - 438, 448.

Olatunji, O. A., Sher, W. & Gu, N. (2010a): Chapter 6: Modelling Outcomes of Collaboration in Building Information Modelling through Gaming Theory Lenses. *In:* WALLIS, I., BILAN, L., SMITH, M. & KAZI, A.-S. (eds.) *Handbook on Sustainable Construction: Industrialised, Integrated, Intelligent (I3CON).* Espoo: VTT, Finland.

Olatunji, O. A. & Sher, W. D. (2010): Chapter IX: The Applications of Building Information Modelling in Facilities Management. *In:* UNDERWOOD, J. & ISIKDAG, U. E. (eds.) *Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies.* Information Science Reference.

Olatunji, O. A., Sher, W. D. & Gu, N. (2010b): Building Information Modeling and Quantity Surveying Practice - whatever you thought, think again. *Emirate Journal of Engineering Research (EJER),* 15**,** 67-70.

Olatunji, O. A., Sher, W. D. & Ogunsemi, D. R (2010): The impact of building information modelling system on construction cost estimating. CIB 2010 World Congress, 2010c. Salford, UK

GLOSSARY

3D	Three-dimensional
AAQS	Association of African Quantity Surveyors
ABS	Australian Bureau of Statistics
AI	Artificial Intelligence
AIA	American Institute of Architects
AIB	Australian Institute of Building
AIQS	Australian Institute of Quantity Surveyor
ANN	Artificial Neural Network
ARIMA	Auto-Regressive Integrated Moving-Average
AS	Australian Standards
ASMM	Australian Standard of Measurement
BAS	Building Automation System
BCA	Benefit-Cost Analysis
BCIS	British Cost Information Service
BESMM	Building and Engineering Standard Method of Measurement
BIM	Building Information Modelling
BoQ	Bill of Quantities
BPIBR	Business Process Initiatives and Behavioural Re-Engineering
CAD	Computer-Aided Design
CADD	Computer-Aided Design and Drafting
CAE	Computer-Aided Estimating
CBA	Cost Benefit Analysis
CCI	Construction Cost Index
CCP	Comparative Cost Planning
CIOB	Chartered Institute of Building
CMSS	Change Management Support System
CMM	Change Management Model
CMR	Construction Management Research
CoF	Cost of Finance
CP	Cost Planning
CPM	Critical Path Method
CPS	Cyber-Physical Systems
CSG	Constructive Solid Geometry
DLP	Defect Liability Period

DBPA	Design-Based Protocol Analysis
DModel	Divisional business structure model
ECP	Elemental Cost Planning
ERA	Evaluated Risk Assessment
ERP	Enterprise Resource Planning
ES	Exponential Smoothing
FGs	Focus Groups
FIDIC	Federation of International Council of Engineers' Condition of Contract
FL	Fuzzy Logic
FM	Facilities Management
FModel	Functional-unit practice structure model
FUs	Organizational Functional Units
GDO CAD	Geometric-Data Only Computer-Aided Design
GIS	Geographic Information Systems
IAI	International Alliance on Interoperability
ICE	Institution of Civil Engineering
ICEC	International Cost Engineering Council
IFC	Intermediate Form of building Contract
IFCs	Industry Foundation Classes
IPD	Integrated project delivery
IT	Information Technology
IDEF0	Integration Definition Format
JCT	Joint Contracts Tribunal
LiDAR	Laser Altimetry Techniques
LND	Logarithmic Normal Density
LP	Linear Programming
LSM	Least Square Method
MModel	Matrix structure model
nD	nth-Dimensional
NEC	New Engineering Contracts
NIBS	National Institute of Building Sciences
NIQS	Nigerian Institute of Quantity Surveyors
NModel	Networked business structure model
NPWC	National Public Works Council
NPV	Net Present Value

NSWPWD	New South Wales Public Work Department
OOP-CAD	Object-Oriented and Parametric Computer-Aided Design
PDFs	Probability Density Functions
PERT	Program Evaluation and Review Technique
RIFD	Radio Frequency Identification
RIBA	Royal Institution of British Architects
RICS	Royal Institution of Chartered Surveyors
SA	Simple Algorithm
SFCA	Standard Form of Cost Analysis
SMA	Simple Moving Average
SMM	Standard Method of Measurement
SMMIEC	Standard Method of Measurement of Industrial Engineering Construction
TEN	Tetrahedral Networks
UK	United Kingdom
USA	United States of America
VBPM	Value-Based Performance Management
VR	Virtual Reality
VDC	Virtual Design and Construction
VM/E	Value Management and Engineering

1 INTRODUCTION

1.0 INTRODUCTION

1.1 RESEARCH BACKGROUND

The last 15 years have seen the introduction of building information modelling (BIM) and the accompanying promotion of its potential in the construction industry. For the first time in the history of the construction industry, there is an IT-based integrated platform, BIM, which facilitates the flow of information between the many and diverse construction disciplines involved in the design, construction and life of construction projects. Furthermore, BIM has the potential to improve collaboration between project stakeholders (clients, contractors, consultants and other role players) leading to direct benefits to all concerned.

Notwithstanding these advantages, there has been considerable information (and misinformation) about BIM and the uses to which it can be put. Many authors have linked BIM to automation and argued that it can change traditional procedures and roles (Deutsch, 2011; Succar, 2009). To others, BIM contains precise data that guarantees the accurate preparation of estimates and a lowering of lifecycle costs (Arayici et al., 2012). Moreover, some reports have consistently put pressure on construction businesses as though non-implementation of BIM as a practice or business thinking could mean the end of such businesses (Abdelkarim, 2010, Hope, 2012, Waterhouse, 2011).

In contrast, there have been cautionary calls from many researchers about BIM. In their view, it does not provide a silver bullet to all the ills of the construction industry (Sattenini et al., 2011). Amor and Faraj (2001) and Amor et al. (2007) note that there are many misconceptions about BIM and its deliverables. For example, these authors, as well as others, have argued that:

- BIM is a multi-disciplinary phenomenon; each discipline has had distinctive interpretations regarding what BIM means and how it should be put to use. In particular, estimators' perspectives on BIM and its deliverables are different from those of designers' (Olatunji, 2010a).
- most of BIM's deliverables (e.g. automation and integration) are not made to replicate or meet estimators' requirements (Olatunji and Sher, 2010a). Thus,

estimators have to understand and deal with BIM in a particular way to deliver the outcomes they require.

- BIM is neither CAD nor its replacement (Zyskowski, 2009). Although some terms have been used to connect BIM to CAD (e.g. *n*D, 3D, parametric CAD (Alwisy and Al-Hussein, 2010, Sacks and Barak, 2008, Hubers, 2010), both paradigms require different activities to deliver workable estimates.
- the procedures involved in preparing estimates based on 2D CAD data are different from those involved when BIM data are used (Dean and McClendon, 2007).

The purpose of this study is to explore the impact of building information modelling (BIM) on estimating practices. The construction management literature notes that estimating is practised in different domains; a range of unique business behaviours sets each domain apart. Authors, including Gruneberg and Hughes (2005), Kometa et al. (1994), Ng and Skitmore (1999), and Sutrisna et al. (2005), have pictured a construction estimate as the cost proposal shared between parties intending to commit to a construction contract. Frequently, each party's business expectations and behaviours are different from the other's. Few studies have discussed construction business behaviours extensively (Chen and Tsai, 2006; Knight, 1977; Price, 2007) and cues have been taken by Olatunji (2011a) to classify estimating practice into four domains of business models viz. the matrix organisational model to represent clients, the divisional organisational model to represent contractors, the functional-unit practice model to represent consultants and the networked organisational model to represent specialized project delivery systems such as integrated project delivery, relational contracting, alliancing and partnering.

The Construction management (CM) literature has provided strong evidence regarding concerns about the accuracy of construction estimates (e.g. Aibinu and Pasco, 2008, Cheung et al., 2008, Potts, 2008). The majority of the views expressed by these authors have not distinguished between the core principles of each of the practice domains. Nonetheless, the most general view is that dissatisfaction with estimates has been mainly as a result of them not being accurate (Ogunlana and Thorpe, 1991, Ogunlana, 1989, Potts, 2008). On numerous occasions, it has been reported that pre-contract estimates have failed to predict post-contract outcomes as a result of many reasons, including:

- Incorrect calculation of quantities (Aibinu and Pasco, 2008).

- Ambiguities in descriptive parameters of projected costs (e.g. description of work items, interpretation and implementation of standard methods of measurement, units of measurement and arrangement of estimated work items) (Davis et al., 2009a).
- Misrepresentation of work items due to inappropriate interpretation of project designs (Acharya et al., 2006b).
- Omissions and wrongful inclusions in contract work items (Afetornu and Edum-Fotwe, 2005).
- Confusions arising from uncertainties in cost descriptors (e.g. provisional sums and contingencies) (Babalola and Adesanya, 2008, Babalola and Aladegbaiye, 2006).
- Fragmented relationships between those preparing estimates and those responsible for implementing cost control measures (Kern and Formoso, 2006).
- Ethical issues arising from actions and inactions of actors in estimating processes (Poon, 2003).
- Macro-economic variability and project risks (Baloi and Price, 2003, Olatunji, 2010c).

In varying degrees, all the issues indicated above pose significant challenges to estimating practices, which should not be under-estimated. Many clients are sceptical of estimators' forecasts, especially when empirical studies have shown that construction is characterised by uncertainties that are both inevitable and difficult or impossible to predict (Ogunsemi and Jagboro, 2006). Thus, both forecasts of, and cost management during, construction are critical problems in estimating practice.

Authors who have worked on contract performance e.g. Hanid et al. (2010), Nummelin and Salo (2010), Potts (2008) and, Sweasey and Skitmore (2007) have similar views i.e. the challenge of contract performance is not a problem for estimators alone. These authors see it as a burden to be shared by the entire project team, particularly designers. Some authors, including Acharya et al. (2006b), have argued that ambiguities in estimators' work are partly due to design issues such as omissions, errors and inappropriate representations. Other problems facing estimators include lack of clarity, design conflicts, process fragmentation and inability of design tools to sustain multidimensional data (Acharya et al., 2006b; Anumba, 1996).

BIM has the potential to address these shortcomings in different ways. Firstly, it has attracted considerable attention as a platform for effective design and multi-disciplinary collaboration. Many studies highlight its revolutionary potential to de-fragment how information is generated and shared between project teams (Hänninen and Oy, 2008; Olofsson et al., 2008). Secondly, there are conflicting views about whether BIM automates estimating or the roles estimators will play in a fully integrated application. While Olatunji and Sher (2010a) have argued that it is impossible for BIM to completely satisfy the requirements of all design and construction professionals, other claims have emerged, suggesting that estimators and their institutions need to accommodate BIM in their practice and business thinking (Abdelkarim, 2010, Bailey, 2010). Some reasons for this are as follows:

- BIM stores both quantitative and qualitative data that purports to be an accurate representation of project models. Consequently, estimators are arguably no longer required to measure quantities from drawings (Azhar et al., 2008; Bailey, 2010, Broekmaat, 2008). This implies that the quantity surveying discipline, a discipline that has provided estimating services for several decades, may be made obsolete by BIM (Olatunji et al., 2010b). Thus, BIM estimation is a substantially different process which estimators must become familiar with and master.
- BIM opens horizons for new roles and data modelling processes in project development (Tse, 2009). As a result, estimators as well as other disciplines are under pressure to, at least, restructure their old roles or adopt new roles.
- BIM imposes various technical and behavioural requirements of users to deliver its outcomes e.g. collaboration, integration, value sharing and a positive team spirit (Aranda-Mena et al., 2009, Aranda-Mena et al., 2008). These requirements are critical as project teams have had to grapple with implementing them (Cooper et al., 1985, van Meerveld et al., 2009). Therefore, for estimators to survive in the new BIM era, their business frameworks, philosophies, professional psychology, business behaviours and process designs are likely to change.
- There is a diversity of views about what constitutes appropriate estimating procedures in the different estimating practice domains (see Chapter 2). This is a significant factor when identifying and measuring estimators' reactions to BIM. The consequent outcomes relating to this are complex.
- More importantly, BIM is a multi-disciplinary platform (Succar, 2009). However, its conceptualization in estimating practice has been vague and minimal because

of its newness. The overriding challenge to this study is to present BIM in the balanced but nuanced views of several domains of estimating practice. This involves exploring the different practice domains in which estimating occurs in construction businesses and the different ways BIM influences the approaches estimators use in these domains.

In exploring BIM, most studies have focused on parametricism in design concepts, some of which are difficult or impossible to relate to estimating practices and procedures. The overarching focus of this study is to investigate estimators' understandings of BIM as well as of the differences between traditional estimating practices and procedures, and those which BIM makes possible. Consequently, this chapter has been divided into the following sections:

- definition of terms
- the research gaps in the practice domains stated above
- the research questions
- the research aims and objectives
- the research methods used, including the research scope and limitations
- the significance and motivation for this study
- an overview of the whole thesis
- a summary of this chapter.

1.2 DEFINITION OF TERMS

Several terminologies were used in this study, some of which have been interpreted differently by various authors. For the sake of clarity, some short definitions are provided below:

- *3D CAD:* 3D CAD is the geometric representation of design components in three dimensions viz. length, breadth and width (Dean and McClendon, 2007). In this study, 3D CAD typifies the single disciplinary use of three-dimensional drawings without parametric properties and multi-disciplinary integration.
- *nD:* nD refers to multi-dimensional extension of the building information model, created by incorporating all the design information required at each stage of the lifecycle of a building facility (Lee et al., 2006).
- *Building information modelling (BIM):* BIM is defined as a digital system for facilitating a data-rich, object-oriented, intelligent and parametric representation of a

construction project, from which views and data appropriate to various users' needs can be extracted and analysed to generate information and enhance decision-making on project economics, and improve project delivery processes (Section 3.3).

- *Design parametricism:* Parametric design is a design that uses multi-disciplinary integration and objects which are well defined by the variables of generative components such that when changes are made to any component of the design, they are reflected in the integrated model automatically. BIM designs are either based on industry foundation classes (IFCs) or parametric platforms (Hubers, 2010).
- *Construction estimate:* A construction estimate is defined as an aggregate of input costs (direct and indirect costs) and mark-up by which a project can be undertaken under a reasonably packaged contractual relationship, described in relation to time, contract duration, work quality and functionality, fixed but not exclusively closed to variability. This is an adaptation of the definition by The Chartered Institute of Building (CIOB) (2009), but integrated into the perspectives of project owners (as described by (Aibinu and Pasco, 2008).
- *Accurate versus workable estimates:* estimates are represented in form of quantitative (e.g. costs, quantity) and qualitative (e.g. description, unit of work) data. An accurate estimate is achieved when mathematical functions represented in the estimate are exact, correct and free from errors. A workable estimate means the estimate representing a construction approach is strategic in achieving project goals (e.g. smoothen cashflow, protect project finance against specific risks and uncertainties).
- *Cost performance:* Cost performance is an analytic method of comparing project budgeted costs with actual project costs and earned project value (Gido and Clements, 2003).
- *Estimate parameters:* Project estimates are defined cost-related parameters such as work descriptions, unit of measured items and measureable costs.

1.3 RESEARCH GAPS

Conventional discipline-specific estimating processes are reported in several texts. For example, Ashworth (2010) and Seeley and Winfield (1998) have reported the theory and practice of estimation in the building industry. Additionally, Seeley and Murray (2001) have addressed estimation for engineering projects. In these texts, estimation is conceptualized as a system that is largely based on manual processes – manual interaction with drawings, manual application of resourcing and cost data, and several decisions which are based on personal

judgements. The applications of information technology (IT) are not new to estimating practice, having been described by authors including Sher (1982, 1996) and Selinger and Stamler (1983). However, estimation is still considered by many to be too sensitive to be delegated to the actions of software applications only. Clearly, many authors (e.g. Lowe and Skitmore, 2001; Green, 1989) have argued that computer-aided estimating processes need to be moderated. This moderation generally involves estimators critically evaluating the outputs of computer-aided estimating (CAE) applications rather than trusting the outcomes produced by these systems. Additionally, Best et al. (1996) discovered a marked reluctance of estimators to use IT, while Akintoye and Fitzgerald (2000) reported a proliferation of CAE applications as a problem in the industry. Apparently, the view of these authors (Akintoye and Fitzgerald) is that estimating activities requires some rational actions which many applications are unable to distil (i.e. implement and refine). Moreover, some of the software may not deliver workable outcomes as claimed by their developers.

The presence of IT in the Australian construction industry has improved in the last ten years. IT competence has become a larger component of employees' attributes, communication approaches and business culture than was reported in earlier literature (Kajewski et al., 2004). The change in construction business practices from conventional manual procedures to IT-enabled platforms has resulted in a clear gap between manual estimating procedures and recent digital innovations. Examples are provided below:

- *In the context of estimating processes:* BIM provides an opportunity for re-inventing estimating processes, as well as estimating procedures (e.g. take-off methods or approaches, abstracting, working-up, drafting, scheduling, cost estimation and tendering). Newer procedures have been explored in other studies including the use of artificial intelligence (Cheng et al., 2009b), IFC-based automation (Zhiliang et al., 2011) and integrated estimation (Moon et al., 2007). Meanwhile, the following issues are crucial to the development of this aspect:
    - In contemporary studies about automated estimation, only estimates for conceptual designs have been addressed. The limitations of conceptual estimates are presented in Chapter 2.
    - The capabilities built into estimating applications have improved over the years. More importantly, current construction management literature provides little guidance on the selection of appropriate methodologies for analysing and evaluating software applications, including data modelling

techniques, software property classifications and empirical analysis of outcomes.

- Knowledge management is a critical issue in estimating practice (Lowe and Skitmore, 1994). There is limited evidence in literature regarding knowledge generation, diffusion and praxis of innovative BIM practices.

- *In the context of business behaviours:* BIM has been noted to raise awareness about commercial opportunities (Aranda-Mena et al., 2009). Commercialisation is underpinned by industrial psychology theories about business intelligence and attitude (Dandridge et al., 1980, Sillince, 2007, Van der Heijden et al., 1998, Vink et al., 1998). However, these theories require re-invention in the era of BIM. This is because contemporary business environments have experienced marked challenges and changes since its introduction:
  - Intra-individual and inter-individual variability exists in all businesses implementing digital innovations (Price, 2007). According to Olatunji (2011b), employees' individual understanding of BIM is different from corporate business behaviour and transition (from non-BIM to BIM compliant orientation); the former is promoted by career goal, the latter by market demand (see Section 3.2). Thus, it is appropriate to investigate and juxtapose the different business behaviours in each of the estimating practice domains in both 3D CAD and BIM paradigms. Consequently, the following activities require attention:
    - Policy formulation – creating new practice philosophies, legislations, targets and corporate mission (Succar, 2009).
    - Culture – communication, social value and leadership (Dainty et al., 2007).
    - Products – productivity, packaging and market influence (Arayici et al., 2012).
    - Core skills – quantification, resource management, planning and cost estimating (Underwood and Alshawi, 1997), and;
    - Knowledge development – training, multi-skilling and, research and development (Olatunji, 2011b).

The changes that are likely to result from the aforementioned activities will have far-reaching consequences. Reports have shown that estimators' views about BIM used to be speculative or sceptical (Aranda-Mena et al., 2008, Olatunji, 2011b). However, as BIM has become

increasingly popular, organizations are re-structuring their businesses to incorporate BIM (Abdelkarim, 2010). Notwithstanding this, little is known about how different estimating practice domains might make full use of and derive benefit from both 3D CAD and parametric BIM, in terms of best business practices and professional standards.

1.3 RESEARCH QUESTIONS

Based on the arguments and research gaps identified above, this study explored the following questions:

i. How does BIM impact on estimating processes?
   a. What are the stages and activities of project estimation using BIM?
   b. How do 3D CAD and BIM estimating mitigate the limitations of conventional estimating processes?
   c. What challenges are intrinsic to BIM estimates?
ii. What tools are required in estimating practice domains to operate and deliver appropriate outcomes with BIM?
   a. What are the attributes of software applications that integrate with BIM and how do they compare with other estimating applications?
   b. How do BIM-enabled estimates compare with traditional estimates?

1.4 RESEARCH AIM AND OBJECTIVES

The purpose of this research was to investigate how BIM affects the practice of estimating in the construction industry. Its aim is to develop process models that could be used in different practice domains to generate workable construction estimates. To achieve this aim, the following objectives apply.

(1) To explore the activities required to develop workable estimates in different practice domains, using 3D CAD and BIM in form of process models.

(2) To investigate the degree of association and reliability of estimating activities (objective 1) as the parameters for developing process models for the different estimating practice domains.

(3) To analyse the discrimination of each practice domain by the outcomes of objective 2.

(4) To propose strategies for implementing the process models in Objective 2 for application development.

1.5 RESEARCH METHODS

This study relies on a mixed methodology approach. The methodology was reviewed and approved by University of Newcastle's Research Ethics Approval Process (Reference Number H-2009-0275). The main data collection approaches used were focus group discussions, interviews and direct observations. The scope, research instruments and design are described below.

1.5.1 Research Scope

Stakeholders in BIM and organizational management of estimating practices are the main targets of this research. However, to compare findings about BIM with those of conventional approaches, developers and users of computer-aided estimating (CAE) applications were also included. Additionally, to compare outcomes of project estimates prepared at different lifecycle stages, the data collected includes pre-contract estimates (conceptual estimates, cost plans, detailed estimates, and tenders, including analysis and negotiation) and post-contract estimates (cashflow management, contract valuation and variation parameters). The types of construction addressed in this study include new and rehabilitation works involving building and engineering projects in Australia.

The target participants were middle-level and top-level managers responsible for bidding, construction, procurement, as well as creators of CAE solutions for estimating BIM and non-BIM projects. Construction and non-construction professionals were involved in this context. Participants included quantity surveyors, builders, cost planners, project planners, project managers, construction managers, software analysts and engineers, and construction business executives. These individuals were recruited from public practices, private consulting practices, contracting firms and software development firms from four Australian capital cities viz. Sydney, Melbourne, Brisbane and Newcastle. The inclusion and exclusion criteria for the research participants are detailed in Chapter 5.

1.5.2 Research instruments

The mixed methods research methodology approach adopted in this study was inspired by Dainty's (2008) who described an approach to modern construction management research (CMR) through methodological pluralism. The philosophical framework of this concept is that instead of relying on single instruments, different research paradigms are combined to develop valid research outcomes with richly nuanced implications. Other researchers have implemented pluralism and have elicited robust findings, especially in the light of re-

inventing estimating processes in a modern world. These include Liu and Fellows (2008), who explored the behaviours of quantity surveyors in their organizations, and Farmer and Guy (2010) who explored architects' cognitive protocols while conceptualising sustainable design solutions.

In contrast, Broquetas (2010), Samphaongoen (2010), Jensen (2011) and Hergunsel (2011) have all used single research paradigms to explore the impact of BIM on estimating processes, project management and construction management. However, their findings were not triangulated between the different domains of practice represented in these disciplines. The studies also downplayed a critical parameter i.e. the levels of sophistication in BIM utilization of those concerned e.g. whether it is 3D CAD, IFC-based BIM or parametric design (Hubers, 2010). To address these problems, the research process for each of the research aims was divided into two stages, viz. data collection for model developments and model validation. The following research instruments were deployed to achieve the research outcomes:

- *Focus Group (FG) discussions:* This involved a group of research participants interacting on the research subject. FG is not new to construction management research; it has been used by many researchers in different ways including face-to-face and online (see Graham et al. (2008) and Rezabek's (2000)). Firstly, six major developers of estimating software applications with BIM capabilities in Australia were approached to determine how BIM was incorporated into their various solutions. Findings from this stage were triangulated with group discussions at two conferences organized by the International Alliance for Interoperability's (IAI) BuildingSMART and the Australian Institute of Quantity Surveyors (AIQS). From both events, participants were recruited to take part in further group discussions. At the end of this stage, 12 organizations (three software developers and eight estimating practices), and a total of 22 participants, took part in the research discussions.
- *Interviews:* Participants were interviewed individually if organizations nominated only one participant and if participants in the same organization were not available for group discussion at the same time. Interviews were conducted between focus group discussions. Participants answered the same set of questions for both individual and group discussions (see the Appendix 2). Interviews were conducted in four organizations; a total of five participants took part. Apart from one telephone interview, participants were interviewed as face-to-face.

- *Direct Observation:* This method is also popular in construction management research. In this study, the specific procedure described by Kristiansen et al. (2005) was adapted. The method involves an independent examination of the nature of the organizations by the researcher, so that they could be grouped and analysed further. The approach used was to group each participating organization in line with the attributes of business structure models described in Section 3.2, viz. the matrix, divisional, functional-unit and networked models. In the end, there were two organizations for each of the four structure models under examination. During analysis, considerable differences were discovered in both how organizations deal with the change caused by BIM and how they have re-invented estimation for BIM projects.

Data Capture

Digital audio recordings were made of both FG and interview discussions. Participants were allowed to demonstrate their estimation processes on screen. Where this was not impossible, they described their estimation approach in detail. Where there were demonstrations, participants were asked to explain their approach in ways that are similar to the protocol studies of Tang et al. (2011). They were asked to demonstrate an estimating task based on different drawing types (pdf, .dwg and jpeg) using their application software and to explain their cognition processes in detail. Participants contributed secondary data including software demonstrations, demonstration drawing files, publications on the nature of their organization's business and other data they considered appropriate for the research. Thereafter, all recordings were transcribed and coded for analysis. The coding process reflects estimating processes used by participants and the peculiarities in the approaches that each of the organizations used. Four BIM estimation processes were coded. Based on Section 3.2, participating organization were divided into four groups reflecting their business organisational model. Data analysis is discussed in detail in Chapters 5 and 6.

1.6 RESEARCH SIGNFICANCE AND MOTIVATIONS

The significance of BIM to the contemporary Architecture, Engineering, Construction and facilities' Operation (AECO) industry is incontrovertible. BIM provides opportunities for construction businesses working in multidisciplinary environments. There is strong evidence that conventional design and estimating processes are changing from fragmented platforms to platforms that encourage collaboration and integration. Moreover, professionals' roles are

changing; new roles are evolving while old ones are adapting to BIM (Tse, 2009). Organizations are also becoming more compact and integrated to increase interdependencies as they focus more on client satisfaction and the longevity of project performance (Ballesty et al., 2007, Abdelkarim, 2010, Eastman et al., 2011). In summary, the construction industry is currently being challenged to adapt to change through BIM more vigorously than at any time in the last decade.

Apart from the practical and social implications of BIM, this study has been motivated by several theoretical considerations. Primarily, as the paradigms of change prompted by BIM become more popular, knowledge generation and diffusion will follow. This study uses empirical evidence to advance scholarly knowledge on process modelling. This involves developing process models for preparing estimates for BIM projects. The following are the specific areas where the study adds to the existing body of knowledge.

- *Construction Economics:* The potential of object-based presentations of construction estimates is explored as previous research on this subject is sparse and inconclusive. Consequently, methodological pluralism has been used to demonstrate the limitations and strengths of text-based estimates compared to those enabled by BIM. Conclusions are drawn on advancing existing theory from text-based estimating approaches, or methods, to object-based simulations.
- *Organizational modelling:* Industrial psychology theories have received considerable attention in information systems' research (Dooley, 1997; Haslam and Ellemers, 2006). In the context of construction science, it is relevant to corporate decision-making in business strategizing, BIM, change management and estimating practice. This study considers BIM interpretations in the context of estimating. In the same vein, it views practice changes in the context of organizational behaviour rather than of individuals' migration to BIM. Consequently, the research findings and conclusions have far-reaching industry implications; construction businesses can derive value from the range of flexible options as they migrate from non-BIM to BIM-ready organizations.
- *Methodology:* The study applies mixed research method and pluralism in a unique way; the organizational models used to describe estimating processes have not been used in construction management research.

- *Praxis and Pedagogy:* The generation and diffusion of knowledge about digital technologies, including BIM, is a major challenge in construction management (Gul et al., 2008). This study has contributed to this knowledge generation by distilling the relevance of BIM to estimating, and vice versa, and eliciting the activities involved in estimating with 3D CAD and BIM.

1.7 OVERVIEW OF THESIS CONTENT

There are seven chapters in this thesis. In Chapter 1: Introduction, a broad overview of the study is presented. The chapter starts by conceptualising the problem under investigation. This is followed by the research questions and the aim and objectives. This chapter also introduces the research methods and the significance of the research findings.

There are four sections in Chapter 2: Estimating Practice. The first section introduces estimating practice as a ubiquitous service in the lifecycle of a project. Kagioglou et al's (1999) Process Protocol is used to explain project lifecycle stages and the estimating methods that accompany each stage. The second section describes the challenges of CAE during the pre-contract stage, while the third section focuses on the post-contract stage. In the fourth section, CAE tools are classified according to their features, highlighting their strengths and limitations with different design platforms. The overarching goal of this chapter is to describe the different ways construction estimates are generated. This creates the foundation for the exploration of the impact of BIM in the following chapter.

Chapter 3: Building Information Modelling is comprised of three sections. The first introduces BIM. A range of views on BIM is reviewed, concluding with an estimators' definition of BIM. The second section explores different BIM models and their applications. This is to distinguish between BIM applications that are related to construction management and those which are not. The third section discusses how BIM deliverables relate to estimating processes. Chapter 4 focuses on organizational modelling and behaviour in three main parts. Section 1 introduces organizational management, while Section 2 reviews the existing knowledge on models of business organisational structure. The third section explores change management models including the drivers, domains and protocols.

Chapter 5: Research Methodology has three sections. Section 1 presents the research philosophy. Section 2 presents the research instruments and their justifications. Section 3 describes the instruments for data analysis.

Data, analysis and interpretations are presented Chapter 6. First, process models for estimating are developed based on the views of representatives of each of the organizational structure models. The models highlight four approaches to BIM estimation and this is compared across four organization groups.

In Chapter 7, the focus is on the implementation of the process models established in Chapter 6. This was addressed in three components: system architecture, EXPRESS-G model and Integration Definition (IDEF0) format.

There are two parts to Chapter 8: Conclusion. The first part focuses on BIM estimation processes while the second part discusses how the research findings can be applied to manage business and structural changes in estimating practices. In both parts, the findings of the research are compared to existing theories. Using clear indications from past studies, the achievements of the research are summarized and further areas of research on contemporary estimating practices are suggested.

1.8 SUMMARY: THE LINK BETWEEN BIM AND ESTIMATING

Estimation is important in project delivery; it is always required when project stakeholders make crucial decisions. However, various authors have expressed reservations about the accuracy of construction estimates. The reasons for this were presented in this chapter; project designs' variability is a major cause of unpredictability in cost and time forecasts. Recent literature has identified the potential of BIM to solve many of these challenges. In addition, this chapter has summarised the following:-

- Apparently, BIM deliverables have considerable relevance to estimation processes. In many reported case studies, BIM has delivered results that overwhelmingly improved the efficiency of the estimation process through visualization, automated quantification, integrated solutions, object oriented simulation and virtual reality. However, these procedures are yet to evolve as part of the theories on estimating practice. In particular, as there was for manual processes, there are no generally accepted guidelines on the procedure for estimating with 3D CAD and BIM, both of which are different from manual processes.
- A background has been laid in this chapter to enhance further arguments on organizational behaviours towards 3D CAD and BIM estimating. The overriding perception is that, rather than considering BIM as a platform to project-based or employees' individual migration from conventional methods, existing knowledge in

industrial psychology is used to draw information on the mechanics of organizational transitioning from conventional procedures to digital practices.

- Based on four models of organizational structure, construction businesses have different views on transitioning from non-BIM to BIM-ready practices. This is the overriding goal of this research viz to provide multiple solutions that can reflect the feature-based peculiarities of the construction business, and at the same time, serve project-based scenarios.
- The practical, social and intellectual significance of the impact of BIM on estimating practice is robust. Its conceptualization of BIM in estimating practice and its focus on theorising the processes of estimation in BIM as well as organizational transitioning to BIM are further supported in other chapters.

2 INFORMATION TECHNOLOGY AND CONSTRUCTION ESTIMATING PRACTICE

2.0 INFORMATION TECHNOLOGY AND CONSTRUCTION ESTIMATING PRACTICE

2.1 INTRODUCTION

The main aim of this study is to explore the impact of BIM on estimating practice (Section 1.4). Previous studies have emphasized construction estimators' preferences for manual estimating procedures (Fortune and Lees, 1996). Where computer applications are used, they focus primarily on improving these manual procedures. The works of Best et al. (1996), Lowe (1998), Lowe and Skitmore (2001), Ogunlana (1989), Ogunlana and Thorpe (1991) have identified a marked reluctance in the way estimators embrace artificial intelligence and associated innovations. They often prefer to rely on their personal judgement when decisions of this nature need to be made. Such a perspective has its impact on estimating practice as a discipline, and the construction industry as a whole. According to Cartlidge (2006) the relationship between estimating practice and IT applications is often threatened by the rapid pace at which software changes, especially when these systems provide facilities that circumvent estimators' decisions. While numerous studies have attempted to measure IT uptake in the construction industry and the benefits that are associated with it, Hardie et al. (2005) compared the generation, adoption and diffusion of digital innovations by quantity surveyors to other professional disciplines in Australia. Their findings were that quantity surveyors, a prominent professional discipline frequently engaged in estimating practice, lag behind all other professional disciplines in the Australian construction industry.

The uptake of digital technology has become increasingly important in the construction industry since the advent of building information modelling (BIM). In Australia, the popularity of BIM has grown considerably (Architectural Evangelist, 2008). Gu et al. (2007) and Sher et al. (2009) argue that BIM promotes practitioners' abilities to work in virtual environments, enhances multi-disciplinary system integration, and supports automation. As such it embeds new business behaviours through communication and collaboration. Notwithstanding the opportunities BIM offers the construction industry, all the associated discipline have been challenged by its implementation. It is important to note the significance of the challenge that affects estimating. Particularly, some studies have argued that core estimating roles such as quantification, simulation and management of descriptive data can readily be performed by BIM (Eastman et al., 2008, Suermann, 2009).

Parliamentary, industry and discipline-specific reports including Latham, (1994), Egan (1998) and Fan et al. (2001) have suggested that estimating practice needs to be enhanced

through the use of IT applications. Implementing such changes transcends the adoption of generic theories and the development of new skills. They require these in combination to generate satisfactory outcomes. Citing García-Bacca (1989), Fernández-Solís (2007) defines an exponentialoid as a change scenario that is represented by a combination of multiple complex forces e.g. changes in technology, process, role and project. Although each of these has had significant impact on estimating practice, they have rarely been measured together. From a project management perspective, specific change domains have been explored individually, viz. project change (Motawa et al., 2007), change in process protocols (Kagioglou et al., 1999), change in management models (Al-Sedairy, 2001, Koskela, 1992), cultural change (Dainty et al., 2007) and organizational change (Buchanan et al., 2005, Zink et al., 2008). Arguably, each of these change domains has different practice implications in terms of how construction estimating is conducted in different business organizations (discussed in Chapter 3). Estimating outcomes are likely to be affected in each of these change domains, as well as in combination. With BIM, there are multiple forces (each with numerous triggers) that motivate change in estimating procedures. Each of these results in outcomes that address stakeholders' requirements in different ways.

Overview of Content

This chapter presents a review of estimating methods and the roles of IT in continually reshaping estimating practice. It focuses on empirical and theoretical evidence of computer-aided estimating from a range practice domains. These include a combination of clients' views, contractors' opinions, consultants' perspectives and integrated project delivery (IPD) concepts. The following four sections have been used to illustrate the trend of change in estimating in light of the proliferation of IT applications in modern estimating and construction management practices:

- Section 2.2 explores the implications of process improvement models as platforms for studying change patterns in estimating processes resulting from IT applications.
- Section 2.3 reviews estimating procedures and methods, and describes how IT is deployed in these procedures to achieve specific outcomes. Estimating processes and outcomes throughout project lifecycle phases are outlined and discussed.
- Section 2.4 discusses the future of IT in estimating practice in line with the practice dichotomy between CAD and BIM.
- Section 2.5 summarises this chapter.

2.2 PROCESS IMPROVEMENT MODELS

Several reports have raised concerns about cost overruns on construction projects. According to Baloi and Price (2003), it is increasingly difficult for estimators to accurately predict costs because of factors such as macro-variability (i.e. costs do not have constant values and respond to macro-economic factors in ways that are difficult to predict). Other difficulties include unforeseeable events, design errors and uncertainties in clients' requirements (Acharya et al., 2006b, Cheung et al., 2008, Kometa et al., 1994, Ogunsemi and Jagboro, 2006). Estimators also experience challenges with the methods and techniques they employ.

Skitmore and Patchell (1990) identified several estimating methods and their limitations. Although the methodology used by these authors is unclear, they concluded that no estimating method is worse than 25 percent below or above the actualcost. Furthermore, in response to the Latham (1994) report (which emphasised, inter alia, the need to substantially reduce construction costs), Gray (1996) warned that the combination of all estimating approaches could not change estimating outcomes. Gray went on to note that each estimating method has its challenges; no method is perfectly accurate. More recently, Aibinu and Pasco's (2008) investigations into preconstruction estimates in Australia suggest that estimation has changed with technology. There is limited evidence to suggest that the improvements enabled by IT have considerably lowered the cost of construction projects.

Skitmore and Patchell (1990), Gray (1996) and Aibinu and Pasco (2008) highlight the need to re-engineer construction estimation and observe that this is a major task. They argue that such developments are timely because clients need accurate predictions of costs prior to project development. A framework for investigating the implications of these changes is provided in Kagioglou et al's (1999) process improvement model (Figure 2.1 and Figure2.2). Kagioglou et al's model is aimed at the construction industry, and emphasizes efficiency gains through the use of IT.

The focus of this section is to view Kagioglou et al's (1999) model from a generic construction estimator's perspective. It seeks answers to the following questions:

- Based on Kagioglou et al's process improvement IT protocols, what theoretical bases represent the change trends in estimating that have resulted from the uptake of IT? This is expedient as estimating methods and software applications have proliferated in the last decade.

- More importantly, the methods of preparing the construction drawings (the documents estimators rely on when preparing their estimates) have changed significantly. While entity-based CAD results in process fragmentation, BIM supports multidisciplinary integration. As disciplinary boundaries diminish with integration, what does this mean for estimation?

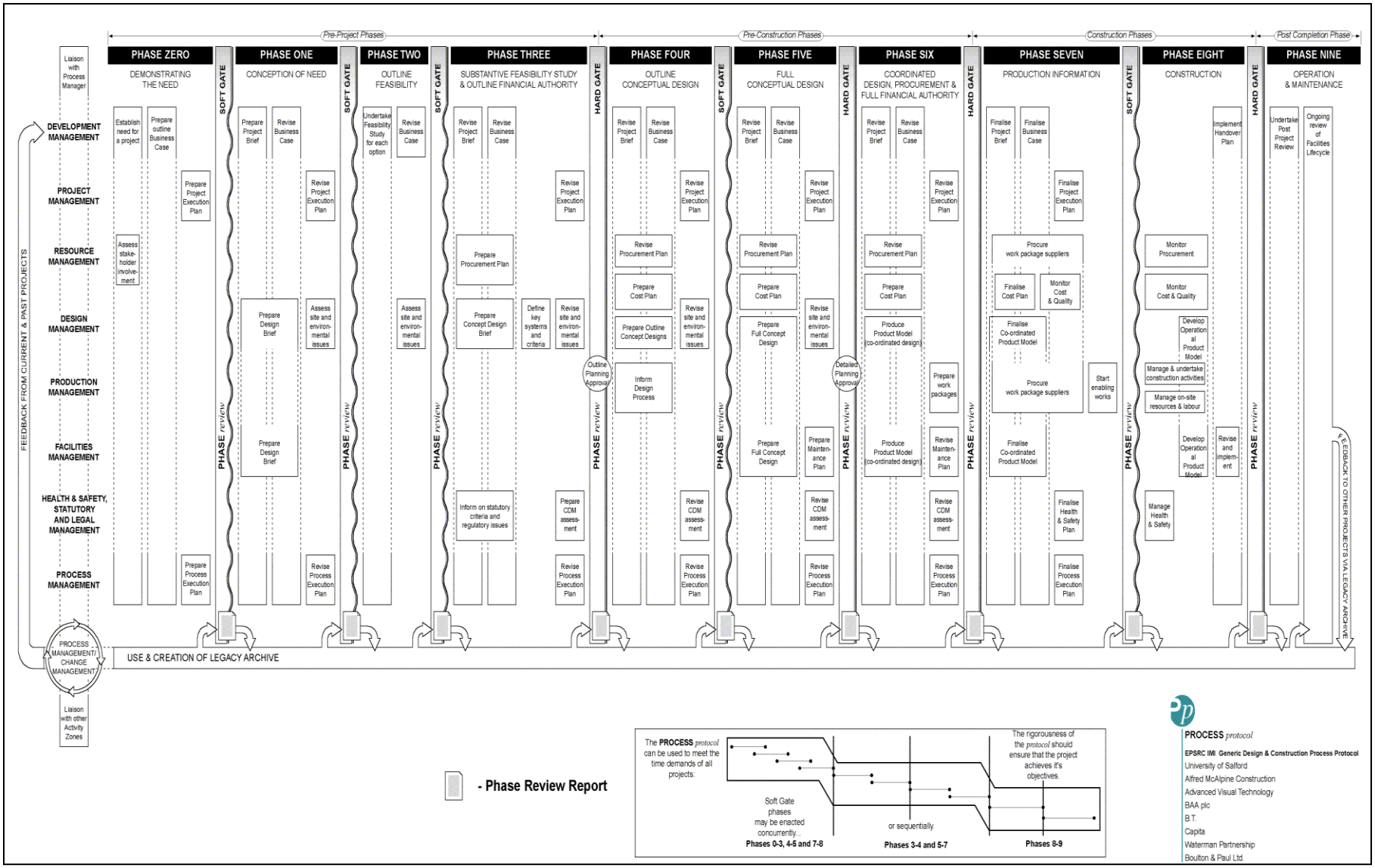


Figure 2.1: Construction project development process model (Kagioglou et al., 1999)

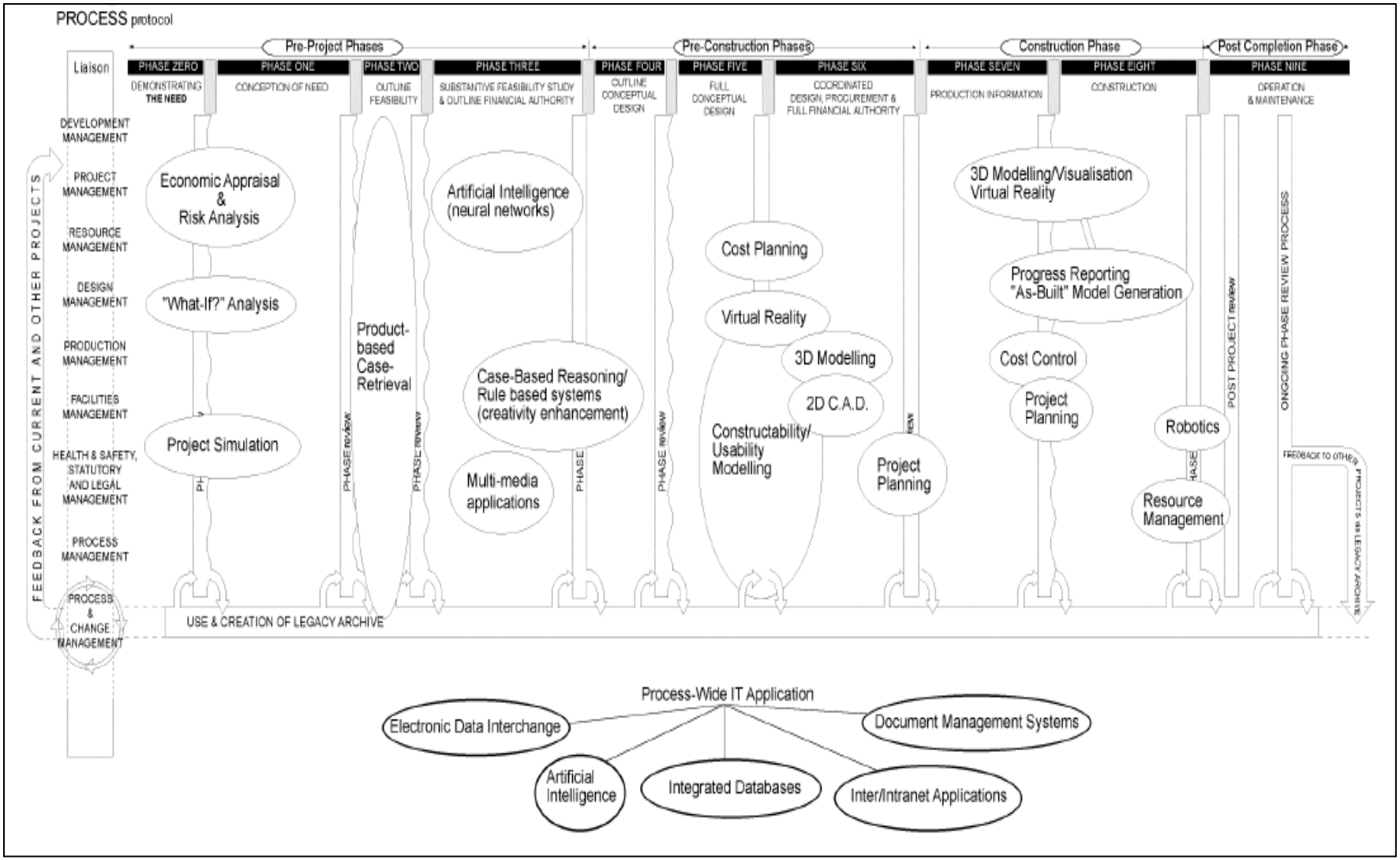


Figure 2.2: IT deployment tracks in construction processes (Kagioglou et al., 1999)

2.2.1 A Taxonomy of Estimating Methods based on Kagioglou's Process Protocols

There are different phases in project development, each of which has been subjected to improvement strategies. Many of these strategies have concentrated on procedural and technological change. However, to measure what has changed and how, each project development phase is examined. Specifically, the approach taken at this point is to review past studies on estimating methods on each of the 10 Phases and the nine action points in Kagioglou et al's (1999) model's matrix in Figures 2.1 and 2.2. In the model:

- the first phase (i.e. the first four phases, *Phase Zero* to *Phase Three*), reflects the **Pre-Project** phase. It involves making preliminary cost decisions based on clients' concepts of their needs, a preliminary identification of risks and a feasibility study.

- the second phase is the **Pre-construction** (*Phase Four to Phase Six)* where decisions are taken on conceptual design and procurement. Across the elements of **Pre-Project** and **Pre-construction** phases, different estimating methods are required to meet the specific needs of different stakeholders. While project lifecycles exist as a continuum (Section 2.3) it is expedient to explore how IT helps integrate estimating methods within phase components and across practice domains (i.e. clients', contractors', integrated project delivery practices).

- the third phase is the **Construction phase** (*Phase Seven* and *Phase Eight*) and is the most researched aspect of construction estimating. Previous studies have developed a wide range of instruments for estimating actual costs and duration of construction works. This take different forms, including:
  - forecasts during bidding e.g. (Skitmore and Ng, 2003)
  - measuring actual costs during construction e.g. (Ogunsemi and Jagboro, 2006).
  - evaluating and reconciling project value post-construction.

  Researchers have found that estimates at this phase are subject to design errors (Acharya et al., 2006a), contingencies (Thal et al., 2010), macro-variability (Olatunji, 2010b), faulty estimating tools and methodologies (Watson and Kwak, 2004), quality of data (Yeung and Skitmore, 2005) and human error (Lowe and Skitmore (2001).

- The **Post-Completion Phase** is the last phase (*Phase Nine*). It considers the economic life of a project from when it is handed over to the end of its lifecycle, with specific emphasis on facilities operation, maintenance and management. Several models, including that of Woodward (1997), have been developed to underpin existing theories on lifecycle cost modelling. However, several challenges are associated with modelling lifecycle costs including those identified by Flanagan et al (1987).

Overall, there are specific estimating methods for each of the project development phases in Kagioglou et al's (1999) model. However, clients require estimating outcomes across the different phases as an integrated product. Clients require accurate predictions of construction costs as well as cost information to plan for other project lifecycle phases. Different estimating approaches can be integrated to address these requirements but their outcomes are not always assured. Kagioglou et al do not recommend integrating different estimating methods; their focus is to harness the power of modern IT developments. They see approaches such as artificial neural networks (ANN), fuzzy logic (FL) and automation through different design platforms (i.e. 2D CAD, 3D CAD and parametric BIM) as building blocks for re-engineering construction estimation.

Estimating methods for the different phases shown in Kagioglou et al.'s model are listed in Table 2.2. Section 2.2.2 explores the integration of CAD and parametric BIM with estimating applications. It is pertinent to review these developments because the popularity of some knowledge-based computational methods (including artificial neural network and fuzzy logic) have been limited to conceptual estimating (Cheng et al., 2009b). This study extends further than conceptual estimating; it seeks estimating solutions using contemporary design methods. While existing estimating theories centre around fragmented procedures (Ashworth, 2010, Harris et al., 2006, Seeley and Murray, 2001), the gaps between these and the techniques in integrated platforms warrant attention if the potential of modern IT applications are to be realised.

2.2.2 Approaches to integrated estimating platforms

According to Aranda-Mena et al. (2008), for parametric design applications to be used effectively (see Section 4.4), designers need to work in an integrated manner. Several studies have identified the following elements as benefits of working in an integrated manner:

- **Value sharing** – the potential for multi-disciplinary interoperation whereby each party working on an integrated platform understands the roles of other parties and the value

such adds to the project's outcomes (Succar et al., 2007, Wi et al., 2009). This is one of the major issues that have encumbered outcomes when conventional fragmented approaches are used (Alashwal et al., 2011).

- **Effective communication** – parametric designs contain data that, although not specifically targeted at estimators' needs, are sufficient to facilitate workable estimating outcomes (Huang et al., 2009b, Lin et al., 2003, Wikforss and Löfgren, 2007). The communication gaps between conventional practice and integrated platforms have been argued by (Anumba, 1996), (Amor and Faraj, 2001, Amor et al., 2007) and (Marshall-Ponting and Aouad, 2005).
- **Collaboration** – wilful commitment of project team members to work together as a team and share data (Aranda-Mena et al., 2008).

Various authors, including Ashcraft (2008), Gu et al. (2008), Olatunji et al. (2010a) have emphasized these attributes. They apply to estimating in two perspectives – simulation and automation. While these are among the known deliverables of parametric procedures, they help in the integration of estimating methods across the different project development phases to facilitate workable outcomes. Further explanations of these deliverables are presented below.

Simulation

Simulation is considered in *Phase Zero* and *Phase One* (Figure 2.2) as a form of digital innovation that helps improve needs conceptualization. Examples of this include:

- Monte Carlo simulation, a probabilistic approach (Chau, 1995, Hulett, 2011).
- Virtual design construction (VDC) simulation, which is based on using visual objects to replicate construction situations deterministically (AbouRizk, 2010, Chou et al., 2005, König et al., 2007).

Simulation is widely used for construction estimating. Its popularity spans beyond the pre-project phase (Figures 2.1 and 2.2) and it has been used frequently to service the pre-construction and construction phases. Recent empirical studies have highlighted the popularity of VDC for parametric platforms (Huang et al., 2009b, Popov et al., 2010, Sherman and Craig, 2003, Whyte, 2003, Whyte, 2002).

The two abovementioned simulation approaches may be distinguished by the theories that underpin them; Monte Carlo is probabilistic, whilst VDC is visual and deterministic. There is

little evidence of these paradigms having been integrated. However, new generation estimating software such as Synchro® promotes outcomes based on simulation. Synchro® integrates quantification, resourcing, scheduling and process modelling based on active parametric agents. This enables estimating decisions to be vetted, visualized and manipulated in line with the interests of individual stakeholders. The challenges associated with VDC include, firstly, how applicable the approach is for construction estimating, and, secondly (and contingent on the efficacy of these applications), the skills required of estimators to use the approach. In addition, how does this affect estimating practice as a whole, considering the different practice domains presented in Chapter 3? The implications of this are drawn out in Chapter 6.

Automation

Other digital applications may be used for the estimating tasks shown in Figure 2.2. Case-based reasoning, artificial intelligence (AI) and process automation procedures may be used for *Phase Two* to *Phase Seven*. Robotics and cyber-physical systems apply for *Phase Eight*. According to Monedero (2000) these approaches are more applicable to parametric design than earlier traditional design methods. However, there is little coverage of these approaches in traditional estimating textbooks; this is of concern.

Existing estimating guides and textbooks (including (The Chartered Institute of Building (CIOB), 2009), (Australian Institute of Building, 1995), (Ashworth, 2010), (Seeley and Murray, 2001), and (Harris et al., 2006)) refer to fragmented approaches. In all of these studies, the application of CAD data to estimating practice (and the ways in which these data may be used by multiple disciplines) has not been covered. As noted by Olatunji and Sher (2010a), CAD-based and conventional estimating methods differ. The investigations of Akintoye (2000) and Sher (1982, 1996) show that the challenges looming for new generation of estimators is not confined to the limitations of data originating from conventional fragmented procedures. Manual estimating procedures are different from CAD-enabled procedures, and these are distinct from those that are BIM-enabled. As digital solutions proliferate, estimators need to develop new skills sets.

Contemporary parametric design methods have the potential to revolutionise construction (Succar, 2009). Some new estimating software has been developed to take advantage of this. For example, VICO® enables estimating data to be derived from different forms of CAD. Embedded data are harvested from CAD data to quantify the components that estimators base

their predictions on. This form of automation is common in several commercially available software applications currently being used. Estimators using these applications are thus able to use several different quantification approaches:

- They can use the data automatically generated from these applications, moderate them or supplement them with manual calculations;
- If they are conversant with the logic and structure of the new applications, they can extend and manipulate data to meet the specific requirements of individual projects. This implies an understanding of, inter alia, data modelling, schemas and industry foundation classes (IFCs);
- For the risk of modelling error, they can decide whether to jettison embedded data and use substituted means to quantify, resource, plan and management costs.

Each of these has different implications for estimating practices. To explore these, Section 2.3 reviews estimating methods for the four main phases of a construction project's lifecycle (Figures 2.1 and 2.2).

2.3 ESTIMATING METHODS AND PROCEDURES

The manners in which estimate data are developed and deployed to achieve different goals at different phases of a construction project are well documented. As shown in Figure 2.2, estimating methods are not restricted to each of the phases in Kagioglou et al's model – some methods cut across several phases. This section focuses on estimating methods and explores how they have been affected by IT. It is important to note that each method may be applied differently. For example, clients and contractors are likely to apply the methods in different ways. Furthermore, different approaches are used in building and civil engineering projects. Similarly, cost data used at the **Pre-project phase** through preliminary and outline specifications are different from those used at the **cost planning approach phase,** where such data are used for elemental and comparative cost analyses.

While estimating methods are summarised in Table 2.1 as they apply to each project development phase, Table 2.2 (see Appendix 1A) takes these methods further in an adapted form (Skitmore and Patchell, 1990). Specifically Table 2.1 identifies the weaknesses of each estimating method and highlights the role of IT in re-engineering them. The relationship between these methods and the project development phases illustrated in Figures 2.1 and 2.2 are discussed in Section 2.3.1. Estimating methods and the impact of IT on them are discussed in Section 2.3.2.

Table 2.1: *Estimating techniques for each phase of project development*

Project Development Phases & Elements	Basic Components of Estimating Service	Estimating Methods	References
Pre-Project Phase: *Pre-Planning*			
Need establishment and conceptualization	Needs assessment	Cost limit calculation Floor area method	(Greer, 1970, Lai, 2010) (Brook, 2008)
	Decision analysis	Functional unit method Approximate quantity method	(Yaman and Tas, 2007) (Pratt, 2011)
	Production and investment needs assessment	Lump sum calculation Preliminary estimates of potential project elements	(Betts, 1990) (Sanders et al., 1992)
Feasibility study	Project feasibility and budget assessment, and risk assessment	Manual method Gross Floor area method Functional dependency method	(James, 1954) (Shen et al., 2010a) (Stocks and Singh, 1999)
	Finance analysis	Approximate quantity method	(Pratt, 2011)
	Estimates of capital or asset costs - to include development costs	Parametric modelling Monte-Carlo simulation Price indexing	(Cheung and Skitmore, 2006) (Gupta and Gupta, 1984, Ke et al., 2008, Vose, 1996) (Yu and Ive, 2006)
	Estimates of operating and manufacturing costs through an asset's life cycle	Intelligent Systems	(Bari et al., 2008)
	Cost benefit Analysis	Cost Planning: • *By approximate quantities* • *By using outline descriptors*	(James, 1954) (Peterson and Dagostino, 2010)
	Preliminary Cost Planning	• *Least Cost Planning*	(Mills, 2001)
Pre-Construction Phase: *Planning*			
Conceptual Design	Siting studies	Monte Carlo Simulation	(Vose, 1996, Gupta and Gupta, 1984)
	Trending of scope and cost changes	Parametric modelling techniques: • *Regression modelling*	(Ng et al., 2004a)
	Value management	• *Knowledge-based modelling*	(Shehab and Abdalla, 2002, Barton, 2000)
	Trending and controlling costs, and assessing design	• *Resource-based modelling* • *Life cycle cost modelling*	(Rahman et al., 2008, Baloi and Price, 2003). (Flanagan et al., 1987, Woodward, 1997)
		Cost planning: • *Elemental approach* • *Comparative method* • *Least-Cost Method*	(Lee and Smith, 2010) (Ferry et al., 1999, Lau, 2006) (Mills, 2001)
		Bill of Quantities Cost scheduling Interpolation techniques Conference Financial method Functional unit Cube Storey enclosure	(Harris et al., 2006) (Ely and Reddi, 2010) (Rowan et al., 1960) (Ashworth, 2010) (Lynch, 1996) (Gerrard, 2000) (Smith and Jaggar, 2006) (Cheung, 2005)

		Approximate quantity	(Pratt, 1995)
		Artificial neural networks	(Christodoulou, 2004, 2010)
Pre-Construction Phase: *Design and Procurement*			
Design and Procurement	Procurement management • *Determination of procurement route* • *Cost planning* • *Project management*	Approximate method	(Ashworth, 2010)
		All types of Bill of Quantities	(Collier, 1974, Harris et al., 2006)
		Schedule of Rates/ Prices	(Harris et al., 2006)
		Elemental cost planning	(Lau, 2006, Smith and Jaggar, 2006)
		Price Index modelling	(Ogwang, 1995, Runeson, 1988)
	Tender action • *Prequalification* • *Preparation of tender documents* • *Tender pricing* • *Tender analysis* • *Tender negotiation* • *Price indexing*	Unbalanced bid modelling: • *Gates' model*	(Gates, 1967, Skitmore et al., 2007b)
		• *Stark's model*	(Stark and Mayer, 1971)
		• *Friedman's model*	(Friedman, 1956)
		• *Ashley and Teicholz's model*	(Ashley and Teicholz, 1977, Bley, 1990)
		• *Diekmann et al.'s model*	(Diekmann et al., 1982)
		• *Yizhe and Youjie model*	(Yizhe and Youjie, 1992)
		• *Afshar and Amiri's model*	(Afshar and Amiri, 2008, Afshar and Amiri, 2010)
		• *Christodoulou's model*	(Christodoulou, 2004, 2010)
Construction Phase: *Contract Securitization and construction*			
Contract documentation	Contract administration	Contract securitization modelling (for Bonds, insurances and guarantees)	(Lynch, 1996)
	Documenting costs	Legal and administrative costs	(Sweet and Schneier, 2008)
Construction	Work scheduling and planning	Cashflow forecast	(Ashley and Teicholz, 1977, Diekmann et al., 1982)
	Resourcing	Network/ Precedence Diagrams	(O'Brien and Plotnick, 1999, Chitkara, 1998)
	Managing cash flows	Interim Valuation	(Skitmore, 1993, Harris et al., 2006)
	Project cost control	Accounts' reconciliation	(Harrison, 1993, Perceval, 1997, Pilcher, 1994)
	Cost management	Financial Statements	(Harrison, 1993, Perceval, 1997)
	Dispute resolution	Final accounts	(Winch, 2010, Upton, 1987)
	Claims management	Quality audits	(Dale and Plunkett, 1999, Tsai, 1998, Foster, 1994)
Post-Construction Phase: *Facilities management*	Quality audits	Parametric methods	(Cotts et al., 2010)
Facilities operation and maintenance	Project analyses, databases, and benchmarking	Bill of Quantities	(Ashworth and Hogg, 2007)
		Payback Method	(Flanagan et al., 1989)
	Taxation Depreciation	Discounted Cashflow method	(Flanagan et al., 1989)
	Scheduling	Casual cost modelling methods	(Raftery, 1991)
	Appraisals of existing assets	Net present value method	(Flanagan et al., 1989)
	Dilapidation Survey	Monte Carlo simulation	(Raftery, 1991)
	Evaluation of costs of		

	periodic maintenance, conversion, alterations, reconstructions, demolition etc.		
Facilities disposal	Assessing life-cycle costs Whole-life appraisals Disposal costs	Parametric methods Bill of Quantities	(Häkkinen et al., 2007, Kirkham, 2005, Woodward, 1997) (Davis and Baccarini, 2004)

2.3.1 Project Development Phases and Estimating Goals

Kagioglou et al's (1999) project lifecycle model (Figures 2.1 and 2.2) contains ten phases which are categorised into pre-project, pre-construction, construction, and post completion domains. These phases are split into eight domains which the authors identified as critical to process improvement. The descriptors (development management, project management, resource management, design management, production management, facilities management, health safety statutory and legal management, and process management) relate to project outcomes. They are not specific to estimating but estimators offer specific services in these domains.

Table 2.1 identifies specific theoretical and empirical domains that are relative to estimating processes and methods across the four project development phases. These are derived from the practice guidelines of the (International Cost Engineering Council (ICEC), 2002):

- In the **Pre-Project Phase**, estimates seek to establish conceptual budget descriptors that contain parameters such as preliminary costs, duration, legal viability, cost of capital and potential of high cost-impact risks. Also known as scope studies, this estimation stage has two main elements:
  - *Need establishment and conceptualization*: At this stage clients establish the need to construct and conceptualize how best to meet their project goals. Project value streams are initiated according to end-users' needs rather than the subjective requirements of stakeholders. A typical example of the procedures involved is presented by the Department of Sport and Recreation (2007). This document describes preliminary estimation during scoping studies to include:
    - Setting objective benchmarks for assessing project needs (i.e. what infrastructural forms, functions or structure are needed and how the allocation of resources are to be justified?).
    - Critical analysis of decision-making processes to establish how project goals are formed. While project needs have been established in the previous step,

additional activities are required to provide budgetary checks and balances to indicate how financial decisions are escalated. This involves setting guidelines for project implementation e.g. creating options for procurement and setting out stakeholders' responsibilities. Each of these steps requires the development and justification of the need for the project, research into the implications of these commitments and ratification that the outcomes meet the established needs.

- The steps above relate to costs. In addition there is an execution perspective that requires consideration. Production requirements need to be scheduled and balanced with investment needs to meet project milestones.

- *Feasibility studies*: These identify whether project expectations are possible and viable (Shen et al., 2010a). While needs' assessment points out value and potential risk streams, feasibility studies extend this in the follow ways:
  - They explore whether a proposed project is feasible based on budgetary requirements and tangible development risks
  - It is often necessary to analyse how decision are made on project finance before project implementation commences.
  - Before financial decisions are made, there must be sufficient information on development costs.
  - Similarly, parameters of financial feasibility include an understanding of on-costs and maintenance costs.
  - It is also advisable to determine the benefits of achieving project success as well as the cost of failure.
  - In scheduling costs for the milestones noted above, tangible and intangible elements have to be planned for and accommodated.

Specific estimating methods apply for all of the above (Section 2.3.2). As information at this phase of project development is usually inconclusive, estimating outcomes are conceptual. According to Bley (1990), conceptual estimates usually lack certainty, accuracy and relevance over time. To address these limitations, several solutions have been developed including:

- improving data quality and modelling techniques (Rahman et al., 2008, Walton and Stevens, 1997)

    - using IT to resolve data complexity and optimize integration (Cheng et al., 2009a, Kwak and Watson, 2005)
    - experimental learning (Lowe and Skitmore, 2001)
- The **Pre-construction phase** consists of two elements, viz. planning, and design and procurement. The overarching aim of estimates at this phase is to guide decision-making for efficient project implementation:
  - When designs progress from concept to those that receive statutory planning approval, estimating processes include:
    - Siting studies which aim to obtain maximum economic benefits for a proposed project by taking advantage of site locations (ARUP, 2009).
    - Scope/cost change trending which includes establishing the cost implications of changes in design scope when additional information becomes available (Rutter and Gidado, 2005).
    - Value management which ensures that primary project components contribute to a project's lifecycle in form, function and value (Barton, 2000, Bowen et al., 2010, Cha and O'Connor, 2005).
    - Cost trending and controlling, and design analysis. The cost of a project can change whilst the scope of work remains constant (Baloi and Price, 2003). Both change domains (i.e. work scope and price regimes) require effective control measures (Potts, 2008).
  - When designs are being finalized for procurement, estimating functions include:
    - Designing procurement routes (Love, 2002, Oyegoke, 2007).
    - Cost planning (Ferry et al., 1999, Lau, 2006, Smith and Jaggar, 2007).
    - Resourcing and scheduling project execution (McKinney and Fischer, 1998)
    - Project management (Parker and Skitmore, 2005, Walker, 2007).
    - Tender action (Aibinu and Pasco, 2008, Brook, 2008).

  As work advances in this phase, project stakeholders have higher expectations of estimates than in the previous phase. They expect improved certainty, accuracy and responsiveness. However, several reports show that these goals are difficult to meet (Bromilow, 1981, Ogunsemi and Jagboro, 2006, Mak et al., 2000). Apart from the work of (Skitmore and Patchell, 1990) where the limitations of estimating methods used during this phase are identified, , project stakeholders reportedly only have one

option i.e. to learn to tolerate estimating errors (Cheung et al., 2008). This finding is also supported by a survey (Aibinu and Pasco, 2008).

Many solutions have been suggested to address this challenge, particularly in the context of maximising the benefits of design-related IT. According to (Acharya et al., 2006b), design errors contribute substantially to estimate errors. Others have argued that, if designs are modelled accurately and cost descriptors could be extracted automatically, estimates will be accurate (Geiger and Dilts, 1996, Tse and Wong, 2004, Sabol, 2008). However, these arguments do not consider the following:-

- Accurate data modelling of project designs is challenging. According to (Amor et al., 2007), this compromises the integrity of data upon which estimates rely on when generated automatically. It is also difficult to represent every possible requirement (e.g. preliminary and general items, as well as contingencies) in design models. Ways still need to be found to automatically generate estimates that account for these items.
- Estimates reflect the business intentions of contract parties (Assaf et al., 2001). (Ray et al., 1999) and (Skitmore and Smyth, 2009) note that to base project estimates on partial disclosure is an amoral business behaviour. This is explained in Section 3.1.
- Construction costs are subject to inflation, exchange rate fluctuations, lending rates, balance of trade and availability of resources. These variables are inevitable but difficult to predict (Olatunji, 2010c).

Estimators have different ways of addressing these challenges. These include exploiting developments in design IT that automatically generate quantities. Chapter 6 explores these challenges in detail and across different practice domains.

- During the **Construction Phase**, stakeholders often measure the performance of their projections by monitoring and controlling their predictions against actual events (Kagioglou et al., 2001). The interface between this phase and the **pre-construction phase** occurs when bids are ratified and contract documentation prepared. Estimating activities related to this include:
  - Bid securitization i.e. estimating how much surety is required to indemnify clients in the case of default at any stage of construction. Examples include prescribing (from

clients' perspectives) and meeting (from contractors' perspectives) bonds, guarantees and insurance requirements (Awad and Fayek, 2011).

- Contractual arrangements frequently involve financiers, consultants, main contractors, nominated specialists and nominated subcontractors. The resulting administrative and legal costs are significant and need to be established and accounted for in estimates (Speaight, 2009, Sweet and Schneier, 2008).

Another perspective on estimating at this stage is to estimate the actual costs during construction (Table 2.1). This usually involves physical measurement and some cost management activities including:

- Scheduling and reviewing project execution in line with contract milestones (Taylor, 2008).
- Estimating what is due to contract parties by way of valuations, financial statements and final accounts (Harris et al., 2006).
- Auditing project value, ensuring value for money and smoothing cashflow (Odeyinka and Lowe, 2001, Park et al., 2005).

Discrepancies between pre-construction estimates and actual cost obligations are the single most important cause of cost overruns in construction projects. Several factors trigger this including:

- Erroneous judgment in pre-contractual estimates (Aibinu and Pasco, 2008, Davis et al., 2009a, Poon, 2003)
- Additional contingencies i.e. those that were not included in pre-contract estimates (Baloi and Price, 2003, Ogunsemi and Jagboro, 2006)
- Design and/or construction errors e.g. rework and unusual variability in general items (Acharya et al., 2006b)
- Variations that are not envisaged or accounted for in pre-construction documentation e.g. design conflicts and ambiguous clients' requirements (Skitmore et al., 2007a, Sutrisna et al., 2005, Yizhe and Youjie, 1992)
- Subjective risk loading (Lyons and Skitmore, 2004, Odeyinka, 2007, Ustinovicuius et al., 2007)

These challenges may be addressed by changes in behaviours and by aiding professional judgement with technologies. For instance, in place of traditional contracts where

contractors bear most of the risk associated with projects, relational contracts present considerable advantages (Ballard and Howell, 2005, Sakal, 2005). Other researchers have suggested the adoption of cyber-physical systems (CPS). These involve the bi-directional engineering of construction data whereby information from physical (actual construction) and computational systems (pre-construction model data and automation sensors) are integrated. The results provide a basis upon which financial judgements on projects can be made (Lee, 2008).

Both of the aforementioned solutions have received scant attention in the estimating literature. Authoritative estimating guides such as (The Chartered Institute of Building (CIOB), 2009) and (Australian Institute of Building, 1995) only provide generic instructions. It is relevant to note that contemporary research findings relate these solutions to BIM. For example, while relational contracting underpins lean building philosophies, lean concepts are deeply rooted in BIM (Sacks et al., 2010). Similarly, the computational systems upon which CPS operations are based rely on BIM and its derivatives (including RFID and mobile computing). The overarching gap to be resolved in this study is to identify the procedures involved in using BIM for estimating, considering its relevance to contemporary solutions.

- The final phase, the **Post Completion Phase**, involves *Operation and Maintenance.* It requires estimates that address facilities' operation and maintenance e.g. alterations, modernization, rehabilitation, conversion and deconstruction. Construction Management textbooks relate estimating at this phase to the methods used in previous phases. Similarly, apart from phase-specific challenges (Listokin et al., 2001), the same challenges and solutions apply to the estimating methods in this phase.

  Ballesty et al. (2007) discussed the applications of BIM in facilities management. In this and other studies (e.g. Olatunji and Sher, 2010b), BIM only serves as a platform for information integration, not as an alternative to estimating methods and techniques. BIM adds value to FM processes, as it does to estimating and contract administration at this stage. The challenge to estimators therefore is to understand the theoretical and skill requirements involved in generating workable estimating outcomes.

In summary, based on Figures 2.1 and 2.2, and Table 2.1, each of the project development phases has specific estimating goals. Some are conceptual, and others predictive, whilst a few are confirmatory. Meanwhile, according to the work of (Skitmore and Patchell, 1990)

and (Cheung, 2005), different estimating methods apply to each of these phases, each with specific problems and solutions. In all, the focus on process improvement in estimating practice has involved either the utilization of IT advancements or the embracing of modern-day business behaviours that promote integration and innovations.

Based on these, some knowledge gaps exist:

- Knowledge about IT applications for estimating has grown but this is not reflected in the relevant literature. Studies such as those of Ogunlana (1989) and Best et al. (1996) suggest that estimators are either reluctant to use IT or they are somehow wary of computer-aided estimating (CAE) systems.
- Patterns of the demand for estimating services have changed during the past decade. In a survey by Masidah and Khairuddin (2005), the authors noted that some estimating services have diminished. Similarly, other studies of estimating practice in Australia have reported a significant decline in the use of standard methods of measurement (SMM) and bills of quantities (BoQs) (Davis and Baccarini, 2004, Davis et al., 2009a).
- Whilst CAE processes generally mimic manual practices, the procedures followed in both paradigms are significantly different. With the number of new technologies growing, this dichotomy is likely to extend further. According to Sher et al (2009), designers and construction management professionals require new skills to exploit advances in IT.
- The overarching question about the impact of IT on estimating is not merely whether this paradigm shift in skilling has an impact on estimating culture, but whether the changes IT brings to estimating tools and processes are significant and worth exploring. How do existing, traditional estimating methods relate to IT-enhanced procedures? As the pace of IT advancement continues, what does this mean for the future of estimating practice and theories? These questions are addressed in the following section.

2.3.2 Estimating methods during the Pre-Planning Phase

Infrastructure development requires the involvement of many stakeholders, each of whom has different requirements and expectations of estimates, from one phase of a project to another. Estimators have always met these needs by using a range of tools and techniques. The performance of these estimates depends on the level of certainty in, and reliability of, the information which estimators are provided (Section 2.3.1). Usually, during the **Pre-Project Phase** and the early part of the **Pre-Construction Phase** the data upon which estimates are

based are not definitive. Both manual and computational methods apply as discussed below under various estimating methods.

Conceptual Estimating methods

Needs assessment is a legislative requirement for all public projects within the Australia (Department of Sport and Recreation, 2007). Citing Bennett et al (1979), Cheung (2005) identifies the following manual estimating approaches as those that have been used for needs assessment:

- cost limit calculations
- the floor area method
- functional unit method
- approximate quantity method
- conference method
- lump sum calculation based on potential scope of work, and
- preliminary estimates of elements of the project.

Guidelines on how these manual methods may be applied have been documented by James (1954) and Ashworth (2010). Two perspectives are common to these types of estimating, viz.

- it is possible to use computer applications to automate manual estimating procedures, in part or in whole.
- it is also possible to use a manual estimating methods across more than one phase of project development.

Generally, manual estimating methods require one or more estimators to interpret or simulate clients' requirements and guide decision-making during design by providing cost advice. However, the reliability of such advice can easily be questioned because many decisions are based on provisional information (Skitmore and Smyth, 2007). In the views of Cheng et al (2009b) and Muscianesi (2003), the divergence between the outcomes of these methods and actual project costs is critical, but could be reduced if estimators integrated their methods and reinforced them with IT applications.

Nowadays, design data at the **pre-project phase** have become more sophisticated and voluminous. Consequently, researchers have investigated using automation to enhance conceptual estimates. For example, Cheng et al's (2009a) fuzzy hybrid neural network model

has produced results where actual construction costs relate to pre-project conceptual estimates. Similarly, Geiger and Dilts (1996) have developed an automated system which converts schematic designs into conceptual estimates. Research on this topic is on-going but proposed solutions are easily impeded by poor data quality (Walton and Stevens, 1997). Looking into the potential of IT has been the focal point of many studies dealing with this issue. Its role in reshaping some estimating methods is discussed below.

Functional dependency method

This procedure is based on how project components relate to each other. For example, building frames, floors and finishes have different functions. Each component can be used in a wide variety of ways, either in isolation or in combination with other components. In this method, the dependencies between different components are estimated based on functional costs i.e. the cost of development, maintenance and maintenance. A digital adaptation of this has been reported by (Niemi, 2001).

This method has its challenges. According to Seeley (1996), it lacks precision as functional parameters do not accurately reflect major cost project parameters (such as component versus project size, shape, finishing, material and construction method). Thus, the remedy is to use procedures that mitigate this challenge. Apart from knowledge-based methodologies such as smoothing, interpolation and application of trend functions, linear programming techniques and algorithm methods are have been used to provide solutions to these challenges (Cheng and Wu, 2005).

Rather than focusing on functions alone, the advances indicated above encourage the use of simulation, risk assessment and process integration. According to Bari et al (2008), reinforcing the old regime of calculating functional costs with more rigorous IT-enabled procedures has boosted the logic of using functional dependencies when making economic decisions on projects. More often than not, it encourages the integration of functional parameters with form and context parameters using objective data that can only be analysed with rigour and sophistication in an intelligent IT-enabled environment.

Parametric estimation techniques

Conceptual estimating is frequently facilitated through regression models (Daschbach and Apgar, 1988). In the past, they were applied manually to predict costs based on abstract

characteristics such as specifications, physical appearance, proposed functions, duration and location (Kwak and Watson, 2005). According to Kwak and Watson (2005), parametric techniques have also been used to predict costs based on relationships between one tangible cost item and another, and between tangible cost items and non-cost items. Nonetheless, the reliability of most manual parametric models has been contested in several studies. For example, Ji et al (2011) argued that traditional parametric approaches are repetitive, cumbersome, and that their outcomes can be jeopardized by poor data. They are also not reusable because each project has unique characteristics that are not reflected in other projects.

Parametricism requires a considerable level of rigour to speed up data processes and improve accuracy. IT applications have been used to integrate multiple algorithms and methodologies to improve the objectivity and reliability of outcomes. Kwak and Watson (2005) identified five IT-enabled ways of transitioning conventional parametricism in estimating practice viz. waterfall methodology, evolutionary development, incremental development, prototyping, spiral development and object-oriented development. The waterfall methodology is based on data in product models; the quality and accuracy of the data drive optimum outcomes. Evolutionary development methodology works well with detailed process models. While the incremental development technique is designed to reflect flexibility in model outcomes based on gradual improvements on projects, prototype parametric estimating models are based on heuristic experimentation. Spiral development methodology is used for analysing risk, while object-oriented development model is targeted at re-use. Chapters Three and Six relate these approaches to BIM and their impact on estimating processes.

There is strong evidence to suggest that with IT-enhanced parametric estimating methods, the reliability of estimate forecasts are enhanced. This occurs through data integration, objectivity in data sourcing and manipulation, and the integration of algorithms and methodologies (AbouRizk, 2010, Chou et al., 2005, König et al., 2007). These authors argue that IT-enhanced parametricism has also advanced simulation and risks visualization to promote project value streams.

Intelligent systems

The use of intelligent systems for conceptual estimating is popular in construction. Literature on construction IT has frequently discussed the applications of tools such as artificial intelligence (AI), neural networks (NN), fuzzy logic (FL) and advanced applications of case-

based expert systems (CBS) or knowledge-based systems (KBS) in generating conceptual estimates (Mohamed and Celik, 2002, Venkatachalam et al., 1993, Ballal and Sher, 2003). Although the outcomes of these tools have been criticized by (Wang and Elhag, 2007), they have delivered workable outcomes in specific case-based scenarios. (ElSawy et al., 2011) observed that these methods place users in passive roles and would be strengthened with collaborative interactions. This observation is shared by previous authors who believe that intelligent systems seldom solve unexpected problems or allow end-users to create solutions through self-directed and self-patterned processes (Xiaoli and Jianguo, 2004).

Meanwhile, the usefulness of these tools has been highlighted by Cheng et al (2009b); they can be integrated with other (and multiple) tools to deliver robust outcomes. According to these authors, an evolutionary fuzzy hybrid neural network (EFHNN) can be generated when neural networks (NN) and high order neural networks (HONN) are integrated into hybrid neural network (HNN). When the resultant network from this integration is combined with fuzzy logic (FL), a fuzzy hybrid neural network (FHNN) is generated. The authors have demonstrated the evolutionary powers of the resultant model in terms of precision, robustness and ability to deal with complex situations.

It is noteworthy that the aforementioned tools are not popular in conventional practice largely because estimators do not trust these innovations. Using algorithms, object-oriented simulation and artificially intelligence to assess risk are foreign to the ways in which many estimators conduct their business (Akintoye and Fitzgerald, 2000). This reluctance raises the following questions:

- Do estimators have the knowledge and understanding necessary to drive these tools?
- How do the outcomes of intelligent systems compare to manual outcomes?
- Can estimating outcomes be sustained without the assistance of artificial intelligence?
- Does reliance on commercial applications jeopardise estimating outcomes?

Arguably, intelligent systems provide sufficient depth to deliver precision and knowledge-based decision support. They also motivate estimators to explore project-based procedures that are flexible and responsive. These methods have increased in popularity as applications that address complex problems including professional service marketing (Houben et al., 1999) qualitative assessment of contractors' capability (Ng and Skitmore, 1994), repair of CAD design errors (Yang and Han, 2006), and improved outcomes of soft planning

paradigms, particularly planning for complex risks and uncertainties (Zozaya-Gorostiza et al., 1990).

Monte Carlo Simulation

For decades, estimators have solved complex problems using Monte Carlo simulations. This technique has been applied to bidding, resource planning and cost estimating (Chau, 1995, Chou, 2011, Kurihara and Nishiuchi, 2002, Skitmore, 2001, Skitmore, 2008). Monte Carlo simulations rely on probabilistic methods to model risks and uncertainties by iterating random values. IT has been used to promote the processes and outcomes of Monte Carlo simulations. Apart from supporting infinite iterations and creating platforms for complex data analysis, IT has enabled dedicated Monte Carlo simulation tools to represent complex dynamics and to provide graphical mechanisms for viewing model structures. Some of these include:

- discrete event simulators for modelling construction processes and cashflow (Chau, 1995);
- agent-based tools for simulating system automation and virtuality (Kurihara and Nishiuchi, 2002);
- continuous simulators for handling structured events which possess clearly predictable attributes (Vose, 1996);
- hybrid simulators which combine the attributes of discrete simulators and those of continuous simulators to handle the most complex equations (Momani and Ahmed, 2011).

The advantage of IT-enabled Monte Carlo simulations is not limited to generating workable outcomes from simulations (which are often larger and more complex than manual cognition can accommodate). They provide flexibility, robustness and add value to estimation processes (Skitmore, 2008). Skitmore and Ng (2002) argue that estimators seldom use the analytical approaches of Monte Carlo simulations because they are viewed as complex and difficult. In a recent demonstration by Hulett (2011), IT-supported Monte Carlo simulation has changed this view by being straightforward and generating robust outcomes.

The merits of using IT in Monte Carlo simulations are clear; in place of conventional methods (which are static and unresponsive to post-contractual variability), the outcomes of

Monte Carlo simulations can facilitate informed decision-making based on scenarios of overruns and their consequences. In other words, Monte Carlo simulations provide an IT-savvy generation of estimators with opportunities to build on historical knowledge to address issues that are increasingly complex, and to deal with soft project dynamics, develop more workable estimates and advance new horizons.

Price Indexing

Price variability is a major issue for construction projects. Price indexing is used to predict changes in pricing regimes over time. Ashuri and Lu (2010) show that persistent changes in cost determinants are stochastic; changes in their trend are difficult to predict and these often compromise the accuracy of construction project estimates. This has been identified as the main cause of poor project performance. However, it is one that project stakeholders have limited control over (Olawale and Sun, 2010, Sweasey and Skitmore, 2007). There are many models which stakeholders use to predict construction price increases. According to Yu and Ive (2006), price indexing models include Laspeyre's model, Paasche's model and Fisher's model. Each of these has different targets and delivers different outcomes that represent time-value of money.

Recently, Ashuri and Lu (2010) have used time-series modelling techniques for indexing prices, including:

- *Simple Moving Average (SMA) approach*, a simple technique whereby construction cost index (CCI) for a period ahead is based on historical data from a relative previous period.
- *Holt Exponential Smoothing (Holt ES) approach*, which predicts CCI by displaying decreasing or increasing trends through the use of least square method (LSM).
- *Holt-Winter Exponential Smoothing (Holt-Winter ES) approach*, an extension of Holt ES, which takes the seasonality of the data into account by using least square method (LSM) to calculate CCI.
- *Auto-Regressive Integrated Moving-Average (ARIMA) approach*, which integrates two methods, Auto-Regression (AR) and Moving Average (MA), by following certain standard modelling steps to calculate stationary data.
- *Seasonal ARIMA approach*, which is designed to compensate for seasonality in time series handling of CCI.

IT has frequently been used to improve price indexing. It is now possible to explore and automatically integrate cost data from remote sources, and at the same time index and match these with resource schedules in a project plan. Advances such as these provide significant advantages over manual price indexing procedures (which can be cumbersome, prone to human error and time consuming). In summary, the IT-enhanced conceptual estimating approaches described above challenge conventional estimating procedures. IT has increased the useability of these methods beyond the pre-planning phase. As IT continues to impact on estimating practices, the implication of this paradigm shift is more significant than ever. The challenge is whether estimators have sufficient incentives, knowledge and skills to adopt these advances or whether they are adequately recognized in the guidelines provided by relevant professional bodies. Arguably, there is substantial evidence to suggest that change will continue to occur. For example, unlike two decades ago, at present, it is possible to capture clients' expectations digitally and match them with appropriate cost databases that can improve process values and visualization of outcomes (Ogunlana and Thorpe, 1991). The next section deals with estimating methods in the **Pre-Construction Phase**.

2.3.3 Estimating Methods during the Pre-Construction Phase

Two perspectives are widely used when estimating at the pre-construction phase; first, proposed projects can be estimated preliminarily while further confirmatory estimation is done during construction. At this time, the available information on the project is sketchy. The second perspective is when substantial information is available for the purpose of detailed pre-contract estimating. Ultimately, depending on the availability of information, as projects advance toward construction, estimates tend to represent expectations during execution more precisely than in conceptual stages.

The Chartered Institute of Building (CIOB) (2009) defined an estimate at this stage as the *"systematic and analytic calculation of construction and overhead costs for a contract"* (pp. 1). There are many views on this; the nature of estimating outcomes depends on stakeholders' perspectives and how these are responded to. For example, while clients focus on creating value for money, contractors' views are different (Wong et al. (2000), (Fine, 1974) and Skitmore and Smyth (2007)). According to Skitmore and Smyth (2007), contractors' views on estimating at this stage include one or more of the following:

- To determine the risks and production costs to their business while deciding whether or not to bid;
- To strategize and succeed in competition during tender; thus the right to disclose the actual potential construction cost is their prerogative
- To maximize commercial interest whether contract parameters are disclosed fully or not.

Apart from clients and contractors, other stakeholders also contribute to and use data from pre-construction estimates. These include consultants and project developers. While the former's views are from the viewpoint of an umpire, protecting the rights of clients and contractors during the short-term, the contract between them exists. The project developer integrates project estimates on a longer-term (lifecycle) basis. Due to the nature of estimate targets (some of which are long-term whilst others are short-term), estimating methods and goals at this **pre-construction phase** vary. This area is widely addressed in the literature (Brook, 2008, Flanagan et al., 1989, Flanagan and Jewell, 2005, Green, 1989, Griffith, 2000).

Conference Method and Value Engineering and Management

The conference method is a popular approach in estimating (Ashworth, 2010). It involves a group of professionals coming together to estimate and debate the cost importance of project components and approaches. Similarly, Barton (2000) advocates the use of value management and engineering (VM/E) procedures as the interface between conceptual design and definitive design-making prior to procurement. This usually involves a group of professionals engaging in rigorous debates to determine how proposed project elements contribute to project values in terms of form, function, cost and aesthetics. In Barton's (2000) review, there are *Soft* and *Hard* methodologies in VM/E; *Soft* being when project scope is not definitive, *Hard* being when project parameters are definitive. Discussions during VM/E sessions form the final basis upon which designs and final estimates are based prior to construction.

Meanwhile, Bari et al (2008) has described different estimating techniques during VM/E stages. These include Monte Carlo simulation, parametric modelling techniques including regression modelling, knowledge-based modelling, resource-based modelling, and life cycle cost (LCC) modelling. Other methods include interpolation techniques, conference, financial method, functional unit, cube, storey enclosure, approximate quantity and artificial neural network (ANN) modelling. Most of these methods are extensions of those applied at the conceptual stage and those not covered earlier in Section 2.3.2 are discussed below. More

importantly, this review focuses on the changes that IT has brought into estimating, considering CAD and BIM as design data platforms. The functional frameworks of CAD and BIM have been detailed in Chapter 4. Some of these include integration, simultaneous access to design databases and ability to communicate with data-rich objects. In the context of VM/E, this presents marked advantages. With teleconferencing and integrated BIM platforms, VM/E can now be conducted as part of the design process rather than a separate procedure. Additionally, the popularity of visualization and simulation in BIM has reduced the time-consuming process of VM/E. Another perspective is that in BIM, visualization and design improvement are a continuous process, while VM/E must end within a certain period of time (cf Kang et al. (2009) and Bowen et al. (2010)).

Cost planning

Cost plans are one of the most widely used estimating methods in Australia. They are prepared through a procedure that has remained relatively unchanged during the past six decades (Morris, 1995). Cost planning involves the concise articulation of project elements in ways that inform decision-making. The different cost planning approaches are:

- *Least-Cost Planning (LCP)*: LCP has been discussed extensively by Mills (2001) and ECONorthwest and Brinckerhoff (1995), with case studies in Australia and United States of America respectively. This approach provides information on the correlations between direct or tangible costs and indirect or intangible costs. Where the correlation is positive, cost-benefit analysis (CBA) procedures apply to minimize the benefits of direct costs on indirect variables (Gupta and Gupta, 1984). Where the correlation is negative, benefits-cost analysis (BCA) procedures apply to identify the positive elements of negative indicators or events. The overarching aim of these procedures is to establish and limit the negative impact of indirect costs on direct costs (Mills, 2001).
- *Elemental Cost Planning (ECP)*: The main principle behind elemental cost planning (ECP) procedures is to constrain designs to cost limits (Pratt, 2011). ECP also serves as a basis for cost control between as-designed and as-built structures, and to compare cost parameters between projects with similar characteristics. There are different ECP models in different parts of the world. Although they all work in a similar way, their outcomes are different because methodologies differ, as do the environments they are applied in. The following location-specific ECP models are publicly available and currently in use.

- *The British Cost Information Service (BCIS) model*, which was first published in 1969 as the Standard Form of Cost Analysis (SFCA). It is based on 10 primary building elements which define project cost characteristics. These are preliminaries, substructure, superstructure, frame, roof, finishes, services, built-in fixtures, external works and contingencies. Smith and Jaggar (2007) state that ECP models in Australia draw on the BCIS model. According to Lee and Smith (2010), the newest homogenized ECP model by the BCIS was introduced in 2010 so that project elements are more distinctive and descriptive.

- *The Association of African Quantity Surveyors (AAQS) model,* which was published in 2003. It contains 17 primary elements and 23 specialist elements and a range of other variables not detailed in the BCIS model (including tax, fluctuations, alterations, training costs and contractor's fees). Moreover, secondary elements such as external works and services, preliminaries and contingency allowances, which are considered as unitary items in BCIS model, are covered in more detail in the AAQS model. Contingency allowances in the AAQS model are based on price and detail developments, and contract contingencies. Similarly, in the AAQS model, *External Works and Services* are broken down into 21 variables; while in the BCIS model these items are covered in less detail.

- *Comparative Cost Planning (CCP):* Comparative cost planning (CCP) procedures propose a range of design options and elements by which projects can be estimated and compared. These enable clients to make informed choices about best value rather than constraining designs to a cost (Ashworth, 2010). The outcomes of ECP procedures are as reliable as other forms of comprehensive estimates. ECP procedures have been documented extensively (Ashworth and Hogg, 2007, Harris et al., 2006, Seeley and Winfield, 1998).

Since 1980s, researchers, including Sher (Sher, 1982, 1983, Selinger and Stamler, 1983), have explored computer applications for cost planning and other forms of estimating. With time, the increased uptake of IT by estimators has further extended the gap between conventional procedures and computer-aided cost planning procedures. For example Harun and Abdul-Rahman (2000) describe multiple Monte Carlo simulation iterations which were used to generate comprehensive cost plans for a range of confidence levels.

Additionally, Harun and Abdul-Rahman's approach has been used by Hulett (2011) to estimate the cost implications of several *'what-if'* scenarios both prior to project commencement and thereafter, including the possibility of predicting post-contract variability in line with specific confidence levels in pre-contract estimates. It is now possible for estimators to extract data automatically from electronic drawings and match these with appropriate cost data, the outcomes of which can be reported as mixed or switched between multiple formats automatically (by trade, sections, locations, elements, graphics and the like). This was a prohibitively time-consuming and unreliable procedure using conventional methods. In summary, the IT deployment for this paradigm of estimating has enabled estimators to improve their estimating processes through rigorous and timely data analysis while they enhance procedural intelligence in ways that reinforce estimating outcomes.

Bill of Quantities (BoQs)

BoQs serve as the basis for estimates worldwide. They require project attributes to be measured according to the rules in a prescribed standard method of measurement (SMM). Conventionally, there are six steps in preparing a project estimate using a BoQ (Seeley and Murray, 2001, Seeley and Winfield, 1998). These are:

- *Taking-off*, the practice of extracting quantities and project descriptors from drawings, specifications and the relevant SMM. The manual process involves using *dimension sheets* and specific conventions such as *dotting, bracketing, 'anding'* and *short-hand writings*.
- *Abstracting*, a procedure for processing and collating data from quantity take-offs in readiness for BoQ drafting. This involves collecting together the quantities for specific items that have been measured for multiple locations. For example, it includes converting reinforcement from linear measurements to tonnage, bulk adjustment for earthwork and conversion of quantities from gross to net quantities.
- *Working-up quantities*, a technique for converting abstracted quantities to final figures that will be shown in the BoQ and for work schedules. This could include rounding-up and making adjustments on calculated quantities.
- *Bolt-checking*, a process for checking that all quantity calculations are correct in readiness for BoQ drafting.
- *BoQ drafting*, which involves compiling all necessary items of work in a specific BoQ format.

- *BoQ estimation and pricing,* a procedure for estimating the cost of resources that will be needed to accomplish every task. Once the cost to the contractor, as well as the duration, has been estimated, estimates are marked up into the price that clients will pay. While most conventional BoQs may not show estimates, BoQ prices are a combination of mark-ups and estimated costs.

BoQs may be prepared in different formats, viz:

- ***The Conventional approach***, a procedure for identifying cost items based on the attributes explicitly shown in a project model. Project models could be in two forms: product model and process model. A product model contains the physical attributes of a project when finished. A Process model provides the details of the methodical procedures that the constructor will undertake to achieve the required product attributes. Both modelling contexts apply to the BoQ drafting approaches indicated below.
  a) *Trade BoQ* is a format that is focused on trades. Project trades includes earthwork, concrete work, steel work, carpentry and joinery and so on (Darley, 2010).
  b) *Elemental BoQ,* a format that is focused on project elements such as substructure, frames, roofing, finishing and so on (Harris et al., 2006).
  c) *Sectional BoQ,* a format that targets project sections such as "all work up to ground floor slab" (i.e. earthwork, foundation walling and finishing, concrete footings and slab), superstructure (i.e. walls and frames), roof work (i.e. roof carcasses and covering), finishes (i.e. floor, wall and ceiling finishes), external works (i.e. fence, landscaping and so like), services (i.e. electrical, plumbing, HVAC and so line) (Speaight, 2009).
  d) *Builder's BoQ,* a format often prepared by contractors in line with a chosen method of construction but with little or no reference to a SMM. These BoQs may appear in any of the formats described above but in less detail (Davis and Baccarini, 2004).
  e) *Direct Labour BoQ,* which is based on a schedule of materials, labour and a well-defined construction process. In some instances, an estimate based on this approach may exclude contractor's overhead and profit (The Nigerian Institute of Quantity Surveying (NIQS), 2006).

  BoQs are drafted to record the physical attributes of a project so that construction contractors can devise appropriate construction methods to price each of the attributes

(Fine, 1974). However, clients and contractors do not always share the same view about what the focus of a BoQ should be (see Sher 1996):

- Product and process descriptors are not usually synchronous; so it is difficult to integrate these two through pricing.
- The difference between the process and product has been the single largest cause of friction in contractual relationships (Cattell et al., 2010, Sutrisna et al., 2005).
- Different people interpret and resource project attributes differently. Thus, it is always a challenge to judge the accuracy of estimates where the interpretations of practitioners vary.
- Where BoQs are prepared by one party (e.g. clients) and made available for another party (e.g. contractors) to adopt as basis for estimation, some level of risk is involved. These include errors and bias which may jeopardize the party submitting the contract price. More importantly, such risks are not estimable during estimation. For this and other reasons, the party involved would include contingency allowance in the proposed estimate to cater for such events.

- ***Cost-Significant item estimating***, a practice whereby only major BoQ items are estimated for. Consequently, these items subsume minor items. The limitations of this approach are a lack of transparency in how estimates are arrived at and the difficulties in influencing project control (from the clients' perspective). For example, minor items may vary without any significant change in the major items they relate to. This makes it difficult for parties agree on reimbursement when the scope of work affecting minor items changes.

BoQs have frequently been criticized as being subjective, lacking accuracy (Skitmore et al., 1990); lacking flexibility (Sutrisna et al., 2005); and being costly and irrelevant (Morledge and Kings, 2006). In Australia, the use of BoQs to underpin estimates has declined in the last two decades (Wood and Kenley, 2004). Some of the reasons for this include:

- the complexities arising from the use of standard methods of measurement. There are several types of SMMs including the Australian ASMM5, Australian Standards (ASs) for building and engineering works, the UK's SMM1-8, the BESMM (building and engineering standard method of measurement), the SMMIEC (Standard Method of Measurement of Industrial Engineering Construction). According to Davis et al (2009a), there is no clear evidence that SMMs cause major errors in estimating. However, problems do occur in interpretation, nuances in application and the strength it has as an

enforceable legal instrument (New South Wales Public Works Department (NSWPWD), 1992).

- errors and associated disputations (Davis and Baccarini, 2004)
- contractors' dissatisfaction with BoQs prepared by clients e.g. issues of clarity and the inability of clients' BoQs to agree with contractors' chosen construction methods (Wood and Kenley, 2004)
- preferences for other alternatives to convey a construction project estimate e.g. the format of the New South Wales Public Work Department (NSWPWD (1992))
- clients' desires for flexible procurement routes which may not make the use of a BoQ mandatory (Ross and Fortune, 1998)

Despite these criticisms, Davis et al. (2009a) have suggested that the use of BoQ for estimating and bidding is still relevant. They argue that there are few alternatives to BoQs, either in terms of their purpose or in terms of their structure, relativity and comprehensiveness. In Skitmore and Patchell's (1990) analysis of the accuracy of estimating methods, there is little difference between the accuracy of BoQ-based estimating and other forms.

Moreover, the use of IT for BoQ estimation has significantly impacted on these problems (Olatunji, 2011c, Fairfield, 2005). It is currently possible to automatically extract cost parameters such as quantities and descriptions from electronic drawings of any type (jpeg, vector or scalar pdf, 2D or 3D CAD and parametric design format) and align these with cost and resource databases. The main challenge has been how to uniformly structure the different data representation formats that are possible with different forms of CAD. This is a critical challenge particularly when there is a significant shift from conventional paradigms e.g. if SMM is avoidable and design modelling approaches render data in formats that estimators are not used to (e.g. using ifcs and pricing models object-by-object).

Automated measurement appears to be gaining acceptance as a deliverable of CAD and BIM. Thus, the era of manual measurement is under threat. However, automatic estimating procedures may sound simple, but are they actually so? Research suggests otherwise; data (quantity, description and resources) must be carefully screened, engineered and managed in order to deliver workable outcomes (Cartlidge, 2006, Harris et al., 2006, Olatunji et al., 2010b). This study views computer-aided estimating as not simply using computer

applications to repeat manual procedures; it is a new complementary procedure. What activities or data manipulation approaches lead to satisfactory estimating outcomes? This is the main question that this study seeks to solve both in CAD and BIM.

Activity-based construction (ABC) methods

According to the CIOB (2009), an estimate is a *function* of resource costs and overhead expenditure. There are many perspectives to this; both primary variables are described in the literature, particularly to justify the correlation between construction cost and time. An example is the Bromilow's Time-Cost model (Kenley, 2001, Ng et al., 2001). Some researchers agree that estimates should be based on resources and the time it takes to complete a project (Chan, 2001, Eshtehardian et al., 2008, Kenley, 2001), whilst others have argued that the ABC approach means that an accurate estimate is not predictable until the project has been completed (Ogunsemi and Jagboro, 2006). Several estimating techniques relate to the ABC method as discussed below:

- ***Resource scheduling and operational estimating:*** Estimators need to schedule construction operations and evaluate their cost implications. According to Davis (1977), scores of approaches dealing with resource scheduling and operational estimating have been practiced since the 1970s. Modern construction management literature (e.g. Ashworth (2010), Harris et al. (2006)) has reinforced its popularity in modern construction and estimating methods. Operational estimates, common to plant intensive estimates, are usually tied to a particular line of operation. As demonstrated by Harris et al (2006), the method is more realistic than estimating from first principles. Instead of calculating construction activities individually, a cumulative cost for an entire operation is calculated. For example, instead of estimating the cost of earthwork in discrete activities (including excavation, filling, treatment to surfaces, double handling and disposal of materials), resource costs for operating the equipment necessary to complete these tasks are calculated altogether.

  There are different approaches to operational estimating. However, studies on this subject have concentrated on establishing the overarching aim most common to all the approaches of operational estimating i.e. they have concentrated on the relationship between the nature of operational estimating and estimating outcomes (Smith, 1998, Smith et al., 2000, Edwards and Yisa, 2001). Rather than viewing construction operations as superficial or cyclic, these authors advocate stochastic simulation

instruments. They provide empirical evidence showing that stochastic simulation models (SSMs) have improved the outcomes of operational estimating. SSMs require rigorous analysis which manual handling or conventional estimating techniques are unlikely to synthesize effectively. Consequently, different dimensions of computational interventions (including Monte Carlo Simulation tools) have been tried extensively with positive results (Kurihara and Nishiuchi, 2002, Skitmore and Ng, 2002).

- ***PERT-Cost estimating:*** program evaluation and review technique (PERT) is an approach to project planning through critical path method (CPM). Evidence by Schoderbek (1966) suggests that the approach to estimate project costs based on a CPM schedule has been practiced since the 1960s . In this approach, construction activities are planned using a CPM while costs are applied along operational lines. This approach has some limitations, e.g.:
  - Conventionally, the design of PERT/COST management system is not usually perfect. This is because it is impossible to indicate all cost carrying items in a CPM schedule; some items are usually omitted for being non-critical. When such omissions become critical, the consequent friction on project schedule and cost comes up as a tedious issue to resolve (Arisawa and Elmaghraby, 1972).
  - Network diagrams are not perfect representations of project schedules; events could upset predicted critical path(s). When this occurs, cost estimates are disrupted.
  - Schoderbek (1966) argues that this method is not suitable for multiple and complex projects.

  The outcomes of PERT/cost estimates have been revolutionized with modern IT tools. Many software applications are now available which address latent errors and complexity issues in scheduling workable outcomes (Taylor, 2008). Krogstad et al. (1977) and Ameen (1987) note that dedicated software applications have been targeted at resolving this problem for more than 50 years. There have been positive results from such efforts; IT has assisted in the delivery of tools that accommodate and synthesize large quantities of data – they can optimize complex activity crashing and a robust Time and Cost actuation simulation (Cosgrove, 2008).

Evaluated risk assessment (ERA) approach

Risks and uncertainties are common phenomena in construction (Flanagan et al., 1987, Flanagan and Norman, 1983). While most estimating approaches may not recognise risk as a concept to be factored into an estimate, the ERA approach primes estimating for risk assessment and management. There are several views on how risks may be identified and assessed, and whether existing methodologies for dealing with them satisfy project stakeholders (Aven, 2003, Hulett, 2011, Linqin, 2010, Khosrowshahi, 2000). The ERA approach to estimating is a popular estimating practice.

The broad subject of risk is outside the scope of this review. This study addresses the subject of estimating for risk from the perspective of preparing estimates. In particular, ERA methodologies approach estimating to reflect on how estimators perceive risks and accommodate them on every item of work to be estimated (Briand et al., 1998, Hegazy, 1993). In modern-day project design and management where parametric design serves as a strong platform for virtualising and simulating variable risk scenarios, stakeholders are able to visualise the impact of risks on projects.

Additionally, there are emerging theories in virtuality which address conventional risk assessment methods for estimating (Gross et al., 1998, Pelosi, 2007, Whyte, 2003). In essence, the implication of shifting from subjective paradigms to data-rich objective compensation for risks is not simplistic; risk evaluations based on virtuality can be more precise than those based on conventional procedures. This does not come without a price; estimators need to familiarise themselves with the attributes and business behaviours necessitated in virtual environments.

Bid unbalancing models

According to the CIOB's (2009) definition, estimating practice involves estimators' attempts to predict construction project costs under contract environments. There are different perspectives to this, each of which is themed in this study as practice domains (i.e. client's perspective, consultant's perspective, contractor's perspective and integrated/specialised project delivery perspective). Regardless of the design platform upon which estimates are based, studies on contractors' perspectives have held strong views on the amoral nature of their business behaviours while contractors' estimators engineer data to come up with what they consider as the most appropriate project estimate (Cattell et al., 2010, Ray et al., 1999, Skitmore et al., 2007b).

Investigations have focused on how contractors balance or unbalance their bids by varying their overhead costs and profit (Akintoye, 2000, Drew et al., 2001). The concept of bid balancing or unbalancing is dynamic; it portrays a strong indication that construction estimates are not always symmetrical. Estimates may be strategized to keep bids competitive or as a reflection of cashflow planning, while seeking to find an optimum tender price (Bennett et al., 1979, Sinclair et al., 2002, Skitmore and Wilcock, 1994). When considering the impact of modern technologies such as CAD and BIM on estimating practice, it is expedient to establish their impact on the psychology of the business behaviours that underlie bid engineering practices, such as bid balancing and unbalancing. The following are the approaches that frequently appear in literature:

- **Probabilistic Methods**, examples of which include:
    - *Gates' (1959, 1967, 1976) Model*: Gates' works sought to predict how mark-ups could be varied (or 'unbalanced') to improve the competitiveness of a bid. Although there was confusion about the mathematical integrity of Gates' model, contractors were allowed to determine the probability of a proposed winning bid directly without specifying the probability density functions (PDFs) of the contributing variables. Skitmore et al's (2007b) attempt to resolve the problem by using Weibull's approach to define the PDFs for the model has not been challenged by critics of Gates' model or any other recent work in a related area.
    - *Friedman's* (1956) *Model*: Friedman's work on 'balanced' bidding is a pioneering mathematical model on bid moderation techniques. The model uses probability to determine the chances of a contractor winning a bid, whether competitors' approaches to bidding and the number of competitors in the same bid are or are not known. As each project has unique bidding attributes, according to Friedman, how bids are strategized depends on contractors' cashflow and cost utilization strategies.

      Friedman developed cost-to-bid ratios (i.e. the relationship between production cost and a contractor's bid price) as tools for strategizing project income either as frontloading, backloading or even distribution (Grinyer and Whittaker, 1973). However, the mathematical proof for the model has been questioned. According to Ioannou (1988), the model violates the axioms of probability theory because observers have found that the model is overly deterministic. Ioannou concluded

that Friedman's model "does not produce results supported by common sense when applied to symmetrical situations" (pp. 214).

- **Linear Programming (LP)**: Pre-occupied with resolving Gates' and Friedman's models (both of which are biased to product-based estimating procedures), some researchers have developed LP techniques to Gates and Friedman's models. Examples are discussed below:
  - *Stark's* (1968, 1972, 1974) *Model:* Stark and Mayer's (1971) approach focuses on resource-based procedures by using linear programming. The authors developed a predictive instrument for determining how a winning bid can optimize expected income per unit time. In place of Friedman's probability density functions (PDFs) approach, Stark and Mayer adopted a logarithmic normal density (LND) approach and Lagrangian's formulation model (Hanssmann and Rivett (1959) and Sakaguchi (1963)). Reasons for this swap include (1) that estimating and bidding environments are dynamic, and (2) that sourcing data to facilitate workable PDFs is cumbersome.

    In Rothkopf and Harstad's (1994) critique of Stark's model, over-generalization was identified as a problem. This is because the model was developed for highway construction contracts using data from timber project bidding. Thus, researchers and contractors appear to be reluctant to risk applying the model outside the environment where it was developed.

  - *Ashley and Teicholz's (1977) model:* This model seeks to determine how cashflow can be manipulated through estimation and taken advantage of during post-tender situations. To achieve this, Ashley and Teicholz defined three forms of cashflow curves:

    (1) the *Earning curve (E_c)* to express contractor's *work-in-place* cash – the actual component of a project already completed as described in BoQs;

    (2) the *Payment curve (P_c)*, which takes the form of payment mechanisms and the residuality of income, including un-liquidated works, deductibles (e.g. retentions, set-offs and tax adjustments) and the variability of net payment value (NPV) (both at valuation intervals and for discounting the

time value of money i.e. between the time an estimate is finalized and the time payments are due);

(3) the *Cost curve (C_c)*, which is used to evaluate the relationship between actual progress made on contract works and expenditures. This curve can be replicated for cost sub-elements such as plant, material and labour resources, overhead and profit.

Ashley and Teicholz (1977) conclude that *Net Cashflow* (NC) is the difference between *Payment Curve* (P_c) and *Cost Curve* (C_c). To determine the real value of NC, it must be converted to Net Present Values (NPVs) using the expected *Rate of Return* (RoR) of the contractor and the *Cost of Finance* (CoF) as positive and negative discounting factors respectively.

Where commercial benefits to the contractor are indicated, a thorough evaluation of strategies for profit maximization becomes expedient. In Cattell et al's (2007b) view, Ashley and Teicholz's (1977) model is a tactical approach for profit maximization, particularly when a contractor takes advantage of work items that will be executed in the contract over those that may not. The authors also argued that the model double counted by considering the cost of finance separately when cashflow had originally discounted this. Park et al's. (2005) criticism comes from a different perspective; Ashley and Teicholz's (1977) model fails to account for time lags between *Estimated Costs* (EC) and *Earned Values* (EV) of projects.

- *Yizhe and Youjie's* (1992) *Model:* This is based on Green's (1989) rationality approach to profit optimization during tender. It aims to take advantage of quantities which are incorrectly presented in tender documents. When such items are highly priced, some contractors may exploit this to maximize their income and profit. Linear programming (LP) and simple algorithm (SA) approaches were used to develop two methods for calculating estimates, tender price and project cashflow. This is done such that a simple algorithm method can be used where linear programming approach becomes unpractical.

There are some concerns about Yizhe and Youjie's (1992) Model. According to Cattell et al (2007b), this perception is only workable when variables are

continuous and not integral. In other words, users of the model face difficulty in generating reliable outcomes when variables are non-continuous i.e. when variables are defined by integers and binary attributes. Except for this, the model is practical and the simple algorithm approach stands out as novel over previous models.

- **Artificial Intelligence (AI)**: Following the approaches in probabilistic and linear programming, neither of which has been without challenges, the following researchers have shifted attention to AI.
  - *Afshar and Amiri's* (2008, 2010) *Model*: Unlike previous models, this model focuses on risks and uncertainties by using artificial intelligence. It measures uncertainties as a function of price boundary (upper and lower) limits and the variability of project attributes between 'as-designed' and 'as-built' descriptors. Apart from the black-box paradox (which means users of such tools are unlikely to know the nitty-gritty of the tool) risks and uncertainties are considered inconclusive in the model. The main drawback is that other negative parameters not accounted for cannot be jettisoned in the real world. Alternatively, Cattell et al (2007, 2010) propose another model in lieu of this.
- **A combination of Artificial Intelligence and Asymmetric Judgments**: The limitation identified in the AI approach is significant. Therefore, researchers have identified an alternative that allows estimators to combine asymmetric judgments with artificial intelligence. An example is discussed below:
  - *Christodoulou's model:* Christodoulou's (2004, 2010, 2008) model introduces a new approach to modelling pre-construction estimates. The author used entropy, a disorder phenomenon, to measure the upper and lower limits of mark-ups when certain attributes of risks and uncertainties of a project are defined. In a similar pattern to Skitmore and Pemberton's (1994) model, logarithmic functions were used to formulate a band of financial entropy. Although Christodoulou relied on similar previous work by Choi and Russell (2005) to establish a relationship between financial risk, entropy, bid-unbalancing and profitability, it is unclear how entropy quotients correlate with a contractor's chances of fulfilling business interests i.e. winning a bid and making profit.

To summarise the existing knowledge on pre-construction estimating through bid unbalancing, there are several lessons to be drawn from the aforementioned models:

- The construction industry has a unique culture of estimating. A bid, whether it is called an estimate or a tender price, encompasses several variables. Rather than an assumed meaning of the potential construction cost of a project, defined by resource costs and overheads, users of estimate data are subject to the complexities in contractors' business interests. An estimate that appears to be aboveboard may bear no relationships to either actual production cost (i.e. contractor's budget) or contract prices (i.e. clients' budget).
- Industrial psychologists have explored the factors influencing how estimates are developed and marketed. For example, see the work of (Skitmore and Smyth, 2009) and further contextual explanations in Chapter 3. Discussions on the above-mentioned models show that estimators in different practice domains have different purposes they intend to achieve with their estimates (cf Fine (1974) and Akintoye (1998)).
- In addition to procedural and mathematical errors, and other factors such as validity and the ability to generate workable outcomes, these models are also vulnerable to macro-economic influences (Baloi and Price, 2003, Olatunji, 2010c).
- The overarching issue is that whichever option is chosen to balance or unbalance a bid, there has been a consistent progression towards IT in recent years to improve estimating processes and outcomes. The impact of CAD and BIM on this is explored in Chapter 5.

Tender Action and Estimating

From a clients' perspective, whether bids are superficial, balanced or unbalanced, they cannot be adopted automatically until the end of tendering process. Usually, at this stage, bids are re-checked and compared to clients' price benchmarks. This may appear to be a simple arithmetical procedure. Clients and their agents often strive to determine how each bid was arrived at and the implication this will have for their goals and cashflow. When necessary, errors need to be corrected and prices negotiated between the potential primary parties to the proposed contract.

Several steps are involved in concluding a bid prior to construction. These are summarized by Brook (2008) as:

- *Prequalification:* Although this often occurs at the beginning of procurement processes to assess bidders' competence to complete a proposed contract, there are exceptions where bids are evaluated to create a balance between 'cost' and 'non-cost' parameters (Waara and Bröchner, 2006). In essence, bids are not adopted for contract implementation on the basis of price data only; rather a combination of the quantitative and qualitative evidence

of such bids are evaluated and those bidders deemed able to successfully complete the project in question are invited to prepare bids (Hatush and Skitmore, 1997, Ogunsemi and Aje, 2006). The roles of IT in strengthening prequalification procedures have been well-documented (Lam et al., 2001, Ng and Skitmore, 1995).

- *Negotiation:* Prior to the finalization of estimates and selection of contractor, there are instances where bids are negotiated. A thorough knowledge of estimating and negotiation are required (Hensher and Stanley, 2008). Uher and Runeson (1984) have documented some of the technicalities in the context of the Australian construction industry. They include deploying analytic skills and diplomacy to deal with compromises without jeopardising the interest in the project.
- Bid analyses and negotiations may result in significant adjustments in pre-tender estimates. These may result from errors or adjustments made to project documentation during the tendering process.

Tender analysis and conditions of contract

There are strict guidelines on how tender analysis and negotiations should be conducted when pre-construction estimates are being finalized. According to Marsh (2000) and Eggleston (2006), conditions of contract form the main framework for such guidelines in different parts of the world. There are several types of contracts, each with different requirements:

- In Australia, different Australian Standards on Conditions of Contracts apply; including NPWC 3 (1981), AS 2124, 2125, 2127 (1992, amended in 2000) and AS 4000 (1997, amended in 1999, 2000 and 2005).
- Other conditions of contracts that have been used internationally include
    - The Joint Contracts Tribunal (JCT) Conditions of Contract of 1998, purposed for major works in building construction.
    - The Intermediate Form of building Contract (IFC) of 1984, designed for minor works in building.
    - The Institution of Civil Engineering (ICE) Conditions of Contract of 1999 (7th edition), designed for civil works.
    - The Federation of International Council of Engineers' Condition of Contract (FIDIC) of 1999, designed for international civil, mechanical and turnkey projects
    - The New Engineering Contracts (NEC) family Conditions (NEC3) of 2005, which is targeted at main contracts, sub-contracts, minor works, professional services, termed services, adjudicators' services and framework contracts.

- Form MF/1 Revision 3 of 1995, designed for specialized projects involving a high degree of sophistication in Mechanical and Electrical Plants contracts.
- Family of Government Contract Forms of 1998, designed for the construction of Process Plant.

All these Conditions of Contract advise clients to re-check all tenders for errors and ambiguities prior to initiating a contract.

Challenges of IT in estimating

The theory and practice of pre-construction estimating is subject to human judgment. Formulating contract conditions, adjudicating bids, setting qualification criteria and mapping appropriate construction processes from a pool of bids all require humans to exercise their judgement. There are core estimating parameters that are difficult to obtain through parametric actuation. For example, using CAD and BIM tools, it is not possible to automatically make accurate provisions for cost components such as contingencies, preliminaries, provisional sums and prime cost sums because these rely on well-considered procedures including:

- Contingencies: These are monies set aside for unforeseen circumstances. There are different approaches to accommodating contingencies in different practice domains. For example, when resourcing and estimating work items, contractors often make deliberate allowances such as catering for unforeseen circumstances. Clients' perspectives are different from this; they rely on intuition and / or historical data and market surveys (Sinclair et al., 2002). To these, they add a fixed percentage or a lump sum as contingency monies. Akintoye and Fitzgerald (2000) and Harris et al. (2006) acknowledge that historical data are the most popular approach to estimating. These data may already contain some activity-based allowance for contingency. When additional provision in the form of percentage additions or a lump sum is made, provisions made by clients for contingencies may result in a multiplier effect with double counting of these allowances.

  Arguably, it is possible to automate how the figures play out. However, it requires sound professional judgment to initiate the parameters for engineering the data to cater for this. Regardless of the power of simulation and virtuality, it is practically impossible to predict unforeseeable events in construction (Ogunsemi and Jagboro, 2006).

- Preliminaries are provisions made for general items. General items are cost-tangible items that relate to an entire project without being limited to specific trades or sections of the project. They include water for works, site security, and storage and site offices. These items can be related to time (e.g. insurances), be specific to construction methods (e.g. scaffolding and material handling) or fixed expenditures (e.g. approval levies and copyright permissions).

  There is a wide range of approaches to estimating contingencies e.g. provisional calculation of measurable parameters, the use of a fixed percentage on the entire project and a lump sum approach. Of these, Babalola and Adesanya (2008), and Babalola and Aladegbaiye (2006) have argued that fixed percentages and lump-sums do not reflect the monies to be expended. Rather, individual preliminary item can be measured, provisionally or otherwise, and re-evaluated during construction.

  Irrespective of the level of sophistication in designs, it is not yet possible to provide definitive information on designs in regards to what should or what should not constitute preliminaries. Thus, the judgment to be made on these during estimating is not fixed on what is visible on drawings, rather contractors' imaginations on how the construction methods they have chosen method is most favoured.

- Provisional costs are budgetary provisions made for items for which definitive information is not available when the estimate is being prepared. These items may be presented conceptually on drawings but they are subject to change during construction. As such, it is insufficient to merely export the inconclusive descriptors of such objects from CAD or BIM and apply cost superficially; estimators must portray adequate understanding of the situation in which cost is applied to such items.

  There are several options in IT-assisted decision-making during estimating for provisional items e.g. by using regression models and by adopting some automated procedures that rely on trusted databases. As argued earlier in the first two points above, each construction project has unique attributes that may not relate to other projects. Such discrepancies vary in size and experienced estimators will make careful judgments about provisional costs on a project-by-project basis.

- Prime cost items are components of a project for which the main contractor may not be liable. They are items to be executed by a nominated supplier, specialist or subcontractor.

Traditionally estimators of prime cost items follow any of the estimating methods already described above (see Tables 2.1 and 2.2), however such estimates are often treated specially, There are at least two perspectives to this:

- Contractors' estimates are based on their potential commercial interest on the whole project. When a part of such items is prime-costed, such contractors' potential profit may be affected significantly. Consequently, there could be a need to review this consideration for non-prime cost items.
- Based on the point above, clients may compensate main contractors by granting them general and special attendance costs as well as profit on prime cost items. It is the prerogative of clients to determine the nature of these considerations and the form they should take.

The dynamics of prime-cost estimating are soft in nature. They are thus difficult to simulate or automate. Estimators therefore generally evaluate them manually.

In summary, it is evident in the review above the there are several stages in pre-construction estimating. Although, considerable research has explored how estimates are arrived at, it is also evident that IT-assisted automatic estimating is subject to several parameters. Many are under-researched, including:

- Estimating is a vast discipline of practice within which there are different domains, each with distinctive business behaviour models. These include clients, contractors, consultants or integrated project delivery organizations (Chapter 3):
  - It is impossible to generalize views from all of these domains to form an accurate reflection on the impact of IT or process improvement.
  - Estimating outcomes respond to project type (e.g. building, civil and engineering projects) as well as to project size and complexity. On a generic basis, IT-assisted procedures have delivered on some of these challenges. However, it is impossible to conclude that deploying IT tools automatically results in accurate pre-construction estimates.
- There are systemic or cultural issues around competition and allied challenges (e.g. bid qualification, bid-cutting and deliberate manoeuvring) that affect the goal of estimates:
  - Skitmore and Wilcock (1994)have argued that estimators target to win bids rather than projecting the actual estimate.

- The term ‘actual estimate’ is not interpreted in the same way by all potential parties to a proposed project. The core of this issue is not in the definition of the term; rather, it is a question of the relationship between ‘reasonable disclosure’ and ‘realistic expectation’. For example, clients reasonably expect contractors to declare all costs to them via their estimates. However, it is unreasonable for contractors to indicate items in an estimate for which costs will not be incurred to them e.g. rebates, cash discounts, commissions, compensations and a budgeted-for but non-occurring float.

- Tender analysis and negotiation create the decision point for definitive mindset on an estimate. No doubt, IT facilitates rigorous data analysis; however it takes reasonable human judgement to supplement this.
- Some variables are not predictable during pre-contract estimating e.g. macro-variability and latent risks to which the project is liable. As well as manual judgment, IT has no definitive answer to these.

This section has reviewed the power of IT to overcome the barriers to efficiency and performance in estimating practice. Estimators have deployed several IT innovations to automate decision-making in the course of pre-construction estimation. With artificial intelligence and data integration in parametric design platforms, estimators have progressively overcome the limitation of human judgments (e.g. errors and subjectivity). However, these advances are not final solutions in themselves; reasonable human actions are still required. The overarching question prompted by this is how estimators specifically deal with CAD and BIM in the light of this knowledge.

In Section 2.3.4, estimating activities during the **Construction Phase** are reviewed. The section continues to delineate the different views on how the value of work done is estimated during construction and how the respective parties determine appropriate approaches.

2.3.4 Estimating During Construction

The actual costs of a project are only known when the final account is settled:

- There are instances where pre-construction estimates are inconclusive before construction commences. In such circumstances, it is expedient to estimate the value of work done as the project progresses.
- Where pre-contract estimates are definitive before construction, depending on the nature of the contract, it is in the contract parties’ interests to control and manage costs during construction.

Invariably therefore, estimating and cost control do not end with pre-construction estimates. Periodically, the value of work completed on a project is quantified and documented in line with the conditions of contract. Like previous phases, the worth of work done during construction is estimated from different perspectives. For clients, the target is to monitor the outlay and management of financial capital in line with budgets. For contractors, the goal is to concentrate on stabilising cashflow, managing risks and controlling production costs.

Some instruments have been reported in literature concerning estimating procedures during construction. They may be grouped under four headings: (1) physical measurement and interim valuations and (2) accounts' reconciliation (3) financial statements (4) final accounts. These protocols, and how they have been re-invented with IT, are discussed below:

Physical Measurement and Interim Valuations

A significant part of estimators' duties during construction is to re-measure work items on site in line with contracted rates and schedule of basic prices. This is necessary because both the quantity of work and prices may vary from pre-contract conditions as the project progresses. Even when such change is not evident, all project stakeholders require detailed records to be kept. For example, in estimating texts such as (Ashworth and Hogg, 2007, Seeley and Winfield, 1998), it is common to find that:

- Based on the contract, clients measure the exact quantity of work done by contractors such that they only pay for actual work done.
- Where a contract price is fixed and in the form of a lump sum, the above-mentioned point does not apply.
- For a contract price is not fixed, and when rates are out-dated or revised, pro-rata rates are usually developed. This procedure is similar to the estimating procedures and business behaviours conducted during the pre-construction phase.
- Where price data are not available, e.g. for added work items, new rates are developed and the new amount generated will be added to the existing contract.

The movement of contract prices are described in literature as contract variations and price fluctuations (Ng et al., 2001, Skitmore et al., 2007a, Sutrisna et al., 2005). There are two goals in the procedures involved in estimating these:

- It is necessary that all contracted parties measure, control and manage their commitments and performance as the project progresses. For instance, it is popular that clients to

physically confirm that a project conforms to contract requirements (and additional instructions provided during construction) (Ashworth and Hogg, 2007). According to Yizhe and Youjie (1992), it is in the construction phase where project teams are confronted with the impact of discrepancies between designs and actual construction situations. Some parties are more likely to take advantage of this than others.

- Such procedures also enable clients and contractors to manage their cashflow and strategize their liabilities, earnings, real income and expenditures as the project progresses (Mawdesley et al., 1997).

For decades, valuation procedures have been manual, involving physical observation and assessment of work items as constructed. The strengths and limitations of this approach have been widely reported; the use of human intelligence to value construction products has been an advantage. However human errors and systemic problems (e.g. corruption, accidents and the time-consuming nature of this work) have presented major obstacles (Kenley and Wilson, 1986).

Over the years, computer-aided procedures have mitigated these limitations. For instance, Candy CCS™, a CAE application, possesses dedicated capabilities to measure and estimate before and during construction. Candy's procedures are semi-automatic. Furthermore, the use of laser scanning and integrated technologies such as RFIDs and remote photogrammetry has enabled access to areas where physical access is constrained. These are not only fast and accurate; rich data may be captured digitally and reports are generated automatically (Jaselskis et al., 2003, El-Omari and Moselhi, 2009, Wang et al., 2010).

Akanmu (2011) has identified the revolutionary power of cyber-physical systems (CPS). CPS is a bi-directional system that integrates physical and computational instruments to actuate automation and decision-making during construction. What this means is:

- Digital approaches to remote sensing and data capture have become popular in some quarters during construction (Di et al., 2003). With this technology, it is possible for estimators and construction project managers to obtain important information that could help them visualize and value the amount of work done.
- Computational technologies such as RFIDs and BIM are used to transmit information from cyberspace which can be translated into developments on construction sites.

- Based on the aforementioned two directions of communication (i.e. data capture on physical progress and those from cyber), it is possible to automate actions such as periodic reporting or creating alerts for scheduled target dates.
- In addition, appropriate courses of action must be initiated, including whether to approve payment or not, issues to discuss during site meeting, and health and safety issues.

Whether estimators are familiar with these systems is one thing; whether the methodologies underpinning these advancements are effective is another. For example, as information engineering is becoming increasingly digital in the industry, what are the implications (i.e. resource, skill and financial) for estimating practice? There are two perspectives to these; although the use of digital technologies for valuation is workable, its limitations are significant. Firstly, apart from the acquisition of software applications, there are few incentives for estimators to acquire and research into or use these technologies (Turner et al., 2006, Sansoni et al., 2009).

BIM is at the centre of many evolving digital technologies recently reported in the literature. Remote sensing, laser scanning and CPS have all been linked to BIM (Penttilä, 2007, Eastman et al., 2008, Hijazi, 2011). The second perspective to the advancements offered in these evolving technologies is that of scepticism regarding their ability to deliver what is promised. For example, laser scanning is able to predict the physical composition of built items but not their strength as constructed. Moreover, although Smith et al. (2000) argue that progress on construction projects can be valued based on photographic images and a range of remote technologies, it is unclear how photographic data will reflect compliance with specified strength. Examples of the possible problems that may arise from this have been described by Fan et al (2001) and Ho and Ng (2003). These authors report instances in Hong Kong where some newly constructed facilities were demolished due to saltwater contamination, after salt water used in the construction works was undetected.

In summary, the main challenge of IT-enhanced post-contract estimation is not only whether IT-enhanced procedures are able to deliver satisfactory outcomes, but whether there is evidence sufficient to conclude that estimators have appropriate skills to take advantage of this new practice domain. At present, there is little evidence of estimators using laser scanning for interim valuations, remote sensing technologies or the whole of CPS. The reliability of these new approaches has also not been validated and integrated into estimators' practice guides.

Financial statements, reconciliation of accounts and final accounts

During construction, estimators regularly summarize and report clients' financial commitment on a project in a format called *Financial Statements* (FSs). The content of FSs often reflects direct and indirect costs on a project as well as the financial status of contract parties (i.e. to show whether any of the party has become or is about to become insolvent). This documentation is often aimed at comparing the percentage of money released to contractors compared to the cumulative value of work completed, based on the contract. Moreover, data which are incorporated into FSs documentation are sourced from various project accounts including each party's balance sheets, client's project expenditure accounts, contractor's project accounts, taxation accounts, project income accounts and sundry purchases accounts. To obtain meaningful results from each of these accounts, individual accounts must be reconciled and balanced. A procedure involved in doing this is called Reconciliation of Accounts (Palmer et al., 1995).

At the end of a contract, final accounts are issued when a project has been completed when the defect liability period (DLP) has expired. These are often aimed at showing the relationships between project budgets and actual construction costs. They also account for how floats, provisional allowances and monies set aside for contingencies and contract administration have been utilized. To date, the impact of information technology on the issuance of final accounts using intelligent IT systems is minimal. This is because this involves personal contact between contracting parties to assess the quality of the project during the DLP.

2.3.5 Estimating during operation of facilities: Post-Occupancy and Lifecycle estimating

Estimating the cost and duration of a project does not end with the **Construction Phase**. As the project has just started of its working life, it is often useful to estimate and plan for post occupancy running costs as well as maintenance and other life-cycle operations. This may be in the form of one-off, periodic and consistent operations on an annual basis (Zimring and Reinzenstein, 1980). Post-occupancy operations also include modernization, alteration works, conversions, repair works, feature sustenance efforts and rehabilitation works (Lacasse et al., 2008). Al-Hajj and Horner (1998) have modelled the cost of running a building project during the first ten years of occupation. Apart from its limited lifespan and its failure to consider maintenance attributes as a factor of running cost, other studies (e.g. Winden and

Dekker (1998)) have used similar methods, including Al-Hajj and Horner's (1998) model to estimate and plan the immediate and future maintenance costs of a construction project.

Modelling lifecycle costs and post-occupancy budgeting has attracted attention in the construction literature (Flanagan et al., 1987, Flanagan and Norman, 1993, Flanagan and Jewell, 2005, Redmond et al., 1997). However, Al-Hajj and Horner (1998) have questioned the accuracy, reliability and effectiveness of these models. This is because both the physical and economic attributes of these models are susceptible to the impact of nature and macro-economic variabilities, respectively.

A way of overcoming these constraints has been summarized in some recent studies as deploying robust and flexible price indexing methods and using artificial intelligence to model maintenance and life-cycle management activities. In Lin et al's (2003) perspective on deploying artificial intelligence for building automation systems (BAS), adequate understanding of the deliverables of integrated project delivery system (IPDS) has been shown as a reliable vehicle for the much needed change from the problems of fragmented procedures. In Section 2.2 existing estimating theories were shown to be biased in favour of stand-alone solutions. It is worth examining the impact this will have on BIM as an integrated platform and vice versa. This helps to know whether manual data moderations are necessary in BIM or if estimates can be reliable when generated from BIM automatically, regardless of the shortcomings in BIM models. Chapter 6 discusses whether by default or by a dedicated course of action, integrated estimating methods or procedures are evolving in the context of these technologies such that they can be theorized across the different practice domains in the estimating discipline.

Moreover, although traditional construction procedures are fragmented and the knowledge of project teams on maintenance issues is often insufficient, recent studies have reported breakthroughs on the applications of digital technologies in facilities management using BIM (Ballesty et al., 2007, Lundgren and Björk, 2004, Olatunji and Sher, 2010b). In terms of large scale adoption and industry-wide understanding of these applications, some of the findings in these studies are yet to be validated. However, through various functions (including virtual prototyping, mapping and the generation of auto alerts and automated reports on the timing of maintenance actions) (Luciani, 2007), this is gradually becoming increasingly possible, even during the early phases of the lifecycle of a project.

2.4 CONCLUSION: A SUMMARY OF THE REVIEW ON THE IMPACT OF IT ON ESTIMATING METHODS

It is clear from the discussions above that different estimating practices are deployable at different phases of the lifecycle of a project. Although most studies on this subject are fragmented, some of the arguments presented above have indicated that recent advances in digital technology have made integrated estimating practices considerably easier, and have resulted in more valuable outcomes than manual methods. Table 2.2 (see Appendix 1) provides a list of estimating methods and models for each construction phase, domain of use and how they are applied. This table includes updates on the work of Skitmore and Patchell (1990) and Cheung (2005).

From the barrage of criticisms on existing estimating methods, there is still a popular view that pre-construction estimates are rarely a 'true' image of the actual construction cost. The question is not whether estimators are responsible for this, but whether design, construction and facilities management industries have the ability to deal with the issues of cost variability. The impact of BIM is yet to be established. Several reports, including Skitmore (1991), have acknowledged the need to act fast. Another example is Gray's (1996) response to the Latham Report's (1994) challenge. The author suggested a revamp of estimating methods and process control tools. Many reasons have been listed on why this is difficult to achieve:

- *Quantification and assessment methodologies*: measurement methods are often encumbered by inefficiencies such as errors, ambiguities, misinterpretation, omissions and conflicts of interest (Morledge and Kings, 2006, Rosli et al., 2006). Are automation platforms in BIM able to resolve this? Chapter 5 addresses this question.
- *Pricing dynamics and techniques:* market forces are dynamic. Thus, cost indexing has been difficult to predict over a substantial length of time (Olatunji, 2010b, Akintola and Skitmore, 1990). Moreover, while the main focus of an estimate has been to predict and control *product price*, competition and market dynamics have often forced contractors to hide the 'real' *production costs* (Bennett et al., 1979, Sinclair et al., 2002, Skitmore and Wilcock, 1994). Object-oriented estimating, or a shift to estimate presentation by way of process modelling, is a potential solution. This is discussed further in Chapters 5 and 6.
- *Practice technology:* Digital technologies have not remained static in the estimating industry over the past decades. Evidence from previous studies has shown that many estimators are still reluctant to deploy digital innovations (Best et al., 1996, Lowe and

Skitmore, 1994, Ogunlana, 1989). The new procedures and their impact on estimating cultures have not been reported in either practice guides or contemporary theories on estimating practice. This gap is discussed in Chapter 5.

- *Professional ethics*: In two recent surveys by Poon (2003, 2005), the frequent denial of fault is identified as the common misconduct of construction professionals. The author identified conflicts of interest, family and work-place influences as possible problems with young estimators. Ray et al.(1999) have articulated some serious ethical concerns in the procedures of estimating and tendering in Australia. Perhaps as a panacea, is BIM a new professional 'demand' for estimators where technical issues encumbering professionalism in estimating practice are resolved? The future of estimators in BIM is an open question; some conclusions on this are drawn in Chapter 6.
- *Organizational influence*: estimating services are widely utilized in the construction industry. In many instances, estimators' dilemmas are not limited to the difficulties in their professional assignments; they may also be required to favour certain business interests of their employers. The consequences of this can be grievous, and Ray et al (1999) described this as *amorality* in construction business. Further evidence in more recent studies shows that this type of influence is a popular business practice in the construction industry. As argued in Section 2.3.3, *mark-up loading* is a widely accepted practice and is frequently affected by business ideals of estimators' work environments (Cattell et al., 2010, Rasbash, 1991). The influences of organization models on estimating procedures are discussed in Chapter 3 and Chapter 5.

Despite all of these challenges, IT innovations have continued to grow and thrive in certain aspects of estimating practice; particularly the pre-contract phase. Since the 1980s, many Australian estimating companies have used CAAD-generated drawings as the basis for measurement. Although, there are instances of reluctance and complementing manual procedures with CAD (see Best, 1996), substantial evidence suggests that Australian estimators have had a good understanding of how to deal with CAAD; and this has progressed with transitions in CAD regimes from non-parametric to parametric paradigms.

Furthermore, there are several documents (including the Chartered Institute of Building's *'Code of Estimating Practice'* (2009) and the Australian Institute of Building's *'Guide to estimating practice for building work'* (1995)) which provide detailed guidance about preparing estimates and tenders (before the construction phase). Additionally, there are guides on quantity surveying practice before, during and after construction phases (Cartlidge,

2006). In all of these guides, discussions on the varying impact of IT, particularly electronic estimating processes with CAD and its derivatives, are limited.

This does not mean that contemporary estimating with CAD or BIM is merely a replication of manual procedures. Even if this was so, such nuanced procedures need to be theorized appropriately. In the light of CAD and its derivatives changing the face of information utilization in the construction industry, Chapter 3 argues on the relationship between organizational behaviour and estimating outcomes. The particular emphasis of Chapter 3 is to strengthen the framework for the existence of multiple views regarding estimating processes and outcomes across the various business domains in the construction industry where estimation is a core function. Following this, Chapter 4 reviews BIM deliverables in the context of estimating and construction management.

3 ORGANIZATIONAL BEHAVIOUR AND ESTIMATING PRACTICE

3.0 ORGANIZATION BEHAVIOUR AND ESTIMATING PRACTICE

3.1 INTRODUCTION

Construction businesses are under immense pressure to work with BIM. According to Waterhouse (2011), the Chief Executive Officer of the Royal Institute of British Architects (RIBA):

> *"….BIM will have an impact on most areas of* ***business management and operation****. It will revolutionise methods of working and fundamentally redefine the relationships between construction professionals* (businesses, stakeholders). *It will challenge* ***current thinking on contracts*** *and insurance and most importantly, it will* ***support the integration*** *of the design and construction teams. …There are distinct areas of expertise developing in many organisations and* ***they are already challenging current methods of working****. However, there is a risk that many others will be left behind as other organisations fail to achieve the returns required for investment in both technology and training."* (pp. 3 (emphasis added)

In this chapter, the characteristics of different types of organizations are used to explain the different views on estimating practice and their relationship with BIM. The relationships between business behaviours, BIM and estimating serve specific purposes in process re-engineering. The underpinning view is that the manner of process re-engineering as implied by the introduction of BIM requires the restructuring of business practices. As discussed in Section 4.3, BIM encourages disciplines to integrate their efforts and change their business behaviours. These developments result in different domain-specific views about estimating procedures and outcomes. Thus, it is crucial to map-out the theoretical framework for understanding each practice domain, focussing particularly on the changes triggered by CAD and BIM.

As argued in Chapter 2, construction estimates reflect the cost implications of the business intentions of the parties in a contract. Invariably, business interests occur in different forms, each of which has richly nuanced behavioural patterns and different roles that estimators play in them. For example, conventional texts have often categorized contract actors as clients, contractors and consultant (Carolynn et al., 2000, Cheung et al., 2008, Kometa et al., 1994, Mills and Skitmore, 1999, Sebastian, 2011). According to Olatunji (2011a), it is grossly inadequate to categorise business interests as simplistically as this. This is because there is no clear delineation between these terms. For instance, a contracting business could be a client to

a consulting company, and a client to their suppliers and subcontractors. Thus, the term 'client' can conveniently mean a party who owns a project as well as a contractor, to whom some other actors (suppliers, subcontractors and consultants) are answerable. Similarly, a corporate organization, consultancy or a contractor could provide specialized integrated services as an integrated project delivery (IPD) business. It is thus confusing to categorize these organizations as IPD businesses when they may not all be wholly responsible for such projects.

To avoid this confusion, the behavioural patterns of construction businesses and their approach to estimating can be understood by their business structures rather than by their size (e.g. large, medium or small) or by their business outcome (e.g. whether they are wholly or partially responsible for overarching business outcomes). According to Price (2007), all business entities have specific structures which influence their approaches to estimating outcomes. Even when individuals are construction contract actors, project organization theorists repeatedly refer to these as a simple form of organization-type business identity (Oakley, 2001, Reeser, 1969, Lindkvist, 2008). Thus, individuals' actions in construction contract environment are seen in the form of business behaviour rather than being a form of simplistic behaviour.

According to Davis et al. (2009a), about 95 percent of the Australian construction industry is made up of small and medium scale businesses. Data from the Australian Bureau of Statistics (ABS) show that these small businesses currently have over one million employees and have consistently added an average of 7,200 jobs to the economy every quarter in the past six years. Further evidence from ABS data also shows that after retail businesses, the construction industry provides the highest number of jobs in Australia through its small-scale businesses. Invariably therefore, construction businesses, their profitability, their strength to sustain growth over time and understanding of change effects that could affect their prospects, are critically important to the Australian economy at large.

To put this in context, all construction businesses prepare estimates, and they need to understand the impact of changes to platforms underlying project development in their businesses to remain competitive. As indicated in Section 1.2, design platforms underlying project development have changed significantly in the past decades, from manual to CAD, and from CAD to BIM. Construction businesses view these changes differently; and their perceptions of estimating practice and procedures differ as well (Skitmore and Smyth, 2007).

More importantly, estimating practice extends beyond a superficial conceptualization of individuals' views and behaviours. It encompasses a combination of strategic organizational procedures that are targeted at specific outcomes (Harris et al., 2006).

In the following sections, existing theories regarding organizational structures, and their impact on corporate outcomes (e.g. service delivery, commercialization and performance frameworks) are explored:

- In Section 3.2, the relationship between construction business structures and estimating practice concepts are described.
- Section 3.3 reviews practice change in the context of organizational management theories, while;
- Section 3.4 presents agents of change in CAD and BIM and how they apply to organization structures.
- In Section 3.5, a summary of the impact of organization structure and estimating practice, vis-à-vis strategies for transitioning into BIM compliance.

3.2 CONSTRUCTION ORGANIZATION STRUCTURES AND ESTIMATING PRACTICE

Estimators are used ubiquitously in dissimilar construction businesses, by project owners, by contractors, by public regulators, as consultants and as a major stakeholder in specialized project delivery (Sakal, 2005, Poon, 2003). In several studies, the skills that enable estimators to work in such a wide range of business domains have been elicited (Nkado and Meyer (2001), Odusami (2002), Fellows et al. (2003)). These include analytic, quantitative, communication and leadership skills. Invariably, across dissimilar business domains, these skills are applied in different ways to achieve the specific business goals of the employer. These goals have been described in Chapter 2.

Most conventional texts often align estimating procedures with a single line of command. For example, Brook (2008) and Ashworth and Hogg (2007) describe estimating procedures in the following way:

- Estimators work in teams to measure quantities from drawings
- Outcomes of quantity measurement may be transmitted to another team for estimation
- Finally, estimates are converted to tender by a management team

This does not occur in the same way for all construction businesses:

- Some organizations are structured to have fewer estimators such that the hierarchy of responsibilities described above does not apply. For example, estimators in client organizations or consultants for project clients mostly rely on historical data; they estimate by applying past contract prices. Consequently, the line of command could be:
    - shorter i.e. involve fewer estimators to ensure strict protection of data (Cummings and Worley, 2009, Hitt et al., 2011)
    - singular (i.e. project estimation only) or double (i.e. project estimation and other functions in business management (Price, 2007, Tiwari et al., 2007) ,
    - within one level of authority (i.e. can be transmitted directly to the client once an estimator has measured quantities of work and applied cost data) (Skitmore and Smyth, 2009).
- Estimating practice in these organizations goes beyond estimating costs, and may include:
    - Risk management (Akbiyikli and Eaton, 2004, Flanagan et al., 1987, Flanagan and Norman, 1993).
    - Project leadership (Fellows et al., 2003, Nkado and Meyer, 2001, Oke and Gbadura, 2010, Sutcliffe, 1999).
    - Dispute management (Younis et al., 2008)
    - Business management (Frame, 2002, Weske, 2007)
    - Contract administration (Bello and Odusami, 2009, Liston et al., 2007, Skitmore and Patchell, 1990)
    - Other management needs that are specific to organizational needs (Weske, 2007, Zarkada-Fraser and Skitmore, 2000).

As a result of the above, it is superficial and inaccurate to refer to project estimates as the only outcome of estimating practices. Estimating outcomes relate to business structures

through estimators' skills. Examples of structural identities of construction specific businesses have featured in several past studies (Walker and Ruekert, 1987, Dandridge et al., 1980). These authors and other recent theorists on the subject of construction business systems (CBS) (e.g. Gann and Salter (2000), and Reeves (2002)) have explored various patterns of business formation and commercial outcomes in the construction industry. Evidence from these studies suggests that construction businesses share tangible relationships extrinsically through their structural models.

Furthermore, there is significant evidence to suggest that technology plays a critical role in the ways businesses are structured (Weske, 2007). Digital technologies have had a marked impact on business structure and metamorphosis (OECD, 2004). Furthermore, organization structures have been modelled by:

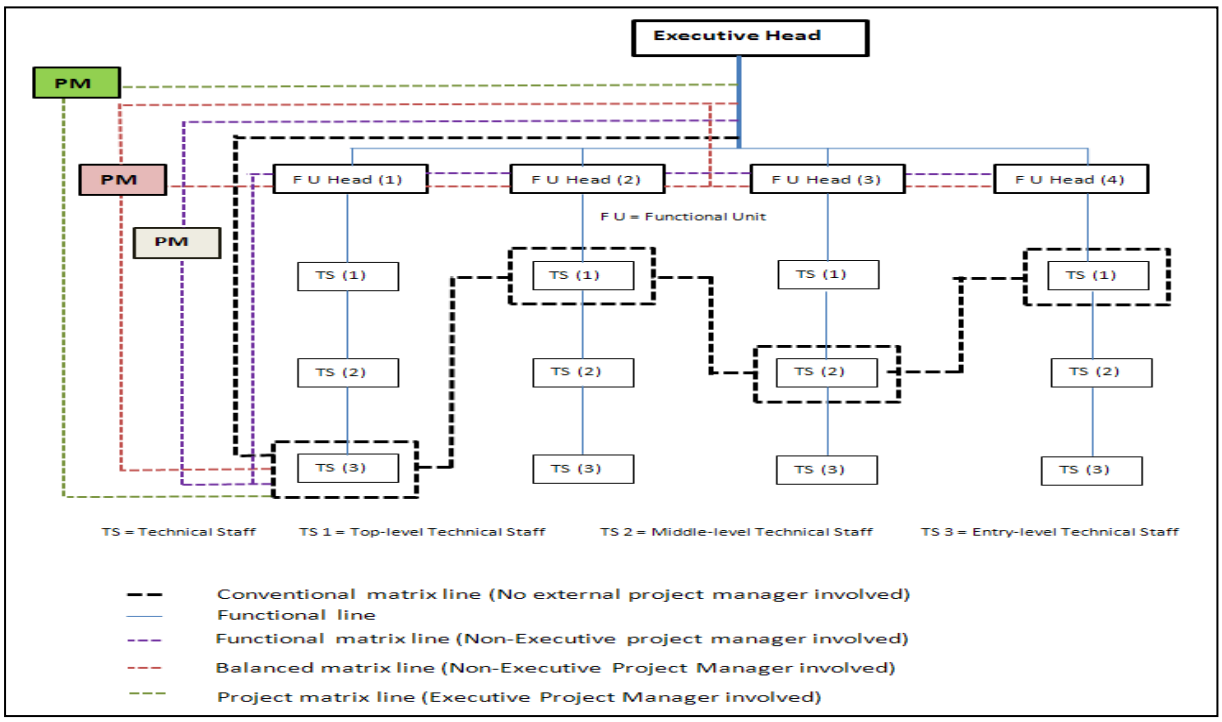
- *architecture* i.e. how resource parameters are arranged e.g. fragmented, semi-integrated or fully integrated (Tiwari et al., 2007, Walker and Ruekert, 1987).
- *the control and flow of authority* i.e. how co-ordination and leadership roles are performed e.g. active or passive, emergent or discretionary, top, medium and bottom level separation of power, the culture of incentives and motivations (Sutcliffe, 1999).
- *fluidity* i.e. how business structures respond or adapt to change situations e.g. mobility, ease of transformation, interdependencies, formalization and approach to contingencies (McKelvey, 1975)

How these apply to construction businesses and clients is explained in Sections 3.2.1 to 3.2.4. These sections describe how the formulation of each business model affects estimating outcomes. In all, four business models have been identified to showcase different domains of estimating practice (viz. matrix business model, divisional business model, function-unit practice model and networked business model). This study does not classify estimators' practice domains according to whether they are client's or contractor's estimators as these perspective are controversial (Mills and Skitmore, 1999). Instead, a generic view of the business models under which estimating practice domains operate is discussed.

3.2.1 Matrix structured Practice model

There are two directions of authority in every matrix: the vertical and the horizontal hierarchy. Conventionally, organizations are made up of functional units, which always appear in a vertical top-to-bottom arrangement. When projectized (i.e. set to achieve

projected goals), multi-disciplinary teams are formed to overlay the *"traditional hierarchy by some form of lateral authority, influence, or communication"* (Kuprenas, 2003: 51). Thus, two lines of command have been created, the first being the original intra-disciplinary line, and the other being the multi-disciplinary, projectized line of communication (See Figure 3.1 for an integrated form of different matrix models).



Note: FU stands for functional units through which businesses structure their operations.
PM stands for project manager. Each colour-coded PM tab stands for specific engagement of project managers as explained under 'Forms of matrix model'

Figure 3.1: Matrix Structure Model; adapted from Knight (1977) and, Larson and Gobeli (1987)

Vertical and horizontal lines are used in Figure 3.1 to show the different directions of the line of command in matrix business models. The vertical lines typify the traditional hierarchical flow of authority through the organizational function units (FUs). FUs are the respective departments and units that organizations are made of e.g. departments for administration, maintenance and works, marketing, research and development, and so forth. Each unit performs discipline-specific functions, only a few of which can be construction-related.

Moreover, in most cases, all workers are expected to work in teams to implement organizational goals, whether they are related to construction projects or not. The line of command across different functional units is represented in Figure 3.1 as horizontal lines. Where organizations focus only on construction business, they exhibit divisional business structure (as discussed later in this section).

To put this in context, matrix models usually represent clients' perspective to construction project implementation and governance. It is popular amongst public and private client organizations to have in-house units, amongst other disciplines, to oversee their construction projects. Such units relate with other units in the organizations as and when necessary. Where an organization does not have such construction-skill-related units or some of the necessary construction skills are not present in their construction FUs, project teams are formed by reinforcing existing units with the required skills, or new units are outsourced. Whether such units are outsourced or not, there is yet another perspective; project managers can be used to oversee project implementation. Where a project manager is not used, each functional unit in the project team relates directly to the client. Where such fragmentation is minimized by the use of project managers, there can be two perspectives viz. project management roles with or without executive powers. The different scenarios of project management have been coded in different colours in Figure 3.1 and expatiated further under the heading 'Forms of matrix model'.

The scenarios described above are common to construction project governance. In all situations, clients require estimators to work on construction projects, and where applicable, carry out other functions in team environments whether such is related to construction or not. Moreover, with or without using in-house or outsourced project managers, BIM plays a significant role nowadays in how teams work together on project implementation. Rather than individual decisions, clients, and perhaps project situations, determine whether BIM will be used at any stage of a project or not. There is adequate evidence in the literature to conclude that the business scenarios where BIM is used on a project is different to conventional approaches in other design forms such as GDO CAD (see Section 4.2). Similarly, estimating methods in BIM and business conceptualization for BIM implementation are also different. To achieve desirable project (and business) outcomes with BIM, the following objectives will have been met:

- *Estimators and Teamwork:* As shown in Fig 3.1, project teams are formed and are meant to interrelate through horizontal lines of command. A line of command for project implementation relates to organizational management through unique vertical functional lines which are different from conventional hierarchical flow that has existed in the organizational system. Thus, team members have two lines of bias viz. their functional lines within the organization, and, the project lines (Asopa and Beye, 1997).
- *Lowering social costs of fragmentation as against equality and integration:* When project teams are formed, emphasis is on collaboration and value sharing, even though each member is required to provide specific technical services. This phenomenon of inclusion has been a long-standing motivational factor used by many organizations to improve employees' reliability and productivity (Perry and Porter, 1982).
- *Multi-skilling through collaboration:* Collaboration is a unique experience for employees as it aids knowledge transfer (Tsai, 2001, Lowe and Skitmore, 2007). In several recent studies, it has been suggested that estimators in this kind of organizational setting are exposed to a mixture of roles, including regulatory, administrative and technical roles (Glick and Guggemos, 2009, Hensher and Stanley, 2008, Zarkada-Fraser and Skitmore, 2000).
- *Co-ordination:* co-ordination and leadership are a sensitive issue in organizational science (Sutcliffe (1999)). With team clusters in matrix organizations, employees may be exposed to co-ordination leadership skills.

How do these aspects affect estimating practice? Teamwork and collaboration are critically important business behaviours nowadays. Estimators are expected to work with their colleague-estimators and other professionals, and non-professionals alike, to deliver workable project outcomes. Invariably, there are several perspectives to estimating, teamwork and collaboration in a business environment. These are:

- Collaborative outcomes supersedes individuals' or disciplinary views (Ingram et al., 1997)
- Intra and inter-disciplinary collaborations are not the same; the former is biased to a functional line of command, the latter is based on objectivity, value sharing and characteristic procedural practice (Kuprenas, 2003, Reeves, 2002).

- Similarly, intra and inter business approaches to collaboration require specific business behaviours (Farmer and Guy, 2010, Zarkada-Fraser and Skitmore, 2000). For example, businesses employ specific approaches to protect data from fragmentation e.g. it could be their knowledge strength and strategic identity. However, during collaboration, these data may have to be shared with other team members. The motivation and consideration underlying collaborative behaviours therefore require some characteristic interpretation by the individual discipline involved. Depending on project scenarios, such interpretation includes creating appropriate legal frameworks and the parameters for such collaboration.

<u>Forms of Matrix Models</u>

Three types of matrix model structures have been identified where estimating practice is paramount:

1. *Functional matrix model:* According to Larson and Gobeli (1987), in this model, employees (estimators and other technical service providers) are more answerable to their line (functional) manager(s) than the project manager (PM) where the role of the project manager is non-executive. Walker (2007) has documented the difference between the executive and non-executive roles of PMs (this is the functional line coded in pink colour in Figure 3.1). Literally, executive powers allow PMs to influence team formation and project outcomes; taking on non-executive roles means their roles are limited to nominal functions. As clearly illustrated by Levy (2011), project managers' lack of executive power in functional matrix model's scenarios creates a gap in their ability to control project resources and outcomes.

   Given the control gap in functional matrix model arrangements, coordination in this form of project organization is often slow and problematic. This is because executive powers are retained in the functional units (i.e. rather than the PM, the leadership role is performed by one of the original units within the organization that the team members were sourced from). The overarching justifications for this approach to project governance include:

   - to sustain bureaucratic standard and control (Griffith, 2000)

- to control information flow and intrinsic values (Knight, 1977, Kuprenas, 2003)
- to protect the project culture against external influence (Bushman, 2007, Larson and Gobeli, 1987).

2. *Balanced matrix model organizations:* this is a re-invention of functional matrix model organizations. In a balanced matrix, project managers and functional managers share project resources and authority equally (the functional line for this is coded red in Figure 3.1). The rationale behind this arrangement is to facilitate cooperation and effective decision-making (Larson and Gobeli, 1987).

3. *Project Matrix model organizations:* In this model, the power of a project manager is more than that of a functional manager; the PM assigns resources, takes decisions and provides leadership as they deem fit (Kuprenas, 2003). This is coded in the green functional line in Figure 3.1.

<u>The connection between Matrix Models and computer-aided estimating practice</u>

The relationship between estimating practice in matrix practice environments, and intelligent and semi-intelligent project development platforms such as CAD and BIM, include:

- *Skilling:* The core competencies of estimators have been documented by Nkado (2000). However, depending on the nature of their business in any of the forms of this structural model, as much as they are exposed to construction-related assignments (i.e. in terms of regulation, contract administration and procurement management), estimators are likely to be exposed to responsibilities outside their core competency areas (e.g. IT, business coordination and administrative functions). The implication of this is that estimators in matrix practice domains are multi-skilled; they are called upon to combine management and regulatory functions as well as core estimating competences.
- *Cultural and procedural values:* As indicated above, the scope of skills required in matrix model organizations is wider than in other domains. Detailed discussions on other domains are presented later in this Section. Additionally, estimating procedures in matrix-model organizations are characterized by the following outcome-specific behaviours:

- By paying attention to widely-accepted and guided procedures that are specific to project requirements e.g. crafting contract instruments on the basis of standardized methods and objective evaluation (Davis et al., 2009a).
- Estimating outcomes are strengthened considerably by openness and accountability e.g. fiscality and open budgetary arrangements before project implementation (Cartlidge, 2006).
- Estimating in matrix model organizations often requires the consideration of more robust parameters than in some other business domains (Drew et al., 2001). This perspective has been evidenced in the numerous examples of special project vehicles (SPVs) and project finance initiatives (PFIs) (Merna et al., 2010).
- Unlike other business domains where estimating outcomes sometimes takes on a marketing perspective (e.g. divisional structure domain – see Skitmore and Smyth (2009)), estimating outcomes in matrix model organizations take strict institutional and regulatory viewpoints.

- *Integration:* The nature of lateral integration in all forms of matrix model organizations encourages value-sharing and teamwork. While these skills have been the Achilles heel of conventional practice (Ingram et al (1997), Aranda-Mena et al (2008) have shown that, aside from technical competence, integrative skills are necessary for project success in integrated project delivery platforms. The question is not whether the integration style in matrix model organizations is sufficient to drive project success in such a platform as BIM, but rather whether the culture of integration in these organizations helps in transiting to effective BIM deployment. According to Olatunji et al (2010a), the advantages of this exposure are clear; because practitioners in this domain have had some exposure to integration, it is easier for them to adapt to integration-related change when the need arises.
- *Projectized estimating:* There are four modifications in matrix model organization practice domains (Figure 3.1). The conventional matrix without a project manager, and the three scenarios of project manager's involvement are colour-coded differently to represent different lines of command. These practice directions have richly nuanced implications on how on-cost and project delivery approaches inform estimates. In some cases, projects may require in-house standardization of estimating protocols; this often leads to each establishment having discrete practice guidelines. Such

procedures are likely to trigger outcomes which may be different from outcomes from industry-guided practice frameworks.

- *New horizons:* As indicated earlier in this Section, matrix model organizations expose estimators to regulatory, administrative and technical responsibilities. There are new practice horizons in each of these domains apart from estimators' core skills, including project leadership (Oke and Gbadura, 2010) and commitment to digital innovation and change management (Hardie et al., 2005).
- *Transitioning:* Change is a difficult challenge in matrix model organizations (Kuprenas, 2003). Rather than individuals' transitioning into modern practices, matrix organizations require bureaucratically controlled frameworks (e.g. legislation, new policies and robust implementation guidelines) to promote impactful change. A range of implications could evolve to estimators in the course of such change; these may jeopardize their commitment to professionalism (Poon, 2003, 2005), or lead to a crucial revamping of their conventions (Pratt, 2011). Both directions have significant cost implications while modelling change management.

The Challenge of matrix business models

The matrix model culture made a major contribution to organization science, especially in large organizations like public institutions and large private companies (for classification of organizations by size, see (Sedera, 2008). In Larson and Gobeli's (1987) research, the merits of matrix models in organizational management were identified in the aerospace industries to include integration and improvement in organizational efficiencies in project delivery. The findings of Kuprenas (2003) are more balanced. The author identified co-ordination problems, politicization, and the latent inhibition to effective integration as some of the major challenges. The study also shows that employees require training or re-orientating when they are assigned to teams.

Other studies have also shown that matrix models are susceptible to '*matrix muddles*'. Lieberthal (2004) and Schlæger (2007) define a *matrix muddle* as a counterproductive syndrome often caused by duplication and confusion when a matrix organization experiences inefficiencies in managing the flow of information within a team, and along organizational lines. The views of organization science theorists such as Asopa and Beye (1997) are such that there is yet no appropriate methodologies for facilitating thorough collaboration and value integration between actors in this model. This is similar to other studies, such as Ingram

et al.(1997) and Aranda-Mena et al (2008), where this challenge has been reported as a major inhibitor to teamwork in the construction industry. As a panacea, many studies have recommended collaborative platforms including BIM as a workable option to promote process integration (Marshall-Ponting and Aouad, 2005, Nakamura et al., 2006, Olatunji et al., 2010a).

3.2.2 Divisional structured Practice Model

Divisional model organizations, also known as 'product structure' organizations, are structured with conventional vertical hierarchical lines made-up of robust functional units. Each functional unit possesses adequate resources to exist as an independent pseudo-organization, made-up of sub-divisions to execute routine and specialized operations (Mintzberg, 1980, Miles and Snow, 1996). A typical divisional practice model is shown in Figure 3.2.

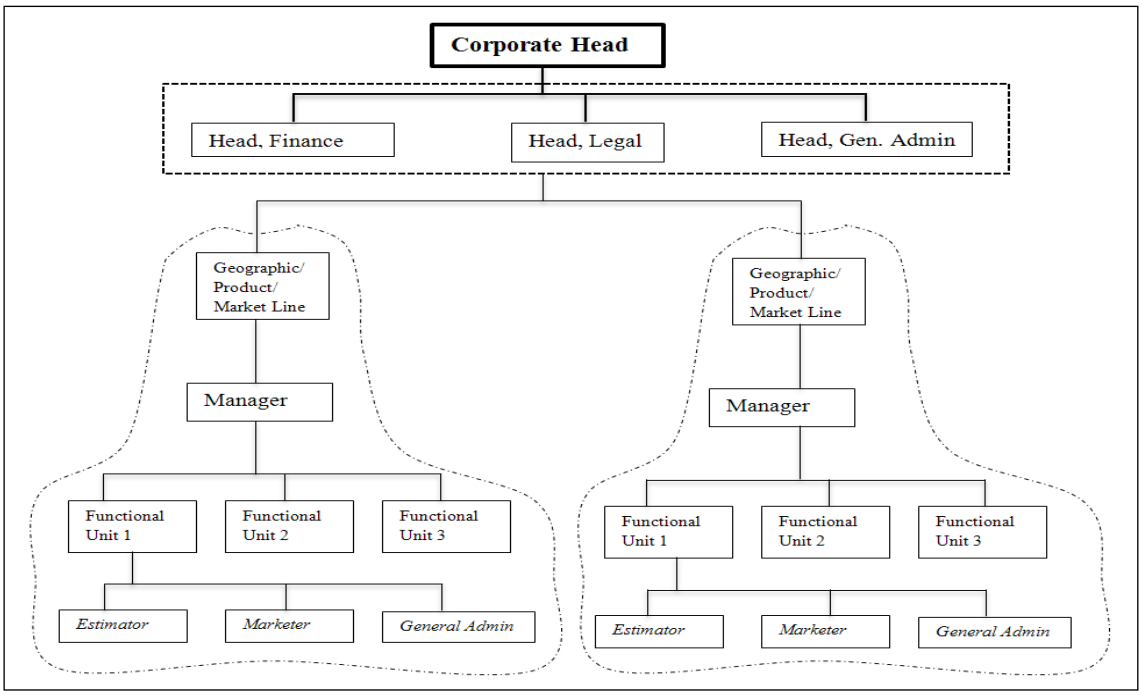


Figure 3.2: Multidivisional business model, adapted from (Bushman, 2007)

Figure 3.2 shows that each organizational division is aimed at facilitating specific corporate goals, including:

- responding to external pressures (Tenah, 1986),

- managing diversification while controlling bureaucratic costs and dealing with loss of internal control (Hitt et al., 2011),
- decentralizing decision-making (i.e. business decisions made by business units while administrative decisions made in corporate head offices) (Za´bojnı´k, 2002),
- as a strategy for multi-directional growth (Hitt et al., 2011),
- improving competitive advantage (Moseley, 2009).

Generally, divisional business models can be grouped into four domain-perspectives:

- *On a geographic basis* – i.e. representation of a businesses in different geographical zones. Australia is a federated country where different rules about contract procurement apply in different states. This, among other reasons, has prompted most large construction companies (including Hansen Yanken, John Holland and the BMD Group) to create divisions in different states and regions to access projects. Each division exists with some level of autonomy (which allows them to source and bid for jobs) while the corporate head office only takes corporate decisions (Bushman, 2007).
- *On the basis of product and service development* – i.e. a division to address each of the product domains of a company. Business opportunities in the construction industry are richly nuanced e.g. building construction, civil engineering, industrial, consulting, and stock management. Construction businesses can create divisions to harness opportunities in each of these domains (e.g. construction divisions, consulting divisions, stock management divisions) (Zott and Amit, 2008).
- *On the basis of general administration* – i.e. distinguishing between the different hierarchical levels in an organization e.g. a division for corporate management under which separate operational divisions operate (Figure 3.2) – see (Burgelman, 1983).
- *Marketing Interests:* Different marketing interests can evolve from the different products and services that a company generates. For example, building construction products can be marketed in the form of cottage, commercial and institutional domains. Similarly, civil engineering projects can be in the form of rail, road and marine projects. For each of these domains, a construction business may elect to explore opportunities with division(s) (Utterback and Abernathy, 1975, Andersson et al., 2007).

Forms of divisional structure model

On the basis of the domain perspectives above, organization scientists such as Bushman (2007) and Hitt et al (2011) have outlined different forms of divisional organization models:

- *Cooperative,* where nexuses exist across functional lines and divisional units can draw from an organization's pool of resources. Where some resources are absent in one unit or cannot be domiciled in all units at the same time, this approach provides competitive advantages. Thus, this formation enables divisional units to optimally utilize central and mobile resources while making significant contributions to the overall corporate goals.
- *Strategic business unit (SBU),* where divisional units operate moderately independently. Each unit has fairly controlled targets; while their growth may not be controlled definitively, their cashflow is moderated and only a portion of the corporate income accruing from the unit will be reverted to the Head office.
- *Competitive,* where each unit exists autonomously. Here there is limited control; growth is not controlled by a central office and the main method of performance appraisal is through a periodic appraisal of each unit's financial success.

The connection between Divisional Models and estimating practice

Estimating procedures in divisional model organizations are more pragmatic on a contract-specific basis than in other estimating practice domains:

- *Adaptive-ness:* Rather than following institutional rules, estimators in this domain concentrate on corporate specific views (Poon, 2003). Thus, they often have different interpretations of estimating parameters (such as construction process approaches and resource costs) than those incorporated in the procedures of other practice domains (Davis et al., 2009a, Sutrisna et al., 2005).
- *Marketing viewpoints:* Several marketing viewpoints about estimating outcomes exist in this practice domain e.g. to prepare estimates mainly to maximize commercial interests or just for bidding purposes or to prepare realistic estimates, at least for control and management measures (Skitmore and Patchell, 1990).
- *Ownership:* Estimates prepared in this practice domain are pragmatic; those of other domains are passive (Skitmore and Patchell, 1990).

- *Nature of robustness:* In addition to focusing on the wide range of hard parameters like the estimating approaches in matrix practice domains, estimators in this domain pay attention to soft parameters such as risks and uncertainties. They do this more than most other practice domains (Christodoulou, 2008, 2010).

Challenges of Divisional business model organizations

The limitations of divisional models in construction organizations are well documented; they include

- *Fragmentation*: Raiden et al (2008) argues that divisional business models support fragmentation. In addition, divisions may compete with each other and the skills of their workforces may be incongruent.
- *Co-ordination problems*: As identified by Miles and Snow (1992), a lack of motivation to collaborate in external environments and frustrations arising from internal crises are additional issues.
- *Temporariness of business relationships*: Contractors' business relationships with clients are generally short-term. To a large extent, their business strategies for such scenarios are contract-specific; and this is often reflected in how they estimate and execute projects (Skitmore and Smyth, 2009).

There is more to these challenges when viewed from specific project perspectives. Integrative platforms such as BIM potentially present attractive prospects in overcoming some of these limitations. Particularly, the impact of BIM on facilities management and project lifecycle modelling is such that model data (e.g. cost, descriptive and graphic data) and input from constructors are valid as long as a project exists (Olatunji, 2011c). This is not usually the case in fragmented situations. Moreover, several case studies about organizational responses to BIM have been documented as well as how project implementation has benefited from organizations' transition to integrated platforms (see (Olatunji, 2010a, Olofsson et al., 2008).

In summary, the formation of divisional model organizations is more common to contracting organizations than any other form of business domain. Moreover, as shown earlier, there is a broad spectrum through which estimating procedures in this domain can be viewed. This

mainly depends on project type and organization size. In each, different customized estimating procedures and outcomes apply (Sedera (2008), Skitmore and Wilcock (1994)). Moreover, according to Abdelkarim (2010), different strategic approaches apply as construction companies adjust their business structures to accommodate BIM competencies. For example, there are strategies for:

- early-entrants (i.e. for those who deploy BIM when other firms have not),
- market-moderated entry (i.e. those who adopt BIM only when there are adequate incentives in the market) (Aranda-Mena et al., 2009).

For each of these paradigms, different risks and marketing advantages apply. More importantly, BIM-propelled change is not driven in either situation neither by the capacity or affiliation of individual employees to change nor their immediate ability to practice with BIM. Rather it is driven by corporate strategic action to take specific business advantage when due. Thus, the procedure for reflecting this in corporate cultures of estimating is richly nuanced; it is based on organizational philosophy and market incentives, and not primarily dictated by the immediate competence of individuals

As noted by Olatunji (2011b), there are different corporate implementation costs within each domain, and each cost descriptor translates into different price regimes for different clients. For example, there are corporate strategies for a gradual transition to BIM which only involve dealing with BIM in the same conventional manner as 2D CAD until clients demand a particular approach. On the other hand, there are emergent approaches that require a spirited acquisition or upgrading of existing resources e.g. staff training, recruitment of new staff, acquisition of new applications, system upgrades and using BIM competences as a basic marketing advantage. In Abdelkarim's (2010) view, it is evident that many contractors in the USA have used integrative platforms such as BIM as their main business domain to promote their main business strength (including integration of procedures, VR or process modelling and a renewed culture of collaboration in corporate philosophy, involving technical and non-technical staff members alike). Arguably, different cost implications apply to clients when contracting businesses deploy BIM gradually and when they elect to use it as their only business platform.

3.2.3 Functional business-unit Model

The difference between matrix and divisional business models is clear; the line of command in the former is multidisciplinary and biased in only two directions, while the line of command in the latter is robust and richly nuanced, but in one direction. Other contrasts across all the four practice domains are summarized in Table 3.1. In contrast, in functional business models, the line of command (also known as functional line) is unitary and discipline-specific (Price, 2007).

Conventionally, all businesses are made up of functional units around which their business transactions are structured. The line of communication and flow of authority along each function unit is called a functional line. Nonetheless, construction businesses have sufficient and appropriate expertise to meet their goals. As shown in Table 3.2, construction project clients may not have the complete set of skills needed to achieve project goals. Moreover, operators of divisional business models, who generally use a pragmatic approach in estimating, may operate their business without a full complement of every necessary construction discipline. Thus, whether in matrix, divisional or networked model, construction-specific disciplinary functions are usually outsourced when such expertise are required.

In Figure 3.3, a functional business-unit model is shown as the smallest service unit that other business models can outsource in order to facilitate specific goals during project delivery. Conventionally, such units are service consortiums and consultancy firms which provide professional services that are specific to project delivery disciplines. In the context of estimating practice, operators of functional model units can be hired to provide a range of services in any other business domain. For example, an estimator working for a project client may protect his / her client's interest by maximising value for money. If the same estimator is outsourced by a contractor on the same project, his / her role will be to project the contractor's commercial goal – to maximize profit and control production cost.

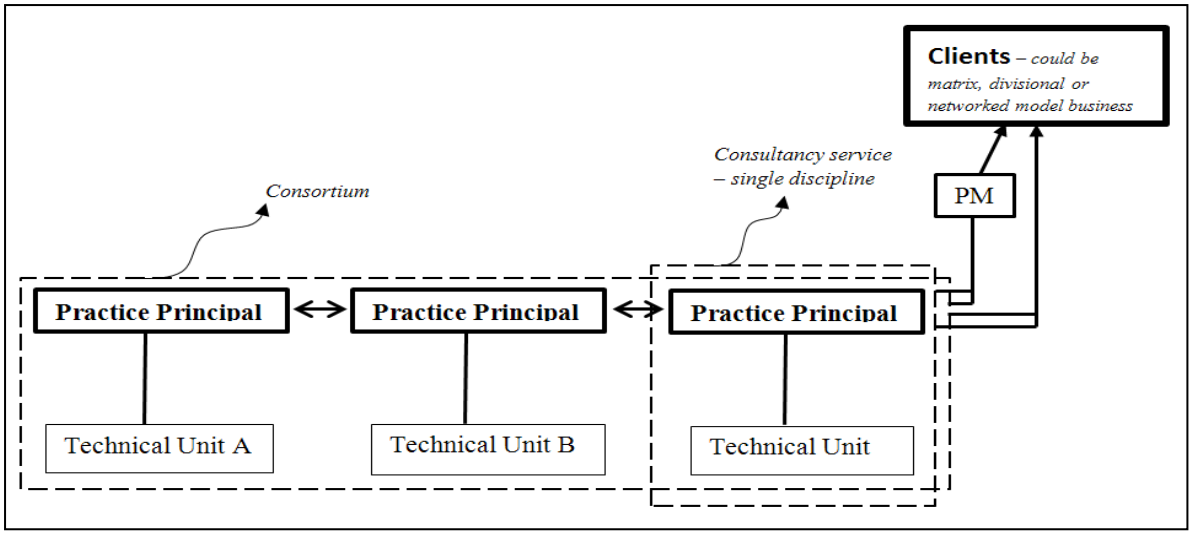


Figure 3.3: Functional business-unit model, adapted from (Bushman, 2007, Chen and Tsai, 2006)

It is critically important to appreciate the contrasts between certain terms in organization science that are easily confused with functional business models. This is necessary before explaining the relationship between functional business-unit models and estimating procedures, especially in the context of semi and fully integrated project development platforms such as CAD and BIM. Specifically, in the functional matrix model has been discussed as a form of matrix business model (Section 3.2.1). This is different from the functional-unit practice model organizations, as shown in Table 3.1.

Table 3.1: *The contrast between the functional-unit practice model and functional matrix model*

Parameters for differentiation	**Functional-unit practice model**	**Functional matrix model**
Sourcing	Outsourced, treated like external organ	In-sourced, have relative recognition of intrinsic content
Disciplinary context	independent unitary, distinctive professional function	Multidisciplinary functional lines within a business
Communication	Fragmented, discipline-specific	Team collaboration is inevitable
Service target	Can only target construction project development	Can be used to implement any form project, whether related to construction or not
Functional line	Closer to client, equality among the project team is a strong motivation	Disciplines can be given uneven privileges

Perspectives on estimating practice in functional-unit business model organizations

Apart from simple business management skills, estimators in function-unit practice domains are highly skilled in analysing the cost implications of construction project development. There are several perspectives to this in construction management literature, e.g.:

- *Professionalism:* Some studies expect higher professional standards in a functional-unit domain than in other practice domains (Fan et al., 2001, Ho and Ng, 2003, Poon, 2003, Priemus, 2004). This is because this practice domain is discipline-specific, unlike other domains where estimating practice involves a combination of core estimating skills and other skills.
- *Innovation:* Expectations are rife regarding the ability of estimators in function-unit practices to deploy sufficient skill and instrumentations that can handle every complex situation. These include:
    - the ability to work in different types of team formations (Abdul-Quium, 2011, Barton, 2000, Molenaar and Campbell, 2009)
    - the ability to use hard and soft techniques to resolve project issues regardless of complexity (Hardie et al., 2005).
    - the ability to use software applications to drive project goals sufficiently and appropriately (Best et al., 1996, Sher, 1996)
    - the ability to deploy flexible and appropriate business behaviours e.g. willingness to share data during collaboration and commitment to system integration (Aranda-Mena et al., 2008).
- *Domain fragmentation:* There is a wide spectrum of forms and practices in construction project development. Examples include building, civil and industrial projects. There are many domains in building projects alone, including residential cottage and industrialized, commercial, institutional and civic buildings. Examples of project development practices include conventional procurement practices, partnering and alliancing, and other forms of specialized procurement routes.

  It is likely that a single functional-unit practice covers a part of this extremely wide spectrum of business potential. Thus, estimators in this domain are likely to be more skilled in areas they are exposed to frequently. The experience of estimators in matrix

practice domains may be different; their organizations may cover a wide range of project forms and procurement methods.

On the other hand, the connection between estimating practice in a functional-unit business model and integrated project development platforms such as CAD and BIM is straightforward, i.e.:

- As the smallest business unit which other models can outsource, it is easier for this practice domain to be flexible and innovative. In other domains like matrix and divisional model organizations, change is either time-consuming or market-driven. However, in a functional-unit model organization, innovative changes are a latent attribute that gives businesses competitive advantages.
- Estimating practice in functional-unit model organizations respond generally to the regulatory powers of professional institutions. Thus, incentives for flexibility are weak due to legal constraints on ownership of intellectual property. Recent studies (Fairfield (2005) and Olatunji (2011c)) have identified complications associated with clients' ownership of project models.
- In addition, integrated IT platforms offer new opportunities for estimators. As indicated in Chapter 2, traditional estimating processes are different from automated processes used for estimating; and to these, BIM has added a depths (Section 4.3). Studies such as Tse et al. (2005) and Sher et al. (2009) have described this situation as having considerable potentiality for new roles, role change, new skills and an objective methodology for performance appraisal.

<u>Challenges of Functional Structure Model</u>

The challenges of functional organization models have been outlined by Hitt et al (2011), e.g.:

- *Discipline-concentric skill:* Construction estimators, regardless of domain of practice often share similar views of professional procedures. However, their skills are usually limited to sub-domains within the industry i.e. some estimators may focus on a particular form of project (e.g. building, engineering) and procurement route (e.g. traditional, integrated projects). The experience of another estimator in a matrix organization could be different from this; such an estimator could be exposed to

different kinds of projects and can adopt multi-disciplinary roles (e.g. regulatory skills and administrative skills, in addition to his technical skills).

- *Friction arising from fragmentation:* In team-oriented environments, friction often arises when fragmented functional lines of responsibility interact. This is because there is a likelihood that some disciplines will be favoured by clients over others; each discipline has to compete for this. Such situations often cause friction within a project team.
- *Absence of objective measures of performance:* Various authors have identified the deficiencies in feedback mechanisms to estimators. (Cornick and Osbon, 1994, Leung et al., 2007, Lowe and Skitmore, 1994, Lowe, 1998). These studies underline the fact that the feedback estimators receive on past projects is very limited. Further evidence from Sutrisna et al (2005) and Skitmore and Patchell (1990) shows that this problem negatively affects the accuracy of estimates.
- *Fragmentation problems:* Procedural expectations in different disciplines are diverse; operators are unlikely to compromise these easily. As each functional line is focused on meeting project goals rather than meeting or supporting other disciplines' requirements, integration has been difficult to achieve. This is the most important reason why some researchers are sceptical of the potential of BIM to deliver real-world solutions (Holzer, 2007).

3.2.4 Networked structure Model

In the three business models presented above, contractual relationships in projects are usually short-term, and this clearly reflects estimating procedures and outcomes in these practice domains. Networked business models are different from these; they are structured to implement projects on a long-term basis, where facility development and lifecycle management is a part of the project. Another difference is that professional services in networked structure models are integrated; thus identities of individual functional units are subsumed within networks (Rockart and Short, 1996).

Texts on specialized projects (e.g. Glick and Guggemos (2009), Merna et al. (2010)) have described integrated project platforms like networked business structures as special project vehicle (SPVs). The peculiarity of these, in the context of organizational behaviour, is that they can take the form of any other business model. They can partner with project clients in arrangements like public-private partnering (PPP), built-own-operate-and-transfer (BOOT) and build-operate-and-transfer (BOT). In such arrangements, they share the same rights as

clients. They can also take the roles of contractor and consultants when they provide integrated services to deliver turnkey projects. For each of these scenarios, different estimation parameters apply; regardless of the technology adopted for project design and development, the long-term interest of the project is the main goal of estimating. Estimating in other business domains can have a different focus; they are short-termed and are often focused only on specific aspects of project, as described in Section 2.2

There is another differentiating factor: each component of a networked business structure could have distinctive identities – see Figure 3.4. However, like networked business structures, other businesses also use digital technologies to network their functional units, teams and data, regardless of geographical positioning. In other models, authority, and strategic control is drawn from the epicentre of business structures; however, in networked structures, each terminus possesses the resource and absolute power to take major decisions without compromising the long-term support from the centre. When organizations' business actions are moderated from the epicentre, standardization and internal control are stronger than where business units are autonomous. The implication of this on estimating processes is significant; the autonomy of business units gives estimators ample freedom to innovate and promote professionalism rather than promoting company interest (Poon, 2003). Another perspective is the ability of estimators in this domain to be more strategic with marketing skills than the scientific skills that estimating practice entail (Skitmore and Smyth, 2009). In particular, this is in contrast to the perspectives of estimators in matrix models and functional-unit practices where professional practice is plainly scientific.

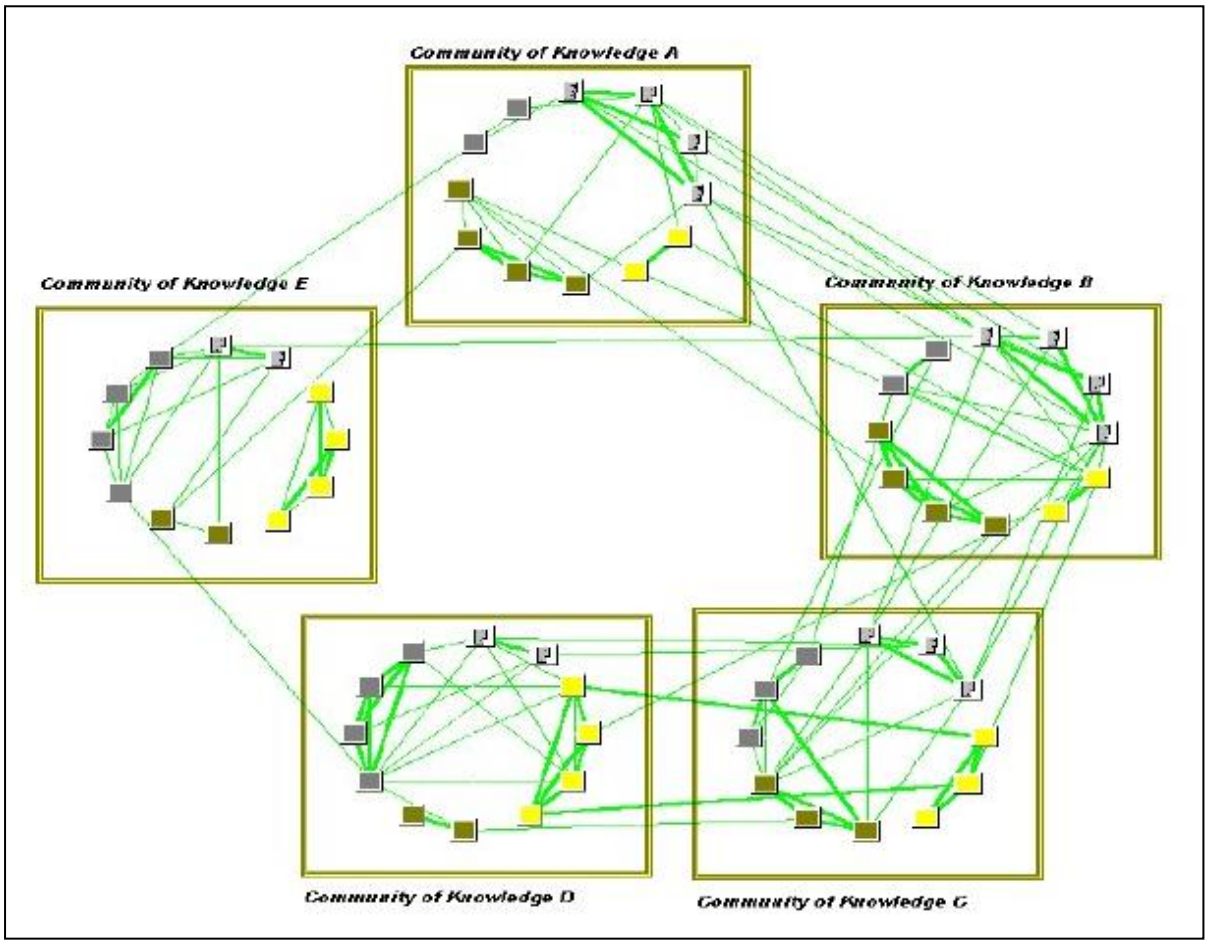


Figure 3.4: Networked business structure (Krebs, 2005)

<u>Structural transitioning to networked business model</u>

Organizational scientists, such as Camarinha-Matos et al (2009), Sviokla (2004) and Rockart and Short (1996), have reported the importance of networked organizations and how other business structures are transforming into it. Why is this important? Some studies have provided specific answers; there are major transitions from mono-centric to polycentric business practices because

- they give organizations a strategic advantage to compete across a wide range of horizons (Malnight, 1996).
- such organizations are project-based rather than conventional models that are institution-based (Brynjolfsson and Hitt, 2000).

- there is a balanced power distribution in networked business practices; in other models, hierarchical flow is longitudinal and top-heavy (Saracoglu, 2009).
- Polycentric business structure facilitates an effective distribution of resources such that business are able to do more with less (Radosevic, 2002).

In Figure 3.5, a transitioning approach, adapted from the work of Rockart and Short (1996), is presented. As shown in the figure, there are five main parameters for organizational transition, viz.

- Business mission and environment – where strategies for competition are most effective
- Organizational challenges – which include willingness and resources to understand risks and manage complexities, openness to change and willingness to take challenges
- Areas of performance emphasis, including the strength of networks, the spectrum of services, low management cost and reputation.
- Coordination and cross-organizational functioning such as strategies for cooperation and skill to manage interdependences.
- Management capabilities: IT-enabled interaction, performance appraisal, teamwork, collaborative business behaviours and flexible business management skills.

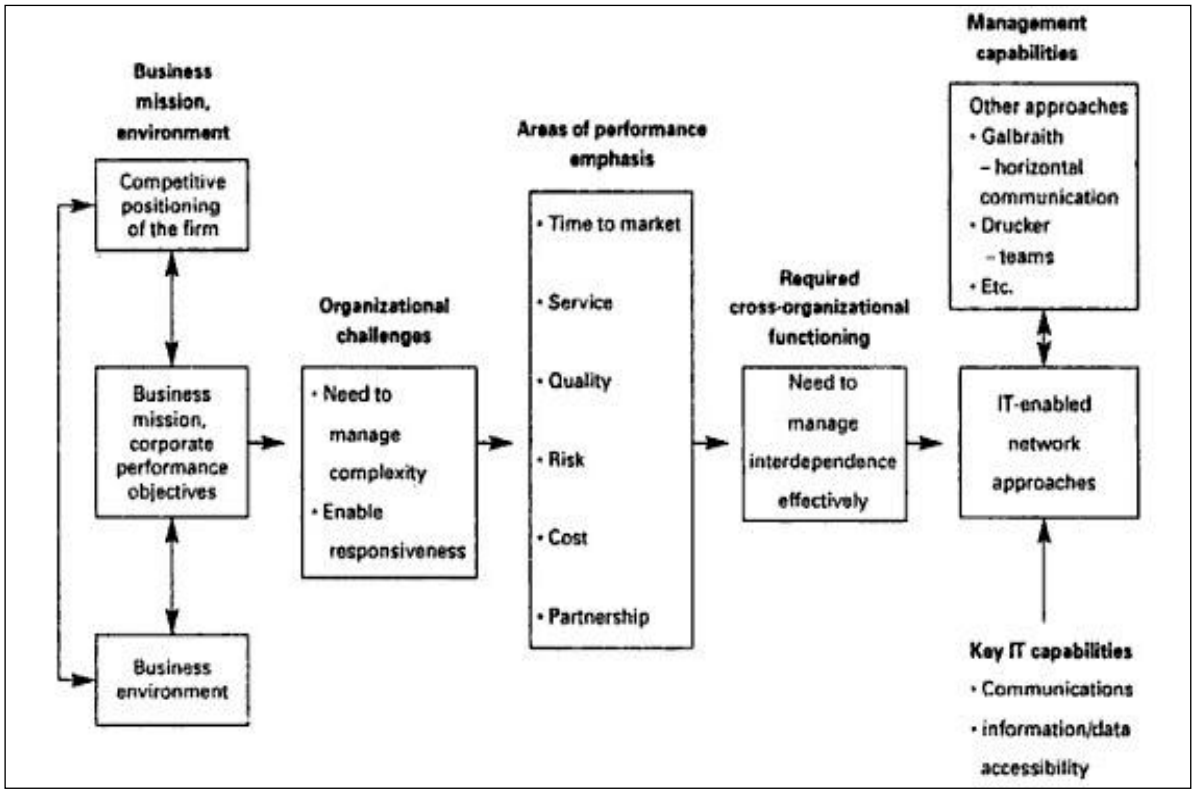


Figure 3.5: The framework for transitioning to Networked organization (Rockart and Short, 1996)

Change is a complex phenomenon; often referred to in the business cycle as a complex risk that is not always 'linear' (Brynjolfsson et al., 1997). In other words, there could be change scenarios that are not soluble by simple management models, and different networked organizations are likely to respond to challenges differently (Cai et al., 2004). Networked organizations therefore exhibit rugged, complex and context-sensitive skills to drive both internal and external interests in moments of system changes. When such changes occur, businesses rely on their estimators to be pragmatic and efficient in their judgements, otherwise the consequences can be dire.

<u>The challenges of transitioning to networked structure models</u>

According to Jarvenpaa and Ives (1994), the major challenges of shifting from fragmented business models to this model include:

- developing a workable system architecture and managing flexible and efficient information repositories that are interoperable between networks;

- establishing new values, attitudes, and behaviours on sharing information in concentric formations;
- building databases that can support integrated networks, and;
- protecting data ownerships, personal freedoms and privacy.

Table 3.2: *The difference between estimators' practice domains*

Differentiation parameters	**Matrix practice domain**	**Divisional practice domain**	**Functional unit practice domain**	**Networked practice domain**
Business domains	Project owner and client, not necessarily construction expert	Contracting	Consulting	Integrated, specialized, relational projects
Nature of estimating outcomes	Passive, robust	Pragmatic, risk-based	Flexible, relative to roles in other domains	Pragmatic, long-term in nature
Domain of functionality	Public, corporate, individuals; not exclusive to construction business.	Corporate, construction business; not exclusive to construction experts	Discipline-specific construction functions	Project-specific business functions; not exclusive to construction experts
Approach to Estimating procedures	Institutionalized, open	Flexible, project-based	Flexible, client-based, relative to the goals of other domain	Project-based
Estimating goal	Value for money, accountability	Maximise profit, cost control	Contract umpire; to facilitate	Long-term project value
Market domain	Social, civic, institutional, corporate, context-specific	No restrictions, commercial	No restrictions, commercial	Partnering, relational, long-term, commercial
Hierarchical flow	Two-directions; functional and project-lines	One direction; functional line	One direction; functional line	One direction; functional line
Skill base	Wide spectrum, regulatory, reliant on databases	Confident on both hard and soft parameters, project specific	Domain-specific, can facilitate the goals of any other domain	Project-specific, long-term, confident on hard and soft parameters
Architecture	Bureaucratic, institutional, large organization (non-construction specific)	Networked, slightly autonomous	Discrete, service-based	Networked, service-based
Adaptation to change	Gradual, requires macro instruments	Gradual or very quick; responsive to market pull	Gradual or very quick; responsive to clients' demand	Emergent, relative to project goal

In addition, several studies have identified a strong correlation between organizational networks and Integrated Project Delivery Systems (IPDS). For example, Griffith (2000), Alston (2003) and Camarinha-Matos et al. (2009) benchmarked this correlation to simulate positive outcomes in heavy engineering construction, specialist institutional construction (e.g. sensitive military and security projects) and partnering projects. These project domains are highly risky and require specific business initiatives to drive project contracts. Therefore, the approaches to estimating in this practice domain are significantly different from other models'; others are fragmented and short-termed, networked model and IPD approaches are relational (see examples in (Sakal, 2005).

Fully and semi-integrated platforms for project delivery such as CAD and BIM offer substantial potential for system integration. Not just as an integrated data repository, they facilitate integration of development processes and multidisciplinary systems (Anumba, 1996, Flager et al., 2009). Rather than taking fragmented roles, construction business might be tempted to take-up integrated responsibilities such as designing, the management of construction and facilities operation. Even if this not the case, estimators providing professional services in integrated projects are required to provide services beyond those provided for in fragmented platforms. In essence, instead of using lifecycle modelling (see limitations in Table 2.2 in Appendix 1), there could be a more attractive approach to estimating using BIM.

There is significant pressure on construction practitioners in Australia to adopt BIM. Evidence from the Australian Department of Innovation's Built Environment Digital Modelling Working Group (2010) shows that there are commissioned studies and new pragmatic government policies on BIM deployment in new projects. Similarly, private construction businesses are re-engineering their business structures and behaviours to remain competitive in BIM (Olatunji, 2011b). The necessary skills required to promote BIM and its deliverables have been researched by Sher et al. (2009). As indicated in Section 4.2, BIM is neither a substitute for CAD nor a replica of manual design systems. Thus, change is inevitable in estimating processes and how organizations prime their strategies in dealing with BIM e.g.

- There is a need to acquire newer skills that are necessary to perform their roles effectively with BIM

- The nature of data representation in BIM is not the same as CAD and manual designs; procedurally, estimators need to acquire skills to enable them to promote automatic procedures and virtuality.
- In conventional practice, business behaviours are fragmented; in BIM, depending on the maturity of implementation, they are collaborative and integrated. Estimating practices must be able to handle collaboration (data sharing) and system integration.
- BIM provides new opportunities. Estimators and estimating businesses have opportunities to provide additional roles including BIM-project leadership, corporate BIM implementation, process visualization, virtuality and augmented simulation.

In the following section, change management theories and models in the context of construction business are reviewed. In Section 3.4, discussions are made on the agents required to achieve these changes.

3.3 CHANGE MANAGEMENT THEORIES AND MODELS

The pressure for change is impacting estimating practice in multiple directions, e.g.

- With changes in technology, estimating procedures are changing in different practice domains. There are new applications and procedural outcomes which tend towards integration. The change in activities leading to estimating outcomes under CAD and BIM regimes are compared in Chapter 6.
- Business parameters (i.e. structures and commercial interests) change persistently, from fragmented structures to integrated platforms, and from hard to soft methodologies.
- The technology and business changes noted above have widened the horizon for new opportunities for estimators:
    - new roles (e.g. digital process modeller, construction model moderator, BIM simulation analysts, for cost, safety, risks and uncertainties; and a digital business coordinator) (Hannon, 2007, Tse et al., 2005);
    - role change (e.g. from conventional quantity surveyor or estimator to BIM cost modeller; from conventional research and development personnel to digital innovation personnel or co-ordinator) .

There is thus clear potential for BIM to change construction management practices and procedures (Bleiman, 2008, Fussell et al., 2007, Gu et al., 2008, Olofsson et al., 2008, Storer

et al., 2009, Suermann, 2009). More importantly, the change has not been contextualized definitively in estimating practice as per the context of the various business domains presented above. However, the impending change is critical; the nature of change that BIM triggers and promises, has often been described in literature as evolutionary, unequivocal and substantial (Succar, 2009). According to Hope (2012), the implication of the change is as though organizations should change or die, i.e. change their business behaviour, estimating procedures and performance parameters.

In Maunula's (2008) account, BIM challenges every aspect of conventional construction procedures for sourcing and modelling information in infrastructure development, including design, procurement, construction and facilities management. Consequently, a high rate of awareness of BIM needs to be demonstrated by construction organizations, many of whom are considering opportunities to change their business patterns and stay ahead of competition (Abdelkarim, 2010). To achieve this, there is considerable evidence that suggests that new skills, new tools, new dedicated habits and new working cultures are required to penetrate the new business horizon BIM provides to the construction industry (Gu, 2006, Aranda-Mena et al., 2009, Sher et al., 2009).

This section describes theoretical frameworks for managing BIM-propelled change in construction business systems, particularly with respect to estimating practices, in client organizations, consulting businesses, contracting firms and integrated project delivery companies. The underpinning argument here is that the opportunities BIM promotes provide a chance for estimators as it is to other construction professionals. As contested by Nassar (2012), rhetorical views on the impact of BIM on accuracy of estimates are rife. Terms such are 5D, automatic estimating and automatically accurate data export from BIM models have featured frequently in many studies as though BIM can take over some of the roles estimators perform (Kim et al., 2012, Sabol, 2008, Shen and Issa, 2010).

Theoretical definitions of change

Change is a constant phenomenon in construction business systems. It is often triggered by a wide range of sources and causes that are either planned or unplanned for, and can occur at any stage of a project or business process. As argued by Motawa et al. (2007), the impact of change can be severe depending upon time, need and effect:

- *Time-based* change can be anticipated or emergent, proactive or reactive and as ad-hoc or post-hoc to fixity.

- *Effect-based* change can be beneficial, neutral or disruptive

- *Need-based* change can be elective or required, discretionary or non-discretionary, or preferential or regulatory.

The opinion of Al-Sedairy (2001) is similar to Motawa et al.'s (2007). Al-Sedairy describes change as a unique expression of dynamism which can only be studied by its observable characterizations. These characterizations have been described by Carr et al (1996) to include *"re-aligning people, resources and culture"*. Figure 3.6 is an adaptation of Carr et al's work; it shows a transformation ontology for organizational change through three primary variables viz. people, resources and culture. Previous studies suggest that these drivers can only deliver optimum outcomes when they are well co-ordinated, using appropriate agents for integration and management (Cai et al., 2004). The relationship between organizational change theories, BIM and estimating are summarized at the end of this sub-heading

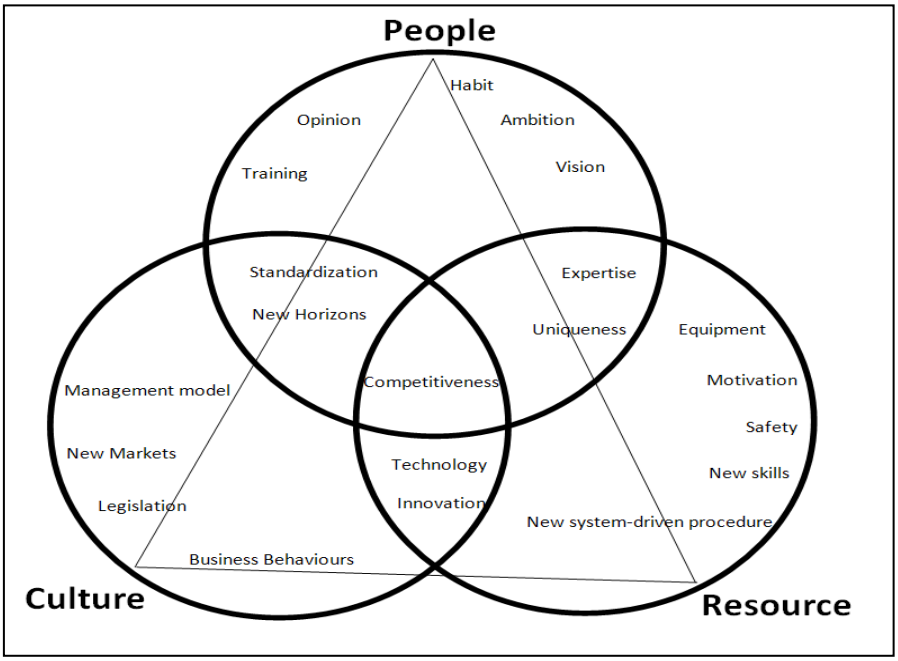


Figure 3.6: Transformation ontology for organizational change (Carr et al 1996)

As shown in Figure 3.6, organizational change occurs through three cardinal determinants viz. people, resource and culture. For example, for an organization to change its outcome,

individuals in such an organization are responsible for the actions that facilitate such change. According to Wirth (2004), this involves enhancing the skills of such individuals through training and motivating uniqueness, and promoting new career horizons. The change triggered in people, business resources and culture often appear in different patterns. For the sake of clarity, there are several theoretical constructs for these variables, e.g.

- *People's change psychology*; which is often triggered by internal and external motives of actors in the business systems where change is occurring (Fisher and Savage (1999).

- *During cultural transition*, people and business outcomes reflect the pattern of change which construction business systems undergo (Ritchie and Burtonshaw-Gunn (2006). New technologies such as BIM mandate a collaborative and integration culture; thus business behaviours must be strategized to implement the modalities for these from one business domain to another.

- *Resources that are specific to change* are required to help organizations in their transition. In the context of BIM and estimating, this involves acquisition of new hardware and applications, resource securitization and change to services.

Why are these issues important? They are crucially important because:

- There are different approaches to estimating practice and philosophies across the diverse practice domains. Consequently, there are different perspectives as to what can change in estimating procedures and the goals of estimating outcomes from one practice domain to another.
- Apart from estimating practice, change affects construction businesses in different ways. As described above, organizational changes only occur when there is adequate motivation to re-engineer business resources and culture in a new direction, not simply because certain individuals have acquired new skills.
- Based on the two previous points, the impact of integrated design platforms on estimating practice, especially across the four practice domains described in Section 3.2, is not limited to conceptual project changes (e.g. software change, increase in change orders, emergent project-specific skill requirements and change in design platform). Rather, Succar's (2009) definition of BIM and case studies report

coordinated by Olofsson et al. (2008), have indicated that specific business behaviours are required to facilitate project outcomes. For example, functional units must be willing to collaborate and share project -specific data. This is in contrast to conventional practice; firms' ability to hold on to discipline-specific information during project implementation has always been a strategic business advantage (Hansen et al., 1999).

In summary, several studies have described the power of BIM change the construction industry (Gu et al., 2007, Olatunji, 2010a, Marshall-Ponting and Aouad, 2005). Particularly, in BIM, estimating processes must shift from moderation-intensive procedures (Section 1.2 and Section 6.3) while retrieving cost parameters from designs to a metadata paradigm where models contain robust data that could be imported and applied to generate estimates. According to Amor et al. (2007), BIM models are not developed to promote accurate estimates. They propose project outcomes in the form of a physical product. It has also been argued in Chapter 2 that BIM models are unlikely to contain all the information required to develop a project estimate as some cost parameters such as preliminaries and contingencies are difficult to represent in a model.

Therefore, rather than viewing the propensity for change in estimating practice as a function of project change, the different nature of estimating roles in construction businesses (as per the four practice domains described in Section 3.2) require their business (or estimating) processes to be re-engineered in the context of BIM and its philosophies (as described in Chapter 4). To achieve this, existing theories on change management models must be adapted according to the characteristics of the practice domains. The following section provides background and specific concepts of change management modelling for construction businesses.

Background to Change Management Models

Change management models (CMMs) apply to businesses in different ways; some work more effectively than others in certain conditions, whilst some only work for certain businesses and not for others (Garside, 1998). To put this in the context of construction-related businesses, Zink et al (2008) note that the only CMMs that will generate acceptable outcomes in construction businesses must be responsive to the risk-context of construction operations. They must also be transparent and pragmatic in how they are developed and applied to

specific project and business situations. The authors recommended that CMM strategies for construction businesses include:

- Case-base holistic processes in place of generic shallow systemic attempts
- Systematic understanding of CMM structure and behaviours, and the interdependencies between both, and;
- Evolutionary process models rather than deploying resource-limited approaches.

Conventionally, some business change management models are tailored to best practice benchmarking to maximize specific outcomes of process reengineering such as increases in productivity and improved cost efficiencies (Clarke and Garside, 1997). Instead of adopting generalized models for managing change, other studies have treated change as specific to projects and business orientation. Cao et al. (2004) argue that all forms of organizational structure will respond to change management models differently, and the overarching feature of such reactions is often complicated by competition, ambiguous client expectations and latent market characteristics.

Invariably therefore, organizations strive to implement change in their business structures in a broad sense, either as part of self-determination or as a strategy to survive competition or both. However, construction organizations' responses to BIM, regardless of practice domain, is currently only a part of in-house reform policies on a specific case basis, while their holistic adoption of wider concepts of change remains strategic and gradual. Some procedures for BIM adoption have been discussed (Succar, 2009). For example, an organization that shifts from fragmented project development paradigms to integrated project development (IPD) system using BIM will only require change practice procedures involving BIM, not in its entire business structure. While some aspects of an organization's business model respond to this on the basis on integrated project delivery (IPD) structure, other aspects of their business system may not respond to this change immediately or in the same way as responding to BIM in IPD.

Consequently, rather than focusing on systemic views about holistic change which cannot be generalized for all business structures, this section focuses on formulating a framework for the different estimating practice domains as they respond to the change patterns stemming from BIM. Whether change occurs at a project level or is inherent in business systems, both

scenarios are not the same. The difference is that, in project change, BIM can be implemented on a single project without affecting the rest of the organization. When BIM is perpetuated in business systems, organizational structures and their business behaviours reflect BIM attributes (Abdelkarim, 2010). This may also include focusing on BIM as the only vehicle of project implementation, and may require large scale awareness within such organizations, involving skilling and creating policies that technical, support staff and management staff must observe (Olatunji, 2011b). Meanwhile, change impacts an organization's sub-systems in different ways. With this understanding, Zink et al. (2008) recommends the use of management models to explore change management in both project management paradigms and construction business management paradigms. These models are discussed below in the context of construction business practices involving estimators.

Change Management Models

To analyse how this affects different system layers (i.e. project management paradigms and business management models), three management models have been selected to examine three impact-layers of change in construction business models. These impact layers have been identified by Akram and Bouguettaya (2004), and further elaborated by Zink et al. (2008), as ontological, interface and exodermis realms i.e.

- The ontological layer is explained as the people, culture and business structure
- The interface layer is explained by technology impact, policy framework and market regulations
- The Exodermis layer is explained by market pressure and interaction with other industries.

Each of these layers may be analysed through management models which are discussed below with relevance to BIM and estimating:

3.3.1 Bleicher's Model

Bleicher's change management model (1999) identifies the primary frameworks of management practices that enable organizations to maintain their business structure and respond to change. According to this model, there are three interdependent levels in management: *normative, strategic and operational* levels. Each level usually interacts with the lateral enablers of business change processes, noted by the author as *behaviour* (people),

activities (resource) and *structure* (culture). As shown in Figure 3.7, together they form nine dimensions of inter-dependent instruments for managing change conditions. Moreover, the figure shows four levels of change implementation; change starts from management philosophy and its objectives are driven by all levels of staff. The overriding principle of Bleicher's model is that change is designed to strengthen structural changes in existing business culture and promote new outcomes through changes made to business processes and behaviours. This means when businesses set goals on how they elect to deploy BIM, they use a case-specific matrix such as the performance matrix developed by Succar et al. (2012). This enables them to create definite targets in their business procedures and outcomes such as whether or not to use automation for estimation or visual simulation for tendering. They also determine how much collaboration they require at the different project levels and what should constitute their progressive change cycle.

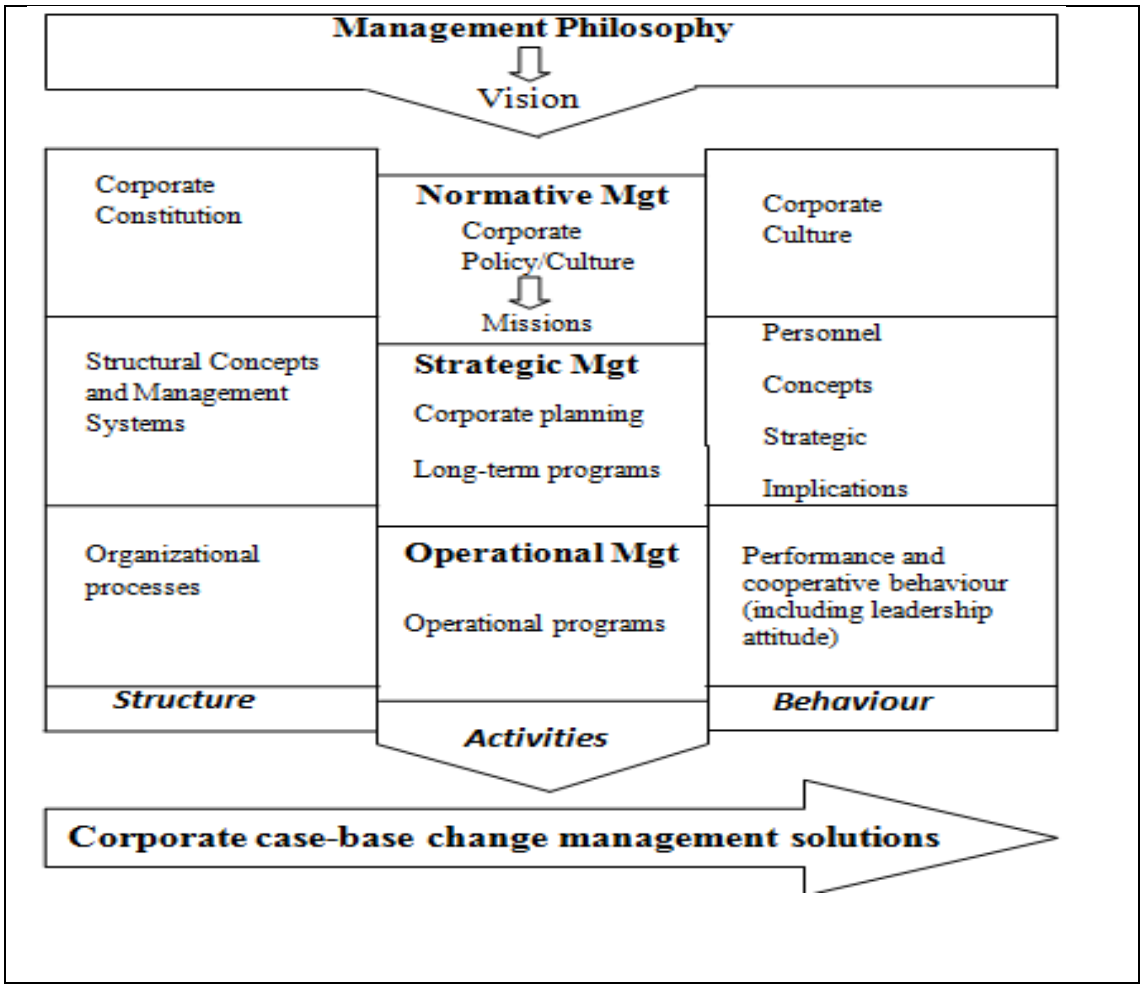


Figure 3.7: Bleicher's integrated change management model (Bleicher, 1999)

Bleicher's model works as a holistic tool for case-based change management solutions. Its strength is in the integration of multidisciplinary processes and inter-relationships between the vertical and horizontal descriptors of the model with vertical being *normative, strategic and operational* levels, and horizontal being *behaviour* (people), *activities* (resource) and *structure* (culture). Particularly, when the descriptors integrate laterally, they transform into structural patterns of business behaviour (e.g. set policies and standards for collaborative behaviours as would be required for specific business and project scenarios). When they integrate vertically, they result in normative frames, strategic content and operational concept. Through this, the impact of BIM can be measured in terms of productivity, accuracy and project success. When the integration in both dimensions fits between and within the levels, the result of the transformation is multi-dimensional, both in terms of structure and content. This outcome triggers new processes, new goals, new skill orientation and enhanced motivation towards meeting more advanced clients' needs, the development of a stronger business structure and a wider approach to social and economic goals. In other words, according Bleicher's model, the change triggered by BIM in underpinned by structured business philosophy rather than individual views. It will require estimators to adopt BIM attributes in their processes, and this means that each of the four practice domains established in Section 3.2 requires new process models to implement BIM appropriately.

Other studies have identified the preconditions for this model to achieve its maximum fitness when applied in different environments e.g. practice domains. According to Vink et al. (1998), technical factors (such as skill and technology) need to mix appropriately with organizational and human factors to achieve optimum results. Other factors are also involved; there should be appropriate tools to appraise coordination as the business model structure changes during integration, especially along value-creation chains (Weill et al., 2005). Furthermore, there is a need for strategic methodologies to align with elements within the same dimension or level, between related elements of a value-creation chain, and behaviour-related personal, structure and technical aspects (Zink et al., 2008).

Of what importance is this to BIM? System integration is the key to project implementation and business success in BIM (Aranda-Mena et al., 2009, Aranda-Mena et al., 2008). As pointed out earlier, there are different business interpretations of this e.g. by default, some functional lines involved in project organization are likely not to integrate in the same way as others (for example, unlike estimating disciplines, design disciplines require increased levels

of integration). Thus, it is necessary to measure integration and create bases for its comparison across different disciplines and project scenarios. This is presented in Sections 6.3 to 6.7.

Many organizations and project systems are currently facing considerable challenges to integrate, interoperate, share value and collaborate (Shen et al., 2010b). The difficulties they face are limited to implementing the change they desire as and when necessary. The discrete stages of BIM adoption are discussed by Succar (2009). According to this author, it involves strategic plans that are tailored to specific BIM-based competences and project requirements. Succar notes that it takes time and considerable effort before organizations achieve a level of integration. However, in the context of estimating practice, BIM makes it easier to integrate estimating procedures from one project development stage to another. Structurally, it contains a wealth of data that are readily available to estimators for moderation. It also enables estimators to trace the procedures that other disciplines have used such as the cost-context of such procedures could be visualized. Moreover, estimators are likely to deploy BIM at different rates (e.g. specialized situations in IPDs usually favour BIM rather than in institutional projects). This means it may be difficult to delineate or limit how BIM is put to use in different practice domains as specific projects may require.

The merit of Bleicher's model is in its orientation for integration. This is because, with its integrative precepts, it reshapes how organizations re-orientate their businesses and project management models. This has a specific value for this study in terms of estimating practice and procedures under BIM regimes; it is useful in identifying discipline-specific views about what constitutes workable procedures and outcomes across the four practice domains. More importantly, the transition to BIM can be studied in relation to the maturity indices developed by Succar (2009). The BIM maturity indices developed by Succar comprised different parameters for facilitating goal setting and progressive benchmarking as disciplines grow their competencies to deploy BIM.

At present, most estimating practices are used to dealing or collaborating on the basis of CAD. However, BIM models are sometime prescribed for particular projects. Using Bleicher's model makes it conveniently possible to measure and discriminate between the views of estimating domains on the necessary procedures involved in estimating with CAD and BIM, both in collaborative and integrative platforms (Section 4.4). There is another perspective to this; as BIM is emerging as an evolutionary instrument, its underlying

philosophy extends beyond project management design tools and project team actors. Rather, as a multidisciplinary platform, it involves a holistic approach to business systems which include technical and non-technical resources (Abdelkarim, 2010, Olatunji, 2010a).

3.3.2 Sun et al's Model

This model measures change management maturity (CMM) using a methodology called a capability maturity model matrix. Similar to Bleicher's model, the model has maturity layers, five in number, as vertical change modes or enablers. Sun et al. (2009) identified these modes as ad hoc (change initiation), informal (repeatable change protocols), systematic (defined change process), integrated (managed change processes) and continuous improvement (outcome optimization process). Sun's change management model is illustrated in Figure 3.8. The logic underpinning this model is that flexibility is a crucial factor in business systems, particularly in construction networked business systems where organizations' functional identities often tend to be stochastic (Mlinga and Wells, 2002, Flanagan et al., 2007).

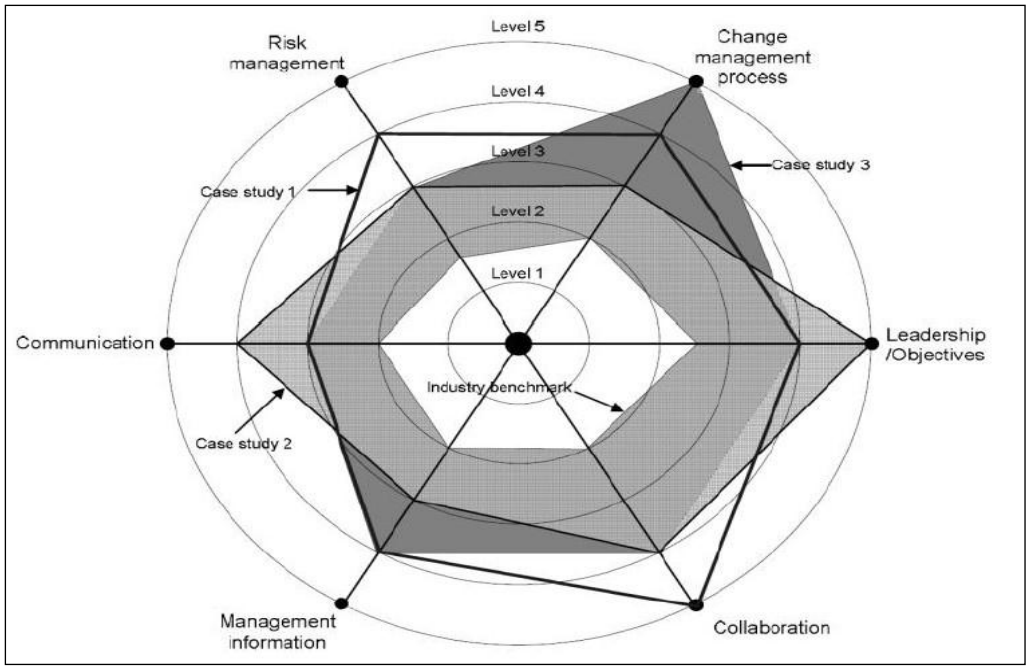


Figure 3.8: The Sun's change management model (Sun et al., 2009)

As shown in Figure 3.8, apart from the vertical dimension, Sun et al's (2009) model has six horizontal descriptors labeled as management process, risk management, communication, management information, collaboration and leadership/objectives. The rationale behind these variables is that they are within the interface domain that connects construction business

systems to external change factors. With these lateral and multi-level descriptors of change outcomes totalling 30 possibilities in the change management matrix, it is possible for the model to test the strength of each scenario of change outcomes in two realms. These realms are identified as *staged* and *continuous* change processes. Meanwhile, the model has another overriding goal, which is to combine change management in the context of project management as well as business process models.

Unlike Bleicher's model, Sun et al's (2009) attempted to validate their model with three case studies. The outcome of the validation process is shown in Figure 3.8. In the three case studies, the authors focused on different levels of project teams' exposure to collaboration and change management support systems. These cases appropriately illustrated the exponential changes in actors' experiences when transiting from fragmented paradigms to BIM's. In Case 1, actors have not collaborated with each other before and never had change management support systems (CMSS). When they were exposed to change processes and measured in Sun's grid model, they all embraced change in their communication procedure and became integrated in their leadership styles and information management processes. In the end, they considered the continuous improvement in their style of collaboration desirable. This suggests that, unlike the skepticisms reported by Hartmann and Fischer (2008) regarding the overall reaction of professionals to BIM, a CMSS that is developed appropriately is likely to change this view. Similarly, as shown in Figure 3.8, the actors in Case 2 had collaborated before, but in this case, they worked without a change management support system. Unlike Case 1, the actors in this scenario communicate better and enjoyed the pattern of leadership style that they have adopted. However, their risk management strategy and management information process was below the outcomes of Case 1. This suggests that, instead of viewing BIM as a one-off phenomenon which is predicated on individual employee's immediate competencies, BIM implementation strategies are less risky when they are strategized on corporate bases.

In Case 3, actors had collaborated before and were duly supported with change management instruments. Findings showed that the outcomes compared well with those of Case 2. Based on this explanation, some conclusions can be drawn from this model, viz.

- The ultimate determinant of outcomes in change management is how CMM instruments are designed and applied; CMM instrument here also refers to CMSS.

- Business systems that have not experienced change often respond to change with a high propensity for achievement. However, whether they are able to carry this momentum through over time is another issue.

- There is no absolute result in deploying change management models; different organizations and actors are likely to have different experiences with a particular change management procedure. Additionally, contingent issues often occur during implementation which are not explained in the change management models that organizations are exposed to.

- To deal with this situation, Sun et al (2009) measured organizations' responsiveness to a change management model in relation to best practice benchmarks.

The merit of this model is its holistic approach; the grids interact at multiple levels, and with this they generate results in exceptional situations, certainly beyond industry benchmarks (Figure 3.8). Moreover, the model also considers change management support protocols for some major attributes of BIM such as collaboration, information management and sharing, and communication. Whilst this strengthens project management systems, the change management system can also be implemented holistically in the business realm. How does this model apply to estimating practice domains and BIM-specific models such as those described by Succar (2009)? Succar argues that construction businesses willing to adopt BIM have to conduct themselves in a particular manner, requiring a well-considered plan and implementation instruments (e.g. policies, skilling and resources) to achieve the appropriate impact. Further discussion of Succar's views on BIM and its implementation can be found in Chapter 4. The difficulty with Succar's views is that they are not specifically directed at any particular construction business domain. For example, in the past decade, there is no generally acceptable standard for designing or implementing changes propelled by BIM. However, there is substantial pressure on construction businesses from proponents of BIM to explore its benefits. Thus, BIM has formed the core of procedural changes in professional practices in the industry (Consult Australia, 2010).

That is not where it ends: organizations have had to develop business-specific models to observe and implement change, some of which are gradual and some immediate (Abdelkarim, 2010). The experience of such organizations, as indicated at the beginning of this Section, is not limited to BIM; rather a significant overhauling of their systems is

required to enable them to increase their competitive advantage. In the context of the four practice domains discussed in Section 3.2, the Sun model holistically applies more to some domains than others. For example, it fits more of the attributes of divisional model organizations (a domain that is pragmatic about estimating and sensitive to change in the industry) than other practice domains (such as matrix model organizations). This is because the pragmatic approach and responsiveness of Sun's model aligns with divisional models' approach to estimating while matrix model organizations require a lot more structured approach. In Section 3.3.3, "best practice models" which apply to construction businesses are discussed.

3.3.3 Best Practice Models

It is a common experience in the business world that organizations are not static. Some businesses often want to improve their strength and progress ahead of others, within and outside their industry domains. To achieve this, they deploy approaches to moderate and benchmark developments in their businesses. Many models are available for this purpose in different parts of the world. In particular, in Australia, considerable reference has been made to the Australian Business Excellence Framework (ABEF) (Odeyinka and Lowe, 2001, Khosrowshahi, 2000, Potts, 2008), as shown in Figure 3.9.

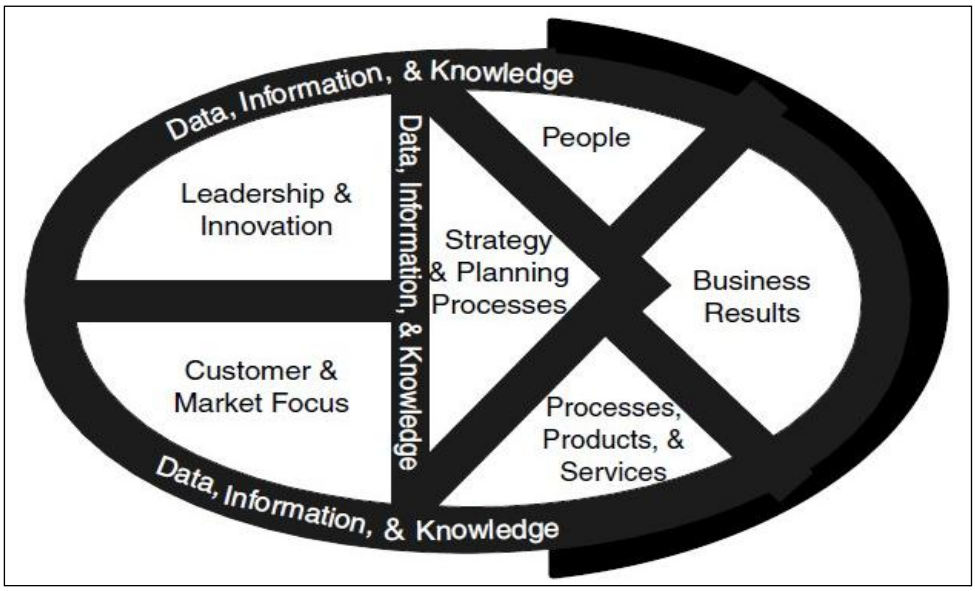


Figure 3.9: The Australian Business Excellence Framework

More importantly, why is it of interest for BIM estimating? The Australian construction industry is the fourth largest GDP contributor to the national economy (Davis et al., 2009a).

About 95 per cent of this industry is made up of small and medium scale businesses. . According to de Valence (2011), the industry is forecast by government to expand into large firms that may play leading roles globally. The purpose of the ABEF model therefore is to help firms grow their competencies, adapt to new market environments and compete better through improved practice procedures.

The ABEF model is used in all sectors of Australian economy, including construction. There are many models like ABEF in different parts of the world, including the Baldrige Criteria for Performance Excellence Model (BCPEM) and the European Foundation for Quality Management (EFQM). Clarke and Garside (1997) suggest that these models may be used as Best Practice templates through which broad-based assessment matrices can be deployed to enable firms to collect a broader range of data for in-depth analysis of systemic performance rather than concentrating on project-based instruments and measurements. For example, if BIM improves productivity and a firm's competitive advantage (Waterhouse, 2011), there are tangible implications of this in both micro and macro levels. Therefore, while individual organizations grow in technical skills and in business competence to deploy digital innovations in BIM, the cumulative impact on the whole economy is yet another gain.

Over the past years, Bleicher, Sun and ABEF models have been applied to change management theories to assess business performance across different sectors. In estimating practice, they are relevant to the concepts of globalizing estimating practice (Zhen-Yu et al., 2008), learning organizations (Hulett et al., 2008), and integrated solutions (Awad and Fayek, 2011). Like Bleicher's and Sun et al's models, most benchmark models contain vertical and lateral *"Enablers",* and the outcomes are reported as *"Results"* (Zink et al., 2008). Particularly, the ABEF model contains seven categories which are based on 12 quality principles, including goal-setting, action planning, customer value and market focus, innovation and continuous improvement, and leadership. This model also deploys change as a cyclic process; organizations engage in it and assess themselves continuously without an end in mind. For this reason, the change management model of ABEF aims to commit individuals, and the businesses they operate, to a particular approach of change. Through this, they deploy their change models, analyse the outcomes of assessment, improve and repeat the process as much as possible. Thus, practically, it can be used to apply the performance matrix suggested by Succar et al. (2012).

There are more applications of change management models to BIM. For example, Thorpe and Ryan (2007b) explore the relationship between parametric design modelling and innovative outcomes in design processes. However, BIM applications are not limited to design processes alone; they are based on interdisciplinary philosophies which result in intra- and inter-business changes. BIM also incorporates an industry-wide desire for change, e.g. changes in business behaviours, in inputs and procedures for generating outcome, in thinking processes and in the determination approach (Gu et al., 2007, Hannon, 2007, Harison and Boonstra, 2009, Whyte et al., 2000, Zink et al., 2008). These changes are not deterministic; they are continuous and are supported by unique agents, as discussed in Section 3.4.

Before reviewing these change agents, it is crucial to define the frameworks linking ABEF to BIM and estimating practice domains. Firstly, the potential of BIM is interpreted differently in the various practice domains. Automatic quantification, virtuality and simulation have had different uses (Huang et al., 2009b). For example, estimators in functional-unit practice models trust their personal judgment in preference to the outcomes of ABEF deliverables (Section 2.1). Secondly, with ABEF and other change management models (e.g. Bleicher's and Sun et al's models), it is possible to strategize and measure BIM implementation procedures across the four practice domains. These models have made it possible to garner appropriate views on how differently estimators in these domains value the stages and activities leading to the development of estimates in CAD and BIM. Thirdly, it is possible to benchmark the changes triggered by BIM for continuous improvement against estimating processes in CAD and conventional approaches. These are explored in Chapter 6.

3.4 CHANGE AGENTS

Some authors regard BIM as a factor that reduces the gap between construction and other industries that have stepped up their generation and deployment of digital technologies (Carmona and Irwin, 2007). The reality is that construction organizations are structured differently to organizations in other industries; and so their reactions to change, are often inhibited by uncertainty. Evidently, while some organizations would only need to upgrade existing systems, others require significant efforts to become compliant (Kajewski et al., 2001). However, no step to change can be underrated; as a minimum, all construction businesses require appropriate methods and tools to engage new business process initiatives and behavioural re-engineering (BPIBR). Advocates of BPIBR, including Sutcliffe (1999), have argued that it would require rigorous re-organization of a business model to make a difference in a rapidly changing market like that of construction. What will this involve?

Effective separation of power, re-orientation of operational paradigms, staff motivation and skilling will be required. Other studies have put this in context; Sher et al.(2009) have identified skills required to support virtual teamwork, while (Bleiman, 2008) has recommended a re-construction of business operations from fragmented procedures to collaborative thinking and new marketing initiatives.

As indicated earlier, every form of organizational structure can transform into BIM-compliant business models. To achieve this, they would require slightly different process models. Details of how to formulate a workable process model has been documented by Heinrich et al (2009). Meanwhile, an effective change management model would include re-orientation of management strategies, training, staff motivation, deployment of appropriate hardware and software applications, and the need to generate marketable products. Once set-up, these operational systems will also require servicing with timely technical support and turn-around maintenance every time necessary.

Training

Most recent surveys of cost determinants of BIM implementation in Australia agree that organizations need new skill sets to drive BIM (Allen Consulting Group, 2010, Consult Australia, 2010). To develop these skills, personnel must be trained to deploy new technologies and demonstrate specific professional requirements. Because organizations are different, they will require different training packages to manage BIM in line with varying business interests. Moreover, different categories of staff (e.g. management, technical, support staff etc.) will require different training to master their new roles. As stated by Shah (2009) and Zyskowski (2009), BIM implementation training is two-fold, viz start-up and in-line training. While start-up training precedes implementation and could involve new recruits, in-line training is periodic and continuous. The challenge however is how to define appropriate methodologies for determining what to learn *(environment, context, content and structure)*, how *(mode, resource and institution)* when *(duration and time)*, and relate these to business goal(s) and market interests. As indicated by Consult Australia (2010), employers may reduce training costs by recruiting new graduates with appropriate skills and experience as staff members to drive BIM initiatives.

Hardware and software applications

The literature on corporate response to technological change (e.g. (Love and Irani, 2004)) has positioned acquisition of necessary hardware and software applications at the heart of

strategic compliance to specific IT adoption. BIM has specific hardware requirements and specifications differ from product to product, as do the costs from one manufacturer or developer to the other. According to Consult Australia (2010) and McGraw Hill Construction (2007), these costs are driven by the nature of projects, market forces and contractual arrangements (e.g. warranties, maintenance and structured technical supports). While some organizations may need to procure new items, others may not. Additionally, some users require minor or major upgrading on their existing installations. Therefore, regardless of the nature of the business model in question, possible causes of variance in the cost of BIM implementation is based on what a specific organization actually requires to start-up or plans to utilize in the future. In addition, a wide range of other business decisions to make include the purpose or goal of such implementation (Olatunji, 2011b).

Services

Both software and hardware components used in BIM are driven by energy, internet access and access to continuous technical support. According to Shah (2009), services determine the rate and direction of change, and involve different cost factors which partly depend on contractual arrangements between software developers, vendors and end-users. In addition, there are latent risks in services which must be indemnified. Depending on specific needs, there are different insurance products under which construction businesses operate, and this will affect the cost of implementing new advancements. Technical support from other organizations, in terms of consultancies and research, may also be required.

3.5 SUMMARY ON ORGANIZATIONAL AND CHANGE MANAGEMENT MODELLING

Construction estimates represent commercial interests; and these take different forms. Estimators engage in change processes in many ways; depending on the nature of their organizational structures and the change management strategies to which their businesses apply. In this chapter, the connection between organizational psychology, estimating practice and BIM has been established. The different forms of matrix, divisional, functional-unit and network-structured business models were explained as they apply to estimators' skills, estimating procedures and outcomes.

In all of the business models operating in the construction industry, fragmentation is a dominant challenge. While BIM is presented as a panacea, the overriding focus is that BIM is a multi-disciplinary platform offering professionals and construction businesses multi-

dimensional opportunities to re-think the conventional processes that they are used to. Although BIM is an offshoot of CAD, its principles are different; it requires more collaboration, integration and information sharing between project teams and businesses.

The challenge for construction businesses and estimators is how to embrace this change. As a result of this observation, change management theories and models were also reviewed to create an understanding of organizational change. Apart from Succar (2009), Bleicher's model for integrated change management has a strong link to BIM at a micro level, and it can facilitate change both in the realm of project management and business management systems. However, there are other models; Sun et al's model and best practice models such as ABEF are more elaborate than Bleicher's model. Sun et al's model is a holistic approach, while ABEF is applicable for continuous improvement and for multidimensional applications.

All of these theoretical frameworks are critical to process improvements in estimating practice. As indicated in Chapter 4, BIM models appear in different forms. The adoption and utilization of each form depends on the technical parameters that satisfy the requirements of end-users in each business model. Therefore,

- how each business model interprets BIM matters; BIM means different things to different people (see Chapter 4).
- the requirements of each practice domain (as per the business models) must be understood as estimating procedures transit from conventional domains to BIM.
- whatever lens BIM is viewed through, it neither fixes conventional problems in estimating definitively nor assumes the position of an equitable substitute. It is therefore expedient that businesses and individuals explore avenues to change and optimize the opportunities arising from these.
- post-modern literature has failed to articulate procedural changes in estimating practice with the recent rise in technology. Activities leading to estimating outcomes are not likely to be the same across different practice domains across different technological paradigms (e.g. 2D CAD and BIM). These aspects are explored in Chapter 6.
- in theorising and documenting what has changed in estimating practice, the wider spectrum of change applies to different business models differently. Some conclusions to this are drawn in Chapter 7.

4 BUILDING INFORMATION MODELLING (BIM) AND ESTIMATING PROCEDURES

4.0 BUILDING INFORMATION MODELLING (BIM) AND ESTIMATING PROCEDURES

4.1 INTRODUCTION AND BACKGROUND

This chapter addresses two critical issues:

- With or without BIM, estimators follow discipline-specific procedures to generate workable estimates upon which business relationships between contract parties are based (see previous arguments in Chapter 2 and Chapter 3 on estimating goals and construction business behaviours).
- Data entered into BIM platforms are robust and multi-disciplinary. However, they represent an individual discipline's view of a project; not specifically targeted at meeting estimators' requirements regarding improved efficiency in estimating procedures (Dean and McClendon, 2007).

In this chapter, BIM (and its deliverables) is contextualized in estimating procedures. This is done with a view to updating existing theory on estimating procedures which have been documented outside the context of BIM (e.g. (Ashworth, 2010, Ashworth and Hogg, 2007, Seeley, 1996, Seeley and Murray, 2001, Brook, 2004, Harris et al., 2006)). First, the chapter explores the differences in the representation of functional data in various design formats in comparison to BIM i.e. from manual and 2D CAD, and from 2D CAD to 3D CAD and BIM. Further to this, the logical relationships between BIM deliverables and estimating processes are presented.

Thus, the chapter is divided into four sections:

- Section 4.2 focuses on establishing the importance of CAD and BIM in estimating practice.
- Different perspectives on the definitions of BIM, BIM maturity index and types of BIM are articulated in Section 4.3.
- Section 4.4 reviews the current knowledge of BIM deliverables and how they apply to estimating and construction processes.
- In section 4.5, the chapter is summarized.

4.2 CAD AND ESTIMATING OUTCOMES

In the past three decades, CAD has had a tremendous impact on design and construction management practices. To an extent, this has shifted business systems in AEC organizations from fragmented paradigms toward process integration systems (Anumba, 1996). In place of manual procedures, estimating practices have upgraded their tools and procedures to reflect advancements in CAD. Today, most CAE applications rely on CAD as a source of quantitative and qualitative data; they can automatically extract and manipulate data as they want. However, these data neither guarantee nor translate automatically into absolute descriptors of estimates. Nevertheless, they have a significant impact on estimating processes in terms of speed, improved outcomes and innovative procedures, and have opened up estimating practice to more opportunities e.g. VR prototyping (Huang et al., 2009a).

Two CAD paradigms are popular:

1. the conventional 2D CAD, which is used as geometric-data-only (GDO) CAD (Duelen et al., 1987), and;
2. the newer version, which is object-oriented and parametric (OOP) (Gujarathi and Ma, 2011). Object-oriented CAD are also in two forms:
    a. the 3D CAD allows design representation in three dimensions, but only applies to single disciplinary and non-parametric use (Dean and McClendon, 2007, Succar et al., 2012).
    b. there is the multi-disciplinary and parametric project modelling. It refers to digital platforms where different project stakeholders are able to collaborate, share data and integrate their processes during design development (Eastman et al., 2011, Aranda-Mena et al., 2008, Fussell et al., 2009, Succar et al., 2012).

GDO CAD systems mainly rely on geometric features like lines, splines, arcs, circles and other basic forms of design expressions to communicate project features in two-dimensional (2D) representations. According to Gujarathi and Ma (2011), the limitations of 2D have had serious consequences on project outcomes. Specifically, these include the loss of information between GDO CAD sub-systems, compatibility problems between data structures, and a breakdown of association between design data from different sources. Additionally, other limitations noted by these authors are lack of re-usability of knowledge, complex geometry, and the need to simplify design analysis. There is considerable evidence to conclude that

GDO CADs have major limitations in the automation of design processes (Anumba, 1996, Tse and Wong, 2004, Whyte et al., 2000).

The effect of these limitations is well documented, including

- a high propensity for design errors (Love et al., 2000, Acharya et al., 2006b);
- poor project outcomes including limited constructability due to issues with simulation and visualization (Feng et al., 2003, McKinney and Fischer, 1998);
- the dissipation of information due to fragmentation problems, especially the lack of automation between data subsystems (Kagioglou et al., 2000);
- communication problems because there are limited frameworks to support extensive communication in CAD (Dorst, 2007) and;
- the crisis in business relationships between project stakeholders due to these problems (Winch, 2006).

In many cases, researchers have argued that the limitations of GDO CAD systems have plagued project outcomes in several ways and have made new methods of design and project documentation inevitable (Bergsten, 2008). This position favoured the birth of Object-Oriented and Parametric CAD (OOP CAD) which uses intelligent design objects such as *free-form* architecture, and adapts these in *multiple dimensions* (*n*D) for a wide range of applications. According to Welch and Witkin (1994), free-form architecture has been around for many years. It involves forming shapes of objects by using definite attributes of spatial and temporal geometry (Dollar et al., 2005). As indicated by these sources, it is intrinsically difficult GDO CADs to simplify complex design expressions and analyses. However, OOP CAD objects can be embedded with robust information, and this renders them less controversial than what is obtainable in GDO CADs.

The limitations of GDO CAD aggravate many of the challenges that estimators experience with estimating processes (see Chapter 2). Whether OOP CAD ameliorates these challenges or estimators devise alternatives to overcome them using OOP CAD, there are discrepancies between manual estimating procedures and GDO CAD, and between GDO CAD and OOP CAD. Apart from the evidence on this which is presented in Chapter 6, literature suggests that the cumulative effects of the disparity have translated into improvements in modern estimating outcomes (Shen and Issa, 2010, Sattenini and Bradford, 2011).

In the context of other disciplines (e.g. design and facilities management, see Deutsch (2011), Ballesty et al (2007) and Luciani (2007), many of recent successes have been ascribed to BIM and its deliverables. Sections 4.3 and 4.4 explore various interpretations of BIM and the applications of its deliverables to estimating practice. First, in Section 4.3, the capabilities of BIM are presented not only as improved design tools, but also as an infrastructure development *engine*. This view has implications for organizational and business philosophies, particularly in the context of BIM's attributes such as collaboration, integration, value sharing, communication and process automation (Marshall-Ponting and Aouad, 2005, Plume and Mitchell, 2007, Maruyama et al., 2000). Section 4.4 identifies the influence that BIM deliverables have on estimating processes.

4.3 DEFINITIONS OF BIM

A range of definitions and concepts has been associated with BIM. As indicated by Azhar et al. (2008), terms such as *nD* modelling, 3D, virtual reality and hyper-model have been used to describe specific known applications of BIM. However, these terms are not entirely the same. Similarly, some conceptual definitions of BIM have also not remained the same over the last decade. Studies such as Amor and Faraj's (2001) have attempted to clarify some misconceptions about what BIM really is and what it has been misconceived to be. Some inferences from this are that:

i. BIM, being a multidisciplinary concept, triggers different applications across different disciplines as though it means different things to different people or disciplines (Aranda-Mena et al., 2009).

ii. Innovative BIM deliverables are still evolving; as people's awareness of BIM deliverables improves with time, newer knowledge constructs are likely to evolve as variants in BIM definitions (Aranda-Mena et al., 2009).

iii. Based on the literature in the last decade, BIM definitions can be analysed using specific indicators, including by age (e.g. early interpretations versus new definitions), by professional bias (e.g. design versus construction or facilities management standpoints and vice versa), and by its methodological architecture (e.g. content generation, standardization and deployment in different fields of use) (Lee et al., 2002).

iv. By its name, BIM could be mistaken to mean a phenomenon that is limited to the building industry. In contrast, its applications in other fields, including civil engineering and urban planning, have triggered some trans-disciplinary and trans-industry interpretations (Strongitharm and Philbrick, 2009).

BIM as a tool

Succar's (2009) basic connotations of BIM terms provide a baseline for the analysis of estimating practice. Succar's (2009) representation of BIM (Figure 4.1) could be interpreted as a tool for structuring, engineering and packaging the design and operational information of a construction project by using parametric concepts to create visual and actionable representations.

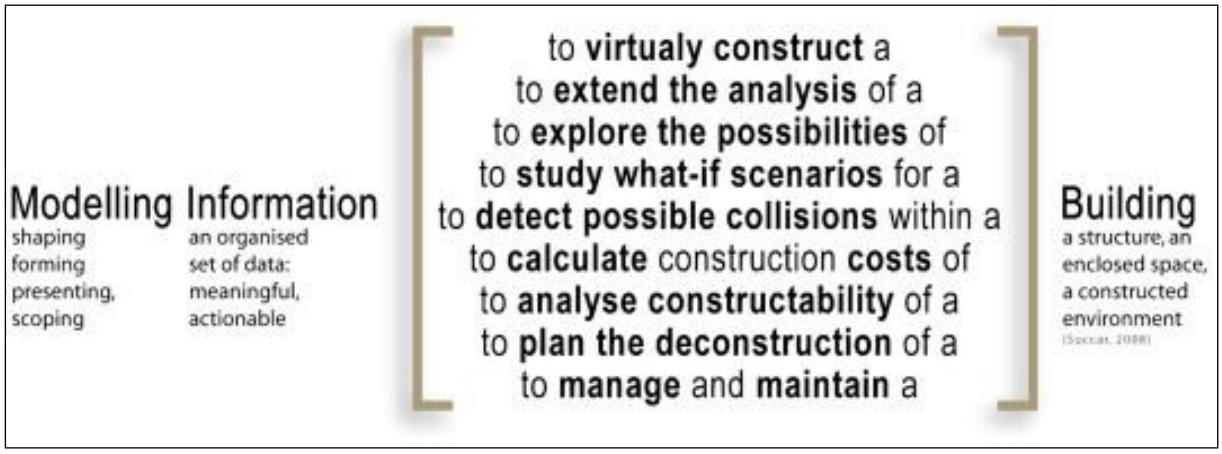


Figure 4.1: Some common interpretations of BIM terms (Succar, 2009)

Earliest BIM definitions have focused on its data representation properties to describe it simplistically as a '*tool*'. For example, in the definition of Gann et al (1996), BIM is described as '*the database for electronic data of a project*' (pg. 3). In Bjork and Penttilä's (1989) definition, BIM is defined as a tool '*for information specifying and structuring'* (pp 178). The perception of Fisher et al (1997) is different, but not markedly better; BIM is described as '*a tool for geometric and parametric representation of a project design*' (pp 5 - 6). Other authors have however had a range of opinions on whether BIM is just a tool or something more. Additional meaning than just as a tool has been ascribed to BIM, especially by looking further into how its parametric features affect infrastructure development either tangibly or implicitly or both. These perceptions are analysed below using basic principles of estimating practice to filter these opinions.

BIM as a system

Amor and Faraj (2001) have challenged the notion that BIM is just a *'tool'*. Citing the works of Gann et al (1996), Bjork and Penttilä (1989) and Fisher et al (1997) where BIM was described as *a tool*, Amor and Faraj concluded that it is technically inaccurate to overemphasize on data representation aspect of BIM alone to illustrate its potential. Rather, they have recommended further reflection on the multifarious applications of its attributes and requirements (or enablers). Figure 4.1 shows that BIM attributes, including virtual reality, simulation, visualization and system integration, are processes involving specific techniques and technologies that drive BIM to achieve specific project outcomes. A definition of BIM without integrating these attributes would be deficient, as it would not convey the complete meaning of BIM.

In addition, the definition of BIM as suggested by the United States of America's National Institute of Building Sciences (NIBS) (2008) has frequently been noted in most literature on BIM as an acceptable perception of what BIM is. Such agreement has emanated from different parts of the world; Aranda-Mena et al (2008) have used the definition to develop a national guideline for BIM utilization in Australia, while Eastman et al (2011) among others have used the same definition to define BIM in Europe. The latter authors have quoted the NIBS' definition of BIM as:

> *"An improved planning, design, construction, operation and maintenance process using standardized machine readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle".* (p. 15 - 16)

Similarly the International Alliance for Interoperability's (IAI) definition has been cited in many studies (including (Hassanien Serror et al., 2008, Munzner, 2009, Aranda-Mena et al., 2008). The IAI has defined BIM as:

> *"...a new approach to being able to describe and display the information required for the design, construction and operation of constructed facilities. It is able to bring together the different threads of information used in construction into a single operating environment thus reducing, and often eliminating, the need for the many different types of paper document currently in use..." (AIA, 2007)*

From the definitions of both the IAI and USA's National Institute of Building Sciences (2007), BIM is defined as an '*approach*' to generate and standardize project information and it is able to 'utilize' a specific stream of cutting edge technology for integrated information.

From these views, it appears that BIM is more than just a '*tool'*. Other definitions, such as the Associated General Contractors' (AGC) (2006) have made this clearer, viz

> ***"Building Information Modeling*** *is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a* ***Building Information Model****, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility. The process of using BIM models to improve the planning, design and construction process is increasingly being referred to as Virtual Design and Construction (VDC)" (pp 3).*

BIM as a Knowledge Domain and Practice Method

Integrating the perception of Penttilä (2006) into previous views, Succar (2009) sets the meaning of BIM into context (see Figure 4.2), stating that

> *"Building Information Modelling (BIM) is a set of* ***interacting policies, processes and technologies*** *generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"* (pp. 357).

There are three components of BIM according to Succar's (2009) definition, viz tools, processes and methodologies. Succar referred to 'interacting policies' as a 'tool' component of BIM. Similarly, other researchers have contextualized BIM in the same way. BIM has been identified as a *tool* for collaboration (Gu et al (2008) and a *tool* for change management (Gu et al (2007). Some other studies have identified BIM as a *tool* for system integration (Hassanien Serror et al., 2008), for communication (Huang et al., 2009b, Marshall-Ponting and Aouad, 2005), as a database (Jeng and Eastman, 1998), and for learning (Gül et al., 2008).

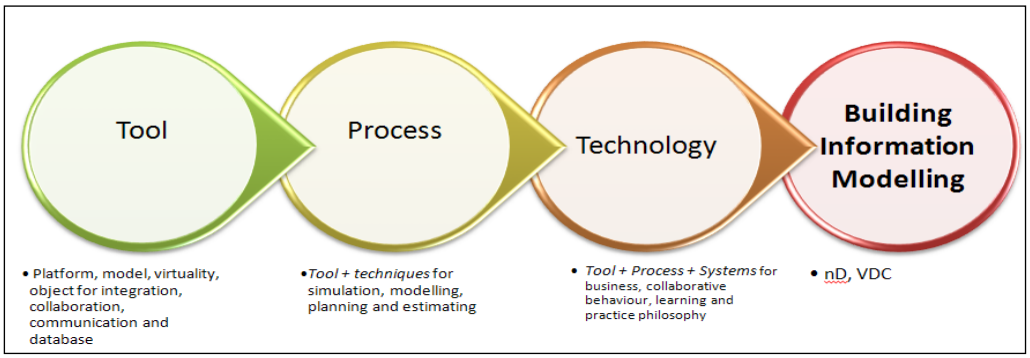


Figure 4.2: BIM interpretation framework. Adapted from Succar (2009)

Process is also identifiable as what BIM stands for (Succar (2009). The conventional meaning of the word 'process' is not synonymous with 'tool': www.dictionary.reference.com defines a '*process*' as '*a systematic series of actions directed to some end*'. This implies, a '*process*' involves at least a combination of tool(s) and techniques in a controlled *environment* to achieve definite outcomes or objective(s). BIM encapsulates certain processes to formulate the lifecycle information of a construction project. These processes have been represented in the form of parametric designs, simulations (Maruyama et al., 2000), project planning (Heesom and Mahdjoubi, 2004), cost estimation (Abdelsalam and Gad, 2009, Broekmaat, 2008), and virtual reality modelling (Lee et al., 2006, Associated General Contractors (AGC), 2006).

Figure 4.2 illustrates the last component of Succar's (2009) definition of BIM as *'technologies'*. In a broader sense, a considerable body of knowledge has underlined for decades the relationship between BIM as a technology and, BIM as a knowledge domain and practice method (Queraltó, 1998). Specifically, the 'business sense' of BIM's digital, integrative practice method has been clarified by Aranda-Mena et al (2009). Meanwhile, apart from Aranda-Mena et al (2009) and Succar et al (2007), some authors have described BIM as an emerging technological and procedural shift affecting all stakeholders within the Architecture, Engineering and Construction industry (Azhar and Brown, 2009, Boon, 2009, Eastman et al., 2011, Fussell et al., 2009, Jiang, 2011). The *'emergence'* of BIM is still occurring; what could be known about its deliverables is still in progress across many construction disciplines. Recent studies that share this perspective have attempted to predict the environment under which BIM will operate when it becomes fully operational (Hardin, 2009).

In another illustration of BIM being a technology, Boddy et al (2007) identified mobile computing as an area of future relevance to BIM, whilst Wikforss and Löfgren (2007) identified it as the next level of communication practice in the construction industry. The perspective of Olatunji (2011a) is similar to these; the author identified BIM as an enabler of business re-orientation, notwithstanding the marked drawbacks in existing legal frameworks for these to be successful. These drawbacks are reflected by Fairfield (2005), McAdam (2010) and Olatunji (2011c) as legal and institutional issues that may impede industry uptake of BIM. These issues are beyond the scope of this study.

BIM in the context of estimating

Based on the analysis above, this study summarises the definition of BIM in the context of estimating practice as follows:

> *"A digital system of facilitating a data-rich, object-oriented, intelligent and parametric representation of a construction project, from which views and data appropriate to various users' needs can be extracted and analysed to generate information and enhance decision-making on project economics, and improve project delivery processes."*

4.3.1 BIM uptake and maturity in Australia

Considerable research has focused on BIM in Australia, investigating the macro-mechanics of its adoption (Succar, 2009), the business dynamics of its implementation (Aranda-Mena et al., 2009), skilling and deployment framework (Sher et al., 2009), teaching and learning pedagogies (Gül et al., 2008), and monitoring the impact of its adoption (London et al., 2008). There is a wealth of evidence in these studies regarding the precise picture of BIM deliverables at later stages of its adoption. As outlined by Fussell et al (2009), and frequently cited in many studies on BIM in Australia, there are four stages in BIM's full adoption:

i. The shift from manual to GDO CAD,
ii. Single-disciplinary use of 3D modelling,
iii. The sharing of object-based models between two or more disciplines, and
iv. The integration of several multi-disciplinary models using model servers and network-based technologies.

Figure 4.3 shows the current BIM adoption in Australia in a universal maturity index. Researchers like London et al (2008) have claimed that the rate of BIM adoption is slow; however recent studies (such as (Garcia, 2011) suggest a marked improvement. According to Consult Australia (2010), progress will continue into the future. Similarly, evidence has emerged on BIM maturity suggesting that there are two directions of growth in BIM utilization, viz. growth through design and through non-design disciplines in project implementation. As BIM is an offshoot of CAD, it started off as biased to design disciplines. Thus, knowledge progression in design disciplines regarding BIM is said to be vertical. The second dimension to knowledge advancement in BIM is how non-design disciplines have advanced BIM-based innovations. While design disciplines advance BIM potentialities

vertically, non-design disciplines apply its potentialities laterally (Koppinen et al., 2008). An understanding, and the implications, of the enablers across both lateral and vertical dimensions is the focus of the review on types of BIM models and BIM deliverables contained in Sections 4.3.2 and 4.4.

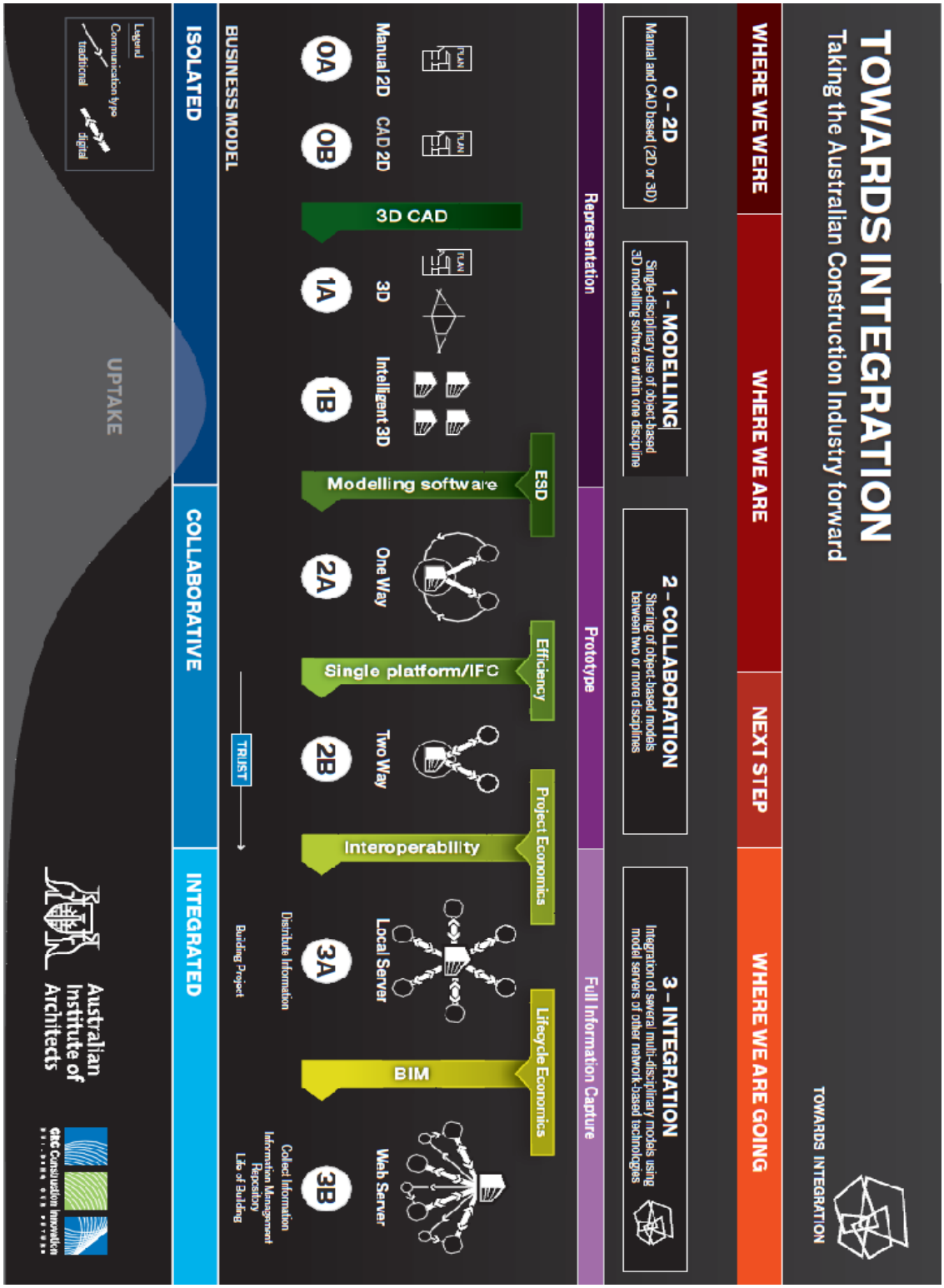


Figure 4.3: Australia in global maturity index for BIM adoption (Consult Australia, 2010)

4.3.2 Forms of Building Information models

BIM is a multi-dimensional (nD) platform that applies to professional operations throughout a project's lifecycle, from surveys and geographic information systems (GIS) to project design, from design to process modelling and resourcing, from resourcing to planning and estimation, from estimation to construction, and from construction to facilities management. Within the GIS domain alone, recent research (e.g. Kolbe et al. (2011)) has focused on improving 3D data acquisition technology through remote sensing, photogrammetry, laser altimetry techniques (LiDAR), and visualization technology (3D CAD and Virtual Reality (VR) system), both for construction and 3D urban environments.

As a consequence of this expansion of knowledge, several types of 3D models have evolved, viz. the Tetrahedral Networks (TEN), Constructive Solid Geometry (CSG) models, Regular Polytopes, TIN Boundary representation and 3D volume quad edge structure, layered and topology models, voxel-based models, polyhedrons and other forms of 3D models which are used in urban planning and *n*D modelling. These 3D forms are not the same as BIM, but have been used to integrated BIM and GIS. Together, both have been applied in building design and construction, and in civil works (Drogemuller, 2009, Shen et al., 2010b, Berlo and Laat, 2011).

What do those applications mean to estimating practice and procedures? There are few answers to this question:

- The term nD means more than one thing, especially to design and surveying disciplines. Each of these views is being integrated, even though they have different applications to estimating procedures.
- The applications of 3D and nD in surveying are as important to estimators as their applications in the design discipline, but such surveying views are under-researched. For example, it is uncommon to have earthworks in building designs in a 3D view. This means estimates of earthworks can only be provisional; they cannot be definitive until all works relating to them have been finalized during execution. Additionally, when this knowledge is used for urban planning, it enables the visualization of fixed capital formation in parametric form (Harris et al., 2006).

- Ultimately, when nD capabilities are integrated into both the design and surveying disciplines, there is more certainty as to what estimators can visualize during estimation than when they are not present.

Furthermore, there are other non-design applications of BIM which are critical to the success of estimating outcomes. Yesilbas and Lombard (2004) have observed/noted how *n*D modelling is instrumental to a sensitivity analysis of a proposed facility. Isikdag, et al, (2007) have also identified similar opportunities in disaster mitigation and emergency response. Although the applications of BIM reported in these studies only apply at best to conceptual estimating, their impact in identifying preliminary cost descriptors is critically important. Whilst Yesilbas and Lombard's (2004) work can be adapted for feasibility analysis and value engineering, Isikdag, et al's (2007) study is applicable to the '*benefit-cost*' analysis of disaster mitigation and the '*cost-benefit*' analysis of post disaster re-construction.

A way to rigorously delineate how estimators put BIM models to use is to explore from the perspective of the vertical enablers i.e. by taking cues from design perspectives. As shown in Table 3.1, there are seven types of BIM models, each of which means different things to estimating procedures and outcomes.

Table 4.1: *Forms of Project Models and their relevance to estimating practice (adapted from (Succar, 2010)*

Stage in Facility Lifecycle	Primary Descriptors	Secondary Descriptors	Relevance to Estimating Practice
Project Initiation, Design and Planning	Visualization	*3D-Design authoring*	Not applicable as estimator's role (Cera et al., 2002)
		Design Iteration and Review	Not applicable as estimator's role (Steinberg and Hunter, 1984, Smith and Eppinger, 1997)
		Documentation and Detailing	Not applicable as estimator's role (Leicht and Messner, 2007)
		Laser Scanning	Relevant, but still unpopular. It applies to automated valuation in the future (Bennett, 2009)
		Photogrammetry	Relevant, but still unpopular. Iit applies to remote access and work progress monitoring (Bayrak, 2008)
		Rendering and Representation	Not applicable as estimator's role (Dollner and Hagedorn, 2008)

	Virtual Reality	Relevant; it applies to process modelling and planning (Whyte et al., 2000, Suermann, 2009)
	Augmented Reality	Applicable, but not yet popular as estimator's role (Haniff and Baber, 2003, VTT, 2009)
Analysis	*Code Checking and Validation*	Not applicable as estimator's role (Hjelseth and Nisbet, 2010)
	Cost Management and Control	Significantly relevant (Nummelin and Salo, 2010)
	Finite Element Analysis	Indirectly relevant. Could be used for value engineering (Balkaya et al., 2006)
	Fire and Smoke Simulation	Indirectly relevant. Can be extended to conceptual estimating of '*cost-benefit'* and *'benefit-cost'* analyses of alternative options (Spearpoint and Dimyadi, 2007)
	Lighting Analysis	Indirectly relevant. Can be extended to value engineering (Brognano et al., 2010)
	Quantification	Significantly relevant (Sabol, 2008, Saleh, 1999)
	Estimation	Significantly relevant, using cost databases (Samphaongoen, 2010)
	Site Analysis	Significantly relevant. Can be used for risk analysis (Clevenger and del Puerto, 2010)
	Solar Radiation	Indirectly relevant. Can be extended to value engineering (Newland, 1989)
	Spatial Coordination and Clash detection	Significantly relevant. Can be used for quantification and estimation (Velasquez et al., 2008)
	Structural Analysis	Significantly relevant. Can be used for value engineering (Nielsen and Madsen, 2010)
	Sustainability	Indirectly relevant. Can be extended for conceptual estimating (Mihindu and Arayici, 2008)
	Life Cycle Costing	Significantly relevant (Kajewski et al., 2003, Mihindu and

			Arayici, 2008)
		Thermal Analysis	Indirectly relevant. Can be extended for conceptual estimating (Laine et al., 2007)
		Wind Studies	Significantly relevant. Can be used for value engineering (Lee and Doosam, 2010)
Construction	On-Site Construction	*Constructability*	Significantly relevant. For process modelling, risk management and project planning (Li et al., 2009)
		Construction Operations' analysis	Significantly relevant. For simulation and virtual reality (Huang et al., 2009b, Kolbe et al., 2011)
		Construction Specification	Significantly relevant (Dean and McClendon, 2007)
		Construction System design	Significantly relevant (Khanzode et al., 2008)
		Demolition	Significantly relevant. For risk analysis and simulation (Azhar and Brown, 2009)
		Field BIM (Mobile computing)	Improving relevance (Venkatraman and Yoong, 2009)
		Planning and Scheduling	Significantly relevant (Bergsten, 2008, Heesom and Mahdjoubi, 2004)
		Trade Co-ordination	Significantly relevant. For on-site training and communication (Chen et al., 2002)
		Work Packaging	Relevant (Maruyama et al., 2000)
		Bid preparation	Significantly relevant (Grilo and Jardim-Goncalves, 2010)
		Contract documentation	Significantly relevant (Luciani, 2007, Mow and Naylor, 2010)
	Off-site manufacturing	*Precast concrete* *Steel Fabrication* *Casework*	Significantly relevant. For on-site training and communication, and to avoid rework (Chen et al., 2002)
	Procurement and Delivery	*Equipment and fittings* *Finishes*	Significantly relevant (Ballesty et al., 2007, Grilo and Jardim-

		Furniture	Goncalves, 2010).
Facilities Operation	Facilities Management	*Asset Tracking*	Significantly relevant (Ballesty et al., 2007, Luciani, 2007)
		Asset maintenance	
		BIM/GIS Integration	Significantly relevant. Could be used for risk analysis (Dollner and Hagedorn, 2008, Kolbe et al., 2011)
		Space Management	Not directly relevant (Nigudkar, 2005)
		Record Keeping	
		Relocation Management	
	Simulation	*Building System Management*	Significantly relevant (Liu, 2010)
		Disaster Planning, Egress and Ingress	Indirectly relevant. Can be extended to the conceptual estimation of 'cost-benefit' and 'benefit-cost' analyses of alternative options (Isikdag et al., 2007)
		Energy Consumption Analysis	Significantly relevant. Can be used for value engineering
		Occupancy Tracking	Significantly relevant (Ballesty et al., 2007, Grilo and Jardim-Goncalves, 2010)
		Site Utilization Plan	Significantly relevant (Nigudkar, 2005)
Process Optimization	Lean Construction		Significantly relevant (Khanzode et al., 2007)
	Materials management		Significantly relevant (Hänninen and Oy, 2008)
	Knowledge visualization		Significantly relevant (McKinney and Fischer, 1998)
	Value management		Significantly relevant (Hänninen and Oy, 2008)

In Table 4.1, forms of project models and how they are put to use in construction project lifecycle stages have been identified. These are visualization, prefabrication and construction models, and models for design analysis. Others are procurement models, and facilities management and simulation models. Specific descriptors of these model forms have also been identified and related to estimating practice by the authors cited in Table 4.1: some are significantly related to estimating processes, some are indirectly related, and some are not

related at all, while some are related but not yet popular at present. As different methods of estimating apply to the various uses of BIM models, additional details are provided below on these BIM deliverables, and their relevance to the theory and practice of estimating in the construction industry.

Design Visualization Models

According to Jefferis and Madsen (2005), presentation drawings, working drawings and sketches are often used in design. While sketches are drawn freehand, presentation drawings are made with raster (made of pixels) CADs and working drawings are made with vector CADs. Wakita and Linde (2003) explain that raster images can be elongated, stretched, compressed and formatted to specific forms of presentation. These modifications need to take place without changing the original geometry of the design when adjustments are made. Vector images on the other hand, can be rotated and viewed from a range of perspectives, viz. top, front, back, left, right, underside and from an unlimited number of views in between the different perspectives. Usually raster graphics are in the form of *.bmp, .png, .jpeg, .jpg, .pcx, .tiff* and *.gif*; while vector graphics are in the form of.*dwg, eps, dxf* and othe forms of patform representation where parameters are mathematically-defined.

Either as architectural or engineering design models, both raster and vector representations can be visualized and manipulated seamlessly, from 3D to 2D and vice versa. Both forms are also made from data-rich objects, which usually contain robust information (Munzner, 2009). However, there are distinctive features in what both forms of representation contain. Unlike working drawings, the objective of presentation drawings is to aid presentation, visualization and analysis. They are often devoid of reference to materials, construction methods or measurement details such as accurate scale and principal measures (Leupen et al., 1997). Both formats can be used for estimating; however estimators prefer to rely on vector drawings because these contain the metadata that they require substantially for quantification and estimation. As raster images have a distinct purpose, viz. to aid static graphic presentation, they are easier to use for detailing documentation.

Estimators use different CAE applications (and procedures) to generate outcomes with both vector and raster visualization models; either through fragmented procedures (e.g. Dean and McClendon (2007)) or in form of integrated solutions (e.g. Bleiman (2008), McGraw Hill Construction (2010)). Among others, Tse et al (2005) have outlined how design processes

have transited from conventional CAD to BIM. Moses et al (2008) have also explored and articulated *.xml* methodologies including *.dwg and .dxf* formats, upon which communication and integration between users of BIM design tools are based. Maher (2008) has put this further into context, stating that communication between BIM design systems is anchored on server-based architecture which allows multiple users to have simultaneous access to BIM servers, including on-screen communication with each other in real-time. The typology for this communication arrangement has been indicated as Figure 4.4.

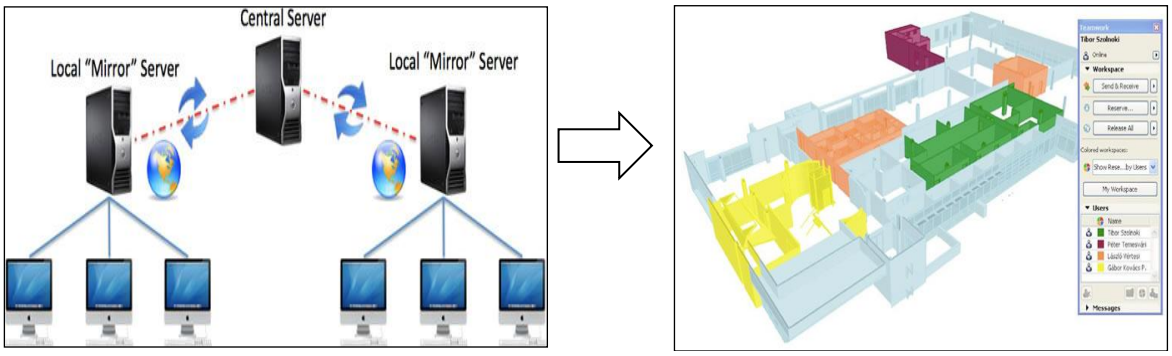


Figure 4.4: System typology and simultaneous access to design visualization model

This has the following implications for estimating:

- A collaborative platform such as this markedly reduces the chances for design conflict (Lee, 2010, Velasquez et al., 2008). For example, Dermott and Cockeram's (2011) methodology for clash and conflict detection illustrate that BIM can be used for this clash and conflict detection.
- As per Chapters 2 and 3, different estimating practice domains require estimators to explore estimate data through different procedures. Therefore, using BIM, what activities lead to satisfactory outcomes in each practice domain? An answer to this is explored in Chapter 6.
- With the range of deliverables in design visualization models (Section 4.4), estimating outcomes are likely to be more accurate, faster to generate and richer than manual and GDO CAD approaches (Sattenini and Bradford, 2011, Suermann, 2009, Vozzola et al., 2009).

Design Analysis Models

Project teams often subject design models to rigorous analyses to ascertain how major components will perform under specific circumstances. When design models are analysed, data models are tested for ease of use, transferability to other platforms and their ability to support project goals. According to Salmasi (2010), features of design analysis models include increased cohesion and de-coupling of model visualization and controllers such that model outcomes are strengthened. As outlined by Amor et al (2007), design models at different design stages could be analysed through data models by using a wide range of metrics which include:

(1) testing the strength of the data upon which design models are based

(2) determining whether such data can be maintained over a long period of time

(3) evaluating the correctness, accuracy and completeness both in the data themselves and when they interact with other data models.

As argued by Piattini et al (2002), analysing data models can affect project costs and quality significantly. Moreover, researchers (e.g. Amor et al. (2007)) have explored whether current forms of schemas and data modelling approaches used for creating BIM models possess appropriate quantitative and objective measures to reduce subjectivity, bias, and hidden and unintended errors in BIM modelling processes. For example, Amor et al (2007) conclude that, although some progress has been made on how schemas and data models are created and deployed, there are still unnecessary complexities which may impact on the integrity of BIM processes and project outcomes. These complexities are mainly based on technical limitations which are inherent in how data models are structured.

How then does this affect estimating? Among other ways, project models are based on IFCs and schemas, and these are driven by data modelling mechanics. If the semantic integrity of data is compromised, there are dire consequences for estimating outcomes as the models move between data input ends. Moreover, if there are inconsistencies in data modelling mechanics, confusion will arise in the outcomes of project modelling. This is not the only problem that can affect project outcomes and construction costs in particular; translators of descriptive data used as disciplinary ends also have to be accurate. If they are not, errors and omissions will jeopardize estimates' integrity. Translator-applications used for estimating are further discussed in Section 4.4.

On-Site Construction Models

Design models are usually *static*. They are usually aimed at showing how the final product will appear when constructed. To achieve this, specific construction processes must be undertaken. Mainly, this will involve combining human, materials and plant resources in a strategically planned manner to achieve project outcomes. Norberg (2008) used BIM, location-based planning, 4D modelling and Field Force Automation to illustrate how design models can synchronize co-ordinated process agents (CPAs) in a particular work-flow pattern, such that project models are rendered interactive and motional. This procedure is popularly known as Virtual Reality (VR), Virtual Construction (VC) or Virtual Design and Construction (VDC) (Huang et al., 2009b).

Pelosi (2007) has also described process-based BIM modelling in the form of architectural hyper-models (AHM). The author made a strong case that this could be the next preferred style of contract documentation in the construction industry. This means that instead of static texts and images either on paper or in digital form, projects can be documented, visualized and analysed in motional formats. There are many benefits in this, viz.

- In a clear demonstration by Nasios (2001), virtual reality is used to mitigate risks and uncertainties through on-site training.
- Lucas and Thabet (2007) and König et al (2007), among others, have also demonstrated how virtual reality exposes non-value adding activities during construction, improves resource efficiency and gives project stakeholders the opportunity to visualize the values of alternative options in project planning.
- These achievements, already made available in BIM, are the Achilles heel in conventional CAD systems (Popov et al., 2010).

VR is a deliverable of BIM; however there are other deliverables of BIM that help estimators during decision-making i.e. design visualization and design analysis models. While the models made specifically to aid visualization and design analysis are static and only show the product, VR can replicate real construction motions, showing resources and processes that would be necessary to achieve the product. As the adoption of design visualization models continues to improve as a medium for project documentation, VR equally stands a chance. Whether in paper-based or digital forms of estimating processes, or as VR-based estimating processes, the challenge for estimators is how to use these tools to predict construction costs and plan project executions accurately. Whether according to the conventional prescriptions

in the Standard Methods of Measurement or as project-specific *location-based* scenarios, VR simulation is not an absolute solution to estimating challenges. The following factors shows why:

- Realities on site are often different from virtual scenarios. There is therefore a wide gap in existing knowledge on how to balance the two phenomena (realities on site and VR), especially with contingencies and perpetual uncertainties in market macro-variability (Lyons and Skitmore, 2004).
- There is no framework for valuing ownership to intellectual property in VR. To reward professionals' efforts, clients need to understand how to value and protect their rights as well those of the professionals who have contributed in developing the model. Authors such as Hoxley (2007) have expressed their views on this, stating that reward methods as used for fragmented services (e.g. professional scale of fees) do not apply because the procedures and platforms through which such services are rendered is different.

Prefabrication Models

Prefabrication and industrialized systems are popular in construction processes. Recent studies in this area have spanned the standardization of manufacturing and integration processes between off-site prefabrication processes and in-situ construction (Winch, 2003). An additional illustration (Engstrom et al (2007) has demonstrated that the methodologies for prefabrication architecture in building construction should include designing, modularization and integration of forms, functions and construction. CAD drawings are usually made to fabricators, showing the detailed component requirements. Meanwhile, with spatio-temporal complexity in GDO CAD systems, OOP CAD has the edge to drive satisfactory design outcomes (Alwisy and Al-Hussein, 2010). Models made in 3D facilitate multi-perspective manipulation and visualization, and contain robust metadata on design, sourcing, fabrication, installation and other necessary information which is often absent in GDO CAD.

Prefabrication models are different from the other forms of models discussed earlier; only a portion of construction work can be pre-fabricated. While prefabricated models convey details of these components, other model types convey information on all project components viz. the in-situ and the prefabricated components. There is yet another difference; the former contains data on sourcing as though items are prime-cost elements (usually requiring unitary

or all-in estimate), while the latter requires items to be estimated comprehensively i.e. elements broken down into every possible component. The technical implication of this disparity is significant. According to Lock (2007), contractors' *Attendance* benefits and profits could become exposed unnecessarily when prefabricated models are used as the basis for estimation.

Procurement Models

The four forms of BIM models described above are targeted at construction; they contain project-specific details that assist estimators in determining what project estimates should contain. However, estimators need more than these to generate accurate outcomes. They require models to show more than what a design normally contains like the length, the breadth, number, area, volume, weight, height and texture. In contrast, details that suggest how quality and quantities come together to affect cost, including specific data on sourcing and application methods to assist estimators make reasonable decisions.

Until this point, whether procurement information is present in BIM models or not, there are basic components in product model representations that can be moderated or engineered to aid procurement. The following are examples:

i. *IFC metadata:* the primary information domain of product model. Some studies have reported how IFCs have been used for estimating and procurement (Mao et al., 2007, Begley et al., 2005, Halfawy and Froese, 2005, Zhiliang et al., 2011). However, in its application to estimating, IFC grammar must be structured in ways that are specific to estimator's approach to estimating. Firstly, as indicated earlier, product models are not primarily made to meet estimators' requirements. Thus, when exported, such data have to be refined and moderated to meet estimators' needs.

   Secondly, model IFCs are not a perfect representation of either the product or the construction process; models are mere perceptions, actual events could be different (Venugopal et al., 2010). Therefore, errors in models, including the IFCs underlying them, are translated automatically as inaccuracies in project estimates if they are automatically adopted.

Thirdly, a substantial part of what estimators estimate is not present in product models; and thus cannot be contained in IFCs. Examples of such items include general items and earthworks which could account for a significant portion of project costs. These also include other items of work that are only represented in projects models provisionally subject to further evaluation when the actual work is completed.

Fourthly, there are currently no generally acceptable guidelines as to how estimators put costs into models or IFCs; instead they only have software applications to rely on (Dean and McClendon, 2007). In the view of Akintoye and Fitzgerald (2000), such practices can be inimical to estimating outcomes. Thus, such procedures are cut out from the auto-updates that occur when models are updated and published; to keep up with such updates, data would have to be exported from models each time a re-population is made.

ii. *Integrated applications,* which are dedicated to BIM, combine a series of estimating operations, such as resourcing and planning, estimating, conversion of estimates to tender and cashflow simulations (Liu and Wang, 2008, Olatunji and Sher, 2010a). These applications (Section 4.4) can populate and moderate data from BIM models in different ways to strengthen the bases for estimating. This is the most commonly practised approach to estimating with BIM (Dean and McClendon, 2007).

iii. *Process-modelling is* a rapidly growing domain of practice in which estimates are shown on visual process models. They are not 'static' product models as discussed in the two previous approaches above (Popov et al., 2010). While product models are not structured to reflect estimators' rationales for costing or process resourcing, rather than relying on a straight list of items from IFCs, process models allow estimators to moderate and re-model project models to reflect the exact construction approach that would be deployed on the project. Few things are contained in this: the construction method statement-demonstration, integrated project plan, the estimate, cashflow plan, resource plan and a tool for communication and training (Mao et al., 2007).

Recently, the debate on using BIM procurement models has increased both in rigour and objectivity (Grilo and Jardim-Goncalves, 2011). Some potential benefits of this aspect of

BIM have been outlined by Ajam et al (2010). However, there are still some constraints regarding how the benefits can be optimized. In particular, BIM-based integration, being a new phenomenon in the construction industry, has the overarching challenge in creating appropriate mechanics to manage the change it will pose to conventional processes. While its framework is still been formulated, some effort is required to address the legal limitations of such paradigm shift, from conventional fragmented processes to the new era of integration (Ashcraft, 2008).

Facility Management and Facility Simulation Models

All data and information in a product model could play critical roles during facilities operation. Facilities' managers often need as much information as they can get on facilities design to enable them to make appropriate decisions during the facilities' operation (Clayton et al., 1998). However, in conventional GDO CAD systems, it is hard to transfer information from the design to the facilities management (FM) phase. As described in Olatunji and Sher's (2010b) critical analysis on the applications of BIM in FM, BIM marks the end of an era when bulky as-built drawings are stored and transmitted in large boxes. Rather, it has become increasingly easier to transfer extremely large data showing all stages of a project history on one single model, from conception through to design, procurement, fabrication, construction and delivery.

Moreover, the demand for intelligent construction has increased markedly in the past decades (Rutishauser and Schafer, 2002). Many neo-classical facilities now have sensors and actors that make buildings behave automatically. As detailed by Luciani (2007, 2008), the evolution of BIM has triggered a massive revolution in the FM industry; knowledge is easier to transfer between design and facilities operation disciplines, situation reports on facilities operation can be generated automatically, assets can be tracked and facilities can alert users when maintenance actions are required. Additionally, the behaviour of intelligent and human actors can be simulated, analysed and optimized.

What manner of information therefore does FM and FM simulation models contain, and how do they affect estimating practice? FM and FM simulation models integrate any relevant model that had ever existed on a project and inform FM solutions' providers regarding original rationales behind design decisions on components' performance, space creation and allocation. Information from procurement and construction models also assist in modelling

and sourcing replacements and/or their alternatives for future alterations, modernization, conversions and rehabilitation efforts (Ballesty et al., 2007).

The implication of the extensive application of intelligence in constructed facilities is that the performance of asset components can be studied, controlled and scheduled. In the same manner, lifecycle costs of all items can be estimated and indexed to make estimates responsive to time-value of money. Some recent studies outlined by Alexander (2008) and Ballesty et al (2007) have demonstrated how BIM has been applied in a range of case studies, including the context and content of data in FM models and how these were applied for procurement and other FM solutions.

Process Optimization Models

Not surprisingly, the application of BIM in construction has moved in different directions. Theorists of process optimization in construction management have frequently developed and used many IT tools for solutions in the past decades. According to Eshtehardian et al (2008), the main goal of process optimization is to improve process efficiency, save resource input and improve product performance. Conventional theories in this particular area of construction management research include lean construction (Camarinha-Matos et al., 2009, Tzortzopoulos-Fazenda and Kagioglou, 2003), process re-engineering and strategic business management (Ireland and Kennedy, 2001, Kirkham, 2005, Oyegoke, 2007), knowledge visualization (Burkhard, 2005), material management (Georgy and Basily, 2001) and value management (Cha and O'Connor, 2005).

Whilst knowledge in these areas is growing fast, some studies have examined specific applications of BIM in some aspects of those knowledge areas. For example, the popular Eastman et al's (2011) *BIM Handbook* has outlined the synergy between BIM and lean construction including the last planner system, collaboration for integrated project delivery and work scheduling. Moreover, et al. (1999) have developed a process re-engineering model. As explained in Chapter 2, Kagioglou's model underlines the role of BIM in reducing estimating error and promotes integration and cost efficiency construction cost management.

In summary, BIM is a unique phenomenon; it means different things to different people and its forms are used for different purposes. From a richly nuanced context of design application of BIM, a construct of knowledge on the relationship between BIM and estimating has been carved out. To avoid ambiguity in reference to BIM, specific types of BIM models and their

specific applications to estimating processes have also been discussed. The new horizons of estimating have different business implications to different practice domains for estimators. The synergy between these – BIM model types and the business implications of their application in different estimators' practice domains – has been elaborated through a carefully articulated summary of BIM deliverables, in the context of estimating practice.

4.4 BENEFITS OF BIM DELIVERABLES TO ESTIMATING PROCESSES

BIM models have many attributes that offer different deliverables with considerable impact on AEC disciplines in different ways. These attributes have featured in several reports to include parametric information, visualization, simulation, value integration, technological and process integration, collaboration, effective communication between project stakeholders and virtual reality. As discussed below, each of them applies to estimating processes in different ways:

***Parametric Information*:** BIM models contain volumes of data, only part of which estimators require. That is not where it ends: model metadata are updated as a whole when changes are made to models – i.e. when changes are made to a part (e.g. change an elevation), all plans and sections are updated automatically. Estimators benefit from this in several ways:

- Courtesy of parametricism, only updated data are exported and filtered to generate estimates. Otherwise, quantity calculations will have to be repeated as many times as changes are made. Thus, rather than spending a long time calculating quantities of work, estimators concentrate on moderating – i.e. exporting, filtering, ordering and regulating – model data as appropriate and putting costs unto them.
- Metadata are near-perfect representations of product attributes. Although, modellers might now reflect every possible element required to create the model, the descriptive data of the product model are adequately reliable for further steps in estimating – e.g. conversion and moderation.
- Parametric capabilities in BIM facilitate seamless representations of complex shapes (Hubers, 2010). These representations can be viewed in multiple perspectives to generate appropriate understandings of allied risks and construction approaches. More importantly descriptive data can be extracted from such elements automatically.

Automatic Quantification

Estimators have extracted data from electronic drawings several years before BIM – for a list of estimating applications that work with and without BIM, see Section 4.5. Even where such

data are not embedded, images can be digitized and calibrated to make data extraction faster, easier and more accurate than in manual processes (Tse and Wong, 2004). However, electronic data contained in CAD files are not always perfect, and estimators have had to grapple with the limitations of automated quantification from such scenarios.

With BIM, automatic quantification is a common capability (Farah, 2005) – see Figure 4.5 showing an example of automatic quantification underlying BIM model. Demonstrations in studies such as (Kim et al., 2009a) shows quantification in BIM as though quantity take-off requires very little human action. Other studies have further described it as quick, accurate and comprehensive (Nagel et al., 2009, Sabol, 2008, Laine et al., 2007). In agreement with these possibilities, Eastman et al (2011) concluded that automatic quantification in BIM implies that estimators do not need to bother about calculating quantities anymore but to concentrate on pricing, resourcing and planning.

Figure 4.5: Automatic quantification in BIM design models

The technical implication of Eastman et al's (2011) view may be questioned; is it actually true that there are no risks for estimators to adopt auto-generated quantities from drawing? Should anything go wrong with the quantities (e.g. model errors, translators being unable to pick up certain model components or omissions) who takes responsibility? Some studies have addressed these questions. According to Treldal (2008), it is often frustrating for estimators to adopt the outcomes of automatic quantification when models are erroneous and incomplete. Kim et al (2009a) add another perspective; data extracted from product models are unreliable as an absolute basis for estimating because they do not represent the "*exact state of construction"* (pp. 493). A consideration of the "exact state of construction" will include risk management, construction method conceptualizations and considerations for working space, wastes, lapping, bulking and rework. To overcome this challenge, Kim et al (2009a) recommended re-forming the entire design model, a process the authors described as 'tasking'. This is time-consuming and onerous.

In studies where project estimates have been based on automatically generated quantities from model data (or IFCs) (e.g. (Jadid and Idrees, 2007, Stuab-French and Fischer, 2000)), the outcomes are conceptual estimates. Chapter 2 highlights that conceptual estimates are not usually assumed as conclusive predictors in estimating practice (Skitmore and Smyth, 2007). For estimators to generate workable and reliable estimates through BIM, further steps have to be taken on auto-generated quantities. A comparison between CAD and BIM of the steps leading to this is provided in Chapter 6.

Integrated Documentation

In manual and conventional GDO CAD systems, designs are fragmented into the number of disciplines that contribute to project designs, viz architectural and landscaping, structural engineering, mechanical, electrical and plumbing engineering (MEP), and Heating, Ventilation and Air Conditioning (HVAC) systems. Several studies have explained how process fragmentation could cause clashes, errors and omissions in project designs, and how these issues lead to unfavourable consequences in project management (Hugill, 1997).

Clash Detection

Fragmentation in design processes often lead to conflicts in design representation. Many of the ubiquitous consequences that design clashes trigger have been well documented in the literature. These include the confusion of the project stakeholders (Bender, 2009, Suermann,

2009, Eastman et al., 2011). Moreover there are several case studies on the cost of managing design conflicts. As argued by Sutrisna et al (2005), they often lead to variations, delays in project delivery, cost overruns and disputes. Furthermore, there is overwhelming evidence in the literature suggesting that the cost implications of design clashes can be severe, complex and indirect (Ndihokubwayo and Haupt, 2008).

BIM supports technologies for clash detection, and this lowers the uncertainties and costs associated with them. Clear approaches to integrated estimating and resource planning are typical examples of the benefits from these (Bergsten, 2008, Heesom and Mahdjoubi, 2004). When cost parameters being estimated are unclear, estimators tend to adopt the principles of provisional estimating and contingencies to compensate for uncertainties. This approach has been identified by Babalola and Aladegbaiye (2006) as a poor representation of true costs.

Visualization

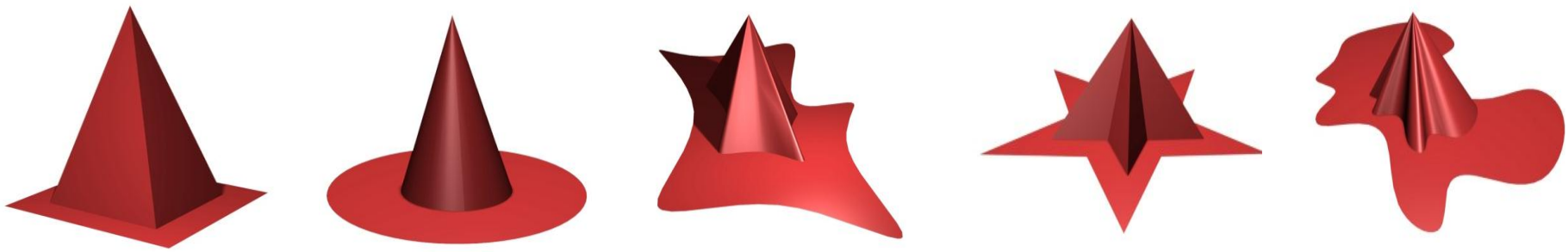
As described in Section 4.3, BIM provides multidimensional views of model objects e.g. with vector images, objects can be rotated and viewed in multiple perspectives. According to Chen (2005), viewing objects supports the empirical relationships between cognition, visualization and communication during the design stages. It is evident in Chen's work that many construction professionals often have problems imagining 3D views from 2D features. Moreover, because of the limited specificity in conventional 2D designs, those who possess strong spatio-temporal abilities often have different understandings of 3D views and interpretations of 2D, most of which could be different from the designer's actual intentions.

As estimates are usually shown as text and numbers it is hard for clients to visualize costs and descriptors. For example, work done in confined and/or irregular shapes may read the same even though they have different cost descriptors. Consider the simple description below:

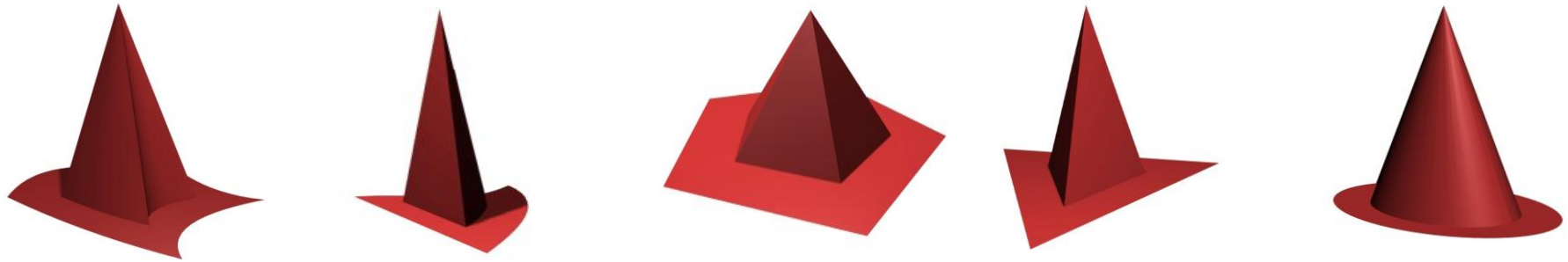
> "*12mm diameter mildsteel reinforcement bars in straight and bend bars in concrete slab – xxx tons*".

In the description above, the shape of the slab and the construction difficulties are not indicated. Thus, misjudgments are a high possibility. Arguably, reinforcement fixed in unconfined space requires less man-hours than those fixed in irregular and confined spaces. In Figure 4.6, the relationship between accurate calculation and visualization is further elaborated. Using 10 different objects, all of the same volume, Figure 4.6 shows that the workable estimate does not end with the accurate calculation of quantity. Rather it involves

making cost descriptors distinctive and visualizable. Consider this: if the objects are to be filled with the same materials under relative conditions, they will have different costs because of the difference in shapes and the construction difficulties that go with that. In past studies, however, there is no correlation between differentiating factors of product outcomes (e.g. surface area and cross sectional areas), but rather with the situational risks and challenges that may be inherent during construction (Akintoye and Skitmore, 1992, Akintoye, 2000). Complexities such as these are better visualiazed than in text; and this, BIM provides. It also enhances the need for quantities to be filtered to get them to comply with the requirements of SMMs.



Vol:	205.33 cm^3	**Vol:**	205.33 cm^3	**Vol:**	205.33 cm^3	**Vol:**	205.33 cm^3	**Vol:**	205.33 cm^3
Base Area:	50.68 cm^2	**Base Area:**	48.30 cm^2	**Base Area:**	78.81 cm^2	**Base Area:**	84.66 cm^2	**Base Area:**	97.82 cm^2
Height:	12.15cm	**Height:**	12.75cm	**Height:**	7.82cm	**Height:**	7.28cm	**Height:**	6.30cm



Vol:	205.33 cm^3	**Vol:**	205.33 cm^3	**Vol:**	205.33 cm^3	**Vol:**	205.33 cm^3	**Vol:**	205.33 cm^3
Base Area:	43.26 cm^2	**Base Area:**	25.86 cm^2	**Base Area:**	91.29 cm^2	**Base Area:**	43.30 cm^2	**Base Area:**	39.90 cm^2
Height:	12.24cm	**Height:**	23.82cm	**Height:**	6.75cm	**Height:**	14.23cm	**Height:**	15.44cm

Figure 4.6: Visualizing shape differentials of objects of common quantity descriptors

Simulation and Value Analysis

BIM simulation has also been used to experiment with construction systems in the virtual world (AbouRizk, 2010) and to develop preliminary construction costs (Chou et al., 2005, Kaka, 1994). Other studies have used it for urban planning (Kolbe et al., 2011), for risk evaluation and management (Kurihara and Nishiuchi, 2002) and to understudy contract and procurement management (Liston et al., 2007). Moreover, some studies have simulated the comprehensive cost estimation and analysis (Yang, 2005), the direct and indirect cost implications of disasters (Zhen et al., 2008) and the management of tender costs (Skitmore, 2008).

The ultimate goal of simulation is to strengthen the prediction of actual events by observing variability in the behaviours of representative agents. Some studies have described BIM as a good platform to enhance the outcomes of simulation. It has been used to replicate the reduction in construction costs, avoid construction risks and integrate cost data in building models (Popov et al., 2010, Vozzola et al., 2009, Wang and Halpin, 2004). In another dimension, Cho et al (2010) have used BIM to model the lifecycle and environmental costs of an experimentation on green buildings.

BIM-based simulation is a novel and emerging approach being used to enhance the performance of existing theories and practices on cost-led simulation. This means every single component can be reviewed as per the contributions it makes to the economic life of the project, and whether its functionality matches the projected cost. This is usually a time-consuming process in conventional design systems. According to Barton (2000) and Bowen et al (2010), value analysis and engineering often takes several days; it is resource-intensive and is only conducted for large-scale projects. With BIM, owners of small and medium scale facilities can benefit as well as owners of large projects. BIM-based simulation and value analysis is fast, cost-effective and adds value to collaboration during the design processes. There are considerable benefits in this, e.g.

i. ***Uncertainties' Prediction:*** Cost prediction of uncertainties has been a critical issue in estimating practice for a long time. With visualization, it is increasingly possible to use robust historical data on the utilization of contingencies in past projects to model contingency provisions for a new project, without unnecessary ambiguity and excesses. Chou (2011) has demonstrated this by using probabilistic estimating techniques.

ii. ***New Horizons:*** Due to drawbacks in the reliability of conventional simulation methods and their applications in construction management and engineering fields, simulation theories have not been explored exhaustively. The reasons for this are clear: it is difficult to harness quality data and prompt appropriate probabilistic density functions; even in absolute cases, real events in new projects adequate unique characterizations (Cheng and Feng, 2003). However, in object-driven simulation, these challenges can be compensated for through *Second Life* concepts. A case for this has been made in several studies on virtual reality (König et al., 2007, Whyte et al., 2000, Whyte, 2002).

As BIM inspires a new order of cognition in cost simulation (Dean and McClendon, 2007), scholarly knowledge in this area will expand to include newer concepts of BIM such as different scenarios of integration. This may take some time before it becomes widespread. However, when this becomes popular, more benefits are likely to accrue to estimators.

Integration

Integration is still a critical challenge for BIM deployment; its goal is to incorporate multidisciplinary data, tools and subsystems into one common data model (Gujarathi and Ma, 2011). Theorists on interoperability have expressed major concerns about the challenges that occur when the tools used by project stakeholders are fragmented. Holzer (2007) and, Dean and McClendon (2007) have argued that BIM modelling without multi-disciplinary integration is not significantly better than conventional CAD systems. However, recent evidence from some reports on this topic suggests that, to a reasonable extent, the availability of data exchange standards has been helpful to collaboration and intelligent estimation processes (Hiremath and Skibniewski, 2004, Jadid and Idrees, 2007, Qin et al., 2011, Shen et al., 2010b).

There are different concerns about interoperability in BIM. The literature suggests it could be in terms of difficulties in the integration of multi-disciplinary tools (Kwon et al., 2009), the inability to align multi-disciplinary systems and sub-systems that relate to conventional practices and procedures (Sattenini et al., 2011), complications in the integration of multidisciplinary processes and concepts (Flager et al., 2009), and problems with data

mining, formats and applications (Popovic, 2004). Meanwhile, integration implies that all data, including cost, are embedded into a BIM database. The use of 5D (a term for cost integration into BIM model) has been used frequently in a number of recent studies (Broekmaat, 2008, Consult Australia, 2010). However, the framework for this has not been reflected in any guide produced by the estimators' professional institutions. Bailey (2010) suggests that cost integration using BIM can only be used for conceptual estimates at the moment.

Integration of Cost data unto BIM models

Although some options have been suggested as to how cost data can be integrated into design models, some of these approaches have not been widely accepted either as estimating practice or theory. For example, the American Institute of Architects (AIA) (2008) have suggested a method called *'buy-out'* price. The conventional meaning of the term *buy-out* is the total amount of money that a client will pay for full ownership of a product. This concept is an ambiguous perception of estimating processes because it has underplayed the dynamics of cost and the reflection of information that must be portrayed to the client.

Meanwhile, many studies have used the idea of buyout price to formulate integrated costing models for BIM. The principle of 5D allows the integration of the cost data of objects into BIM models. When applied in other situations, the results could be complicated and confusing. For example, if a project is small in size, the margin of variability between cost descriptors could be small, such that when cost descriptors are lumped together conceptually, the error margin is manageable. However, on large projects, say multistorey projects, estimators risk dire consequences if clarity and comprehensiveness are compromised.

As an illustration of BIM, project components are represented as objects such that in a multistorey building columns can run through the wall into multiple floors. In the same manner, walls are often modelled to run through multiple floors. As each of these is represented as a single object, there can only be one cost for each of these elements, regardless of the variability of cost descriptors. Apart from the historical data approach, and perhaps guesses based on experience, the challenge here is that there is no known framework on how multiple layers of cost descriptions will be integrated into a single model, especially when they are not arranged by the order of construction. This gap is critical, especially when cost indicators such as risks, plant and material resourcing change with project complexity, quality of resources, location and height of element (Akintoye and Skitmore, 1992). A way

out of this challenge is for models to be broken down to as many occasions as cost determinants may decide. Moreover, as argued earlier, VDC or other forms of hyper models are the appropriate platforms to simulate this.

Up to now, there is no framework for multiple entries of cost data into model objects as per levels, resource differentiation and risk distribution within in the same object. Even if these are possible, there are other descriptors of cost that are not easily represented in a model. This means for the mere fact that they are not represented in the model, there is no space for them to be included in the 5D space. Specifically, preliminaries and contingencies are vital cost elements which cannot be integrated easily into BIM objects. This is because it is practically impossible to include every descriptor of these variables in project models. Further examples of such items include risk mitigation and contract securitization costs, waste handling and disposal, statutory expenditures, consumables such as water, energy and welfare, administrative expenses spent on meetings and project logistics, work items that are disposed offsite and not shown at all the model, statutory levies, as well as other items which are well articulated in estimators' standards methods of measurement and other practice guides.

There are uncharacteristic approaches where these seemingly invisible cost descriptors are built into visible cost items. For example, preliminaries and contingencies could be integrated into individual cost items to form 5D data. This situation is also precarious and complicated. While primary items shown in the model objects are basically estimable, preliminaries and contingencies are provisional (Bello and Odusami, 2009). This means these items are not definitive until they have been confirmed as actual expenditures through appropriate documentations. As these items are not definitive, to base project costs on them as 5D data is as though those items are definitively fixed. This will lead to serious complications which will cause more confusion in project outcomes than in conventional methods.

Although, there are still some encumbrances on the idea of integrated cost data in BIM modelling, there are other areas where data can be captured automatically and be integrated into real-time estimating systems. Only two of these methods (RFID and mobile computing) have been discussed in the literature in relation to BIM (see Chapter 2).

Automation and Virtuality

Theorists have defined augmented reality (AR) as the future of contract packaging in the construction industry (Pelosi, 2007). According to Sá et al. (2007), AR is the link between

virtual reality (VR) and real life situations. According to Haller et al (1999), the goal of Pure and Applied Reality concepts, including other knowledge areas where they may apply, is to vitiate the risks of failures and extend project teams' understanding of uncertainties and their potentialities. The principles of VR, AR and Augmented Virtuality (AV) have been applied in many disciplines such as medicine for training, risk analysis and knowledge management. Their benefits have been well explained in the literature. Although they are still not widely used in construction management and estimating practices, they can be used for training (Haller et al., 1999), to optimize creativity (Gu, 2006), to auto-generate and transmit micro information which are mostly invisible to human eyes, enhance communication (Sherman and Craig, 2003), and to moderate the behaviours of active agents such as robots and virtual design agents (Schuil et al., 2006).

In summary, artificial intelligence is making in-roads into construction conventions. Apart from using representative agents for inhabitable work spaces, creative thinkers now tend to prefer undertaking more work with machines and fewer humans. Evidence from Werfel and Nagpal (2008) suggests that the future of automation and virtuality in construction is clear; less human effort will be required in project development, and that would only be when it is critically necessary. Countries like Japan, The Netherlands and Sweden are among the leading nations where substantial advancements have been made in this area (Balaguer and Abderrahim, 2008, Wing, 1993).

Recent studies on BIM have elicited a strong correlation between design automation and parametric design concepts. Automation systems rely on the well-structured and robust information in BIM to train the behaviours of active agents in virtual space and real life (Gu, 2006, Huang et al., 2009b). As these agents replicate and replace human actors, cost prediction and management will only make sense if they reflect this paradigm shift in construction management systems. However, research on this subject area is still minimal.

There are overarching challenges worth exploring in how BIM, including other deliverables of parametric innovations, is impacting on the construction business landscape. Arguably, estimating theories and practices are also in the heart of these challenges. First, the understanding and novel applications of BIM potentialities in different construction industry disciplines has continued to expand vertically (i.e. in terms of progressive realization of its collaboration and integration potentialities) and laterally (i.e. in terms of the benefits it offer to multiple disciplines, though understood and applied uniquely in individual disciplines and

skill domains). Secondly, the science of business forms and formalism is uniquely dynamic in itself. Organization science theories, showing the correlation between business behaviours and estimating outcomes, have been discussed in Chapter 3.

4.5 SUMMARY ON BUILDING INFORMATION MODELLING: THE ESTIMATING PERSPECTIVE

As a multi-disciplinary platform, BIM has challenged all disciplines in the construction industry to innovate and go the way of digital procedures. The single most important factor in these is how each discipline understands and applies BIM and its deliverables. In this chapter, BIM is a presented in the context of estimating theory and practice; the new directions in estimating theory and practice resulting from BIM has been identified. A summary of these is presented at the end of this Section.

Presently there are several hundreds of estimating applications, several of them with BIM capabilities. However, the targets of these applications are not the same; their positions on the issues identified above are different. For the different stages of design and construction, computer-aided estimating (CAE) has existed for at least three decades (Sher, 1982). Initially, it existed to speed up manual procedures; however BIM has added new dimensions to this. There are several procedural scenarios added to estimating in BIM which are not documented in any of the popular professional guides that estimators follow e.g. the Chartered Institute of Building's (CIOB) (2009) and the Australian Institute of Building's (AIB) (1995). These include

- Automated quantification; There are few methodological questions in this. How exactly are or should model data be captured, filtered, collated and estimated? Based on SMM rules? Project-based? As translated by CAE applications? In anyway data are presented in BIM models? Based on IFC formats? As moderated through human interactions or manipulation with estimating software or model data?
- Model costing and pricing. As discussed in Section 4.4, the conventional procedures for estimating and pricing projects are different from how models are represented. How therefore should estimators deal with or enter cost data into models? Is it by remodelling into styles that estimators are comfortable with or by putting a buyout price into a model? Is it by exporting model metadata and by estimating in the form of BoQs only or by object-based estimation of models components as they appear, regardless of the positions of conventional rules guiding estimating procedures? Is it

by recommending a format which estimators are comfortable with or a particular structure, different from the present format, into which all estimates must be incorporated?

- Process models and Model simulation. This is a visualization procedure, different from conventional simulation practices in the estimating literature (Cf Kurihara and Nishiuchi (2002) and AbouRizk (2010), Azhar et al. (2008), Huang et al. (2009a)). Are there structural requirements that simulation models must conform to and on which estimates are based? Can simulation models become contractual instruments?
- Integrated estimation. There are two directions to this, viz modalities for estimators' integration on a multi-disciplinary platform in BIM (this is different from conventional teamwork scenarios where fragmentation operates) (Olatunji, 2010a), and; how estimators integrate outcomes using very few BIM-compliant applications in place of fragmented tools (see Best et al (1996).

The dichotomy between conventional and contemporary estimators will continue to expand, unless the issues above are explored. For teaching and learning, these issues are also critical. Meanwhile, there are different levels of conformity with BIM maturity in the industry; while some projects are fully parametricized, some are still transiting between 3D (and IFCs) and advanced parametric capabilities. In Chapter 6, the activities leading to successful estimating outcomes in both paradigms are investigated across four estimating practice domains, as proposed in Chapter 3, viz. the matrix model, divisional, function and networked models. The research methodology is presented in the following chapter.

5 RESEARCH METHODOLOGY

5.0 RESEARCH METHODOLOGY

5.1 INTRODUCTION

This chapter presents the research methodology underlying this investigation into the impact of BIM on estimating practice. It describes the methodology underpinning the development and validation of process models for estimating with 3D CAD and parametric BIM across four practice domains identified earlier (Section 3.2). To achieve this, this chapter:

- discusses the research philosophies underlying the methodological choices made in the course of the research
- explains the research methodologies and strategies that were deployed to achieve the study objectives
- justifies the specific choice of the methodological instruments that were deployed in each part of the research.

The chapter has been divided into four sections:

- Section 5.2 presents the research philosophy adopted for the study.
- Section 5.3 outlines the research methodologies and strategies used in the course of the research.
- Section 5.4 describes process modelling approaches used in the research, including data collection procedures.
- Section 5.5 articulates the statistical methods and procedures, and model validation approaches.
- In Section 5.6, presents a summary of Sections 5.3 – 5.5.

5.2 RESEARCH PHILOSOPHY

Chapters 2 and 3 have argued that the views, goals and procedures leading to estimating outcomes are richly stratified and ontologically nuanced across four practice domains. These practice domains are identified as matrix business, divisional business, functional-unit practice, and networked business model organisations. Although popularly considered to be a single discipline, estimating is not simply limited to individuals' views on generating project costs. Rather, it encompasses critical and strategic activities which estimators from the

different practice domains have applied differently to fulfil their business goals. For example, from the project owner's perspective, an estimate is the most probable cost to procure a proposed project, including the contractor's consideration. The perspective of the party that is responsible for the construction is different from this; an estimate is only the production cost i.e. the actual cost of construction without considering the builder's profit. When an estimate is marked-up (i.e. overhead and profit are added to the production cost), this is the contract price i.e. the project owner's view of an estimate. While the constructor's view of a project estimate is limited to the construction phase, the perspective of estimators in an integrated project delivery scenario is the cost of meeting the long-term objective of a proposed project.

The aim of this study is to explore the impact of BIM on estimating, particularly across the practice domains, to compare how estimators perceive the estimating processes and outcomes when they deploy 3D CAD and BIM. This involves:

- identifying process themes and triangulating them across the practice domains.
- analysing and validating the themes as a representation of the practice.
- distinguishing the practice representation across the four practice domains to facilitate the easy implementation of the process models.

There is clear guidance in the construction management literature on conducting research, viz how to generate valid research outcomes through specific data collection approaches, analysis and interpretation (Blaxter et al., 2001, Comas and Sieber, 2001, Currall et al., 1999, Dainty, 2008, Engeström and Sannino, 2010). Broadly, this often occurs under different paradigms with diverse approaches offering assorted merits in different situations. There is therefore a considerable challenge in determining whether to deploy quantitative or qualitative techniques, or to combine both, in order to resolve the objectives of this study. Meanwhile, there are specific guides on when to use a particular research method and how. For example, Nicholls (2009) has made the justification of choosing between the two research paradigm succinctly clear:

> *…."the key tenets of quantitative research – objectivity, value-neutrality, detachment, rationalism, and logical reasoning – work well when we exclude people's subjectivity from the equation, but, when a person's experiences, interconnections with others, or social and cultural systems in which they live, breathe, work, love and play demand attention, quantitative research has some profound limitations"* (pp. 528).

Nicholls made is clear that quantitative techniques are appropriate in situations where the goal of the research is to further explore well-established phenomena. In the case of this study, the phenomena being explored are soft – i.e. the research themes, and the relationship between them, have not been defined conclusively in past studies. Thus, its focus can be explained from two perspectives:

1. It explores data based on estimators' experiences in the different practice domains (Section 3.3)
2. The domains of measurement are variables of estimating processes (stages and activities leading to estimating outcomes in each of the practice domains) in 3D CAD and BIM estimating. Neither of these has been explored and validated sufficiently in past studies.

To put this further in context, it uses qualitative techniques to explore the activities and stages leading to estimating outcomes. Thereafter, the variables were analysed quantitatively to develop process models that can be used across the four practice models that have been identified. This requires some level of quantitative analysis and validation. Consequently, it will be difficult for a single research method to completely resolve the different components of this research; it requires the combination of multiple qualitative instruments (Section 5.3) and mixture of instruments from both paradigms to strengthen the research outcomes. As an illustration to justify this, it would be like constructing a whole house with just one tool. Arguably, the tool will deliver satisfactory outcomes for certain aspects, but will be ineffective in others. Thus, to answer the research questions, aims and objectives of this study, there are several views and components which can only be resolved with multiple methods, both in the form of mixed methods and paradigm plurality. The single most significant reason underpinning methodological choices in this research is that estimators have had different views and approaches to generating their outcomes, and these are soft (i.e. indeterminate) in nature.

The adoption of mixed and multi-method approaches as the main philosophical basis of the research was inspired by Dainty's (2008) explanation of different webs of epistemology and doxology, and their implications to modern constructs of positivism and interpretivism. According to Dainty, pluralism has been debated in construction management research (CMR) for more than two decades. Its merit is to harness methodological strength such that

research instruments complement each other where a single approach could have been weak or impracticable.

Multi-method approach, also known as pluralism, is defined by Frost et al. (2010) as "*the use of more than one qualitative approach with another"* (pp. 442). Moreover, the burgeoning interest in the debates regarding its applicability to CMR varies, e.g.:

- whether pluralism is better *within* or *across* paradigms (Frost et al., 2010);
- whether some approaches work better with each other than others (Onwuegbuzie and Leech, 2005);
- whether the use of multiple approaches (*within* or *across* paradigms) delivers variable outcomes (Comas and Sieber, 2001).

From the directions indicated above, there are two possible combinations of methods, viz. within and across method paradigms. In this research, both patterns are deployed; the justifications for this are argued in Sections 5.2.1 to 5.4.2. Several theorists, including Walker et al. (2004) and Mingers (2001), have explored how these combinations work best together; however,, it is necessary at first to identify the frameworks of each pattern of combination:

- *Objectivity in exploring soft issues:* methods must provoke open-ended, unbiased and articulate responses from the real world (Mingers, 2001). Respondents have different views and experiences which can be viewed and analysed through different instruments.
- *Constructivism:* it is epistemologically inaccurate to limit new challenges to old theoretical frameworks, especially in relation to construction businesses' experiences with digital technologies. This view is crucial because research outcomes may be confusing when new thought constructs have not been definitively explored, analysed and validated with commensurate research methods.
- *Contextuality:* apart from nuanced views in the various estimating practice domains, it has been argued in Section 4.2 that the potential of BIM is revolutionary. The implementation of BIM is triggering changes in roles, skills and processes , as well as substantial changes in thoughts about the way construction businesses should be structured, e.g. legal (Fairfield, 2005, Olatunji, 2011c), procedural (Luciani, 2007, 2008), and systemic (Aranda-Mena et al., 2008, Succar et al., 2012). These changes

in paradigms apply to construction businesses differently (Olatunji, 2011b). Thus, examining them requires an exploration of the intrinsic values underlying construction business behaviours with, and estimators' understanding of, BIM. This is imperative because estimators are skilled in measuring the cost implications for the different parties involved in construction business relationships (Section 3.1).

There is another perspective on using multiple methods in resolving research problems i.e. mixed methods, viz combining approaches across different paradigms. Walker et al. (2004) defines mixed research methods as an attempt to use *"both quantitative and qualitative methods"* (pp. 5) to achieve valid research outcomes. The main merit of this approach is to capitalize on the combined strengths of the research instruments chosen from both paradigms to offset their different weaknesses and to provide comprehensive answers to the research questions.

The overarching conclusion from arguments on plurality and mixed methods has had a significant impact on both ontological and epistemological perspectives. According to Williams (2000), Johnson and Onwuegbuzie (2004) and Johnson et al. (2007), it is difficult to argue that one research paradigm is more important than another. This applies whether in terms of the validity of processes and outcomes or in terms of the accuracy of the concept, regardless of foundational perspectives that a researcher might choose, be it ontological (i.e. objectivism and constructivism) or epistemological (positivism and interpretivism). Nonetheless, as Orlikowski and Robey (1991) argue, each paradigm delivers substantial results. Most importantly, many researchers tend to agree that pluralized and mixed approaches tend to deliver more workable outcomes than single approaches when they reinforce complementary research concepts (Fielding, 2012, Flick et al., 2012, Howe, 2012, Mertens and Hesse-Biber, 2012, Onwuegbuzie and Teddlie, 2003, Sale et al., 2002).

The methodological designs used in relevant studies are described below, followed by a discussion of the research design for this study (Section 5.2.2).

5.2.1 Related Work on BIM and Estimating Procedures

As a pioneering investigation involving 3D CAD, parametric BIM and estimating practice, this study combines and deploys research methods for

- exploring business behaviours specific to construction businesses using new practice technologies,

- developing process models based on individual estimator's experiences with 3D CAD, and parametric BIM; and
- validating process models.

By extension, it concentrates on instrumentalities of information systems in construction project organizations, both in the context of 3D CAD, BIM and multi-disciplinary integration. Lessons have been drawn from studies in related areas, including the work of Broquetas (2010), Hergunsel (2011), Maunula (2008), Sattenini and Bradford (2011) and Suermann (2009). These authors examined BIM in relation to construction processes and project delivery and involved organizational systems and project information systems indirectly.

In all the above-mentioned studies, isolated quantitative methods were used; however the research results were inconclusive in the context of a wide view of a richly stratified estimating practice. For example, Suermann (2009) used case studies to explore the impact of BIM on construction processes through quantitative methods. However, the outcomes cannot be generalized as they did not address vital determinants of the construction processes in relation to BIM. In particular, the author omitted discussions on the cost implication of BIM on contract performance and its impact on business behaviours (i.e. from fragmented processes to collaborative and integrative behaviours).

Similarly, in Sattenini and Bradford's (2011) survey of how US contractors deploy BIM, including its uses for estimating, the researchers avoided discussions on any known standardized procedure about how BIM projects have been estimated for. There is also no indication of how BIM has impacted on the cost performance of the projects it was based on. Furthermore, they did not explore the impact of BIM on the estimating process. Meanwhile, according to Scott and Cheong (2003), an acceptable reason for contractors adopting BIM is to use its integrative tools to save costs and maximize the competitive advantage. These authors also noted that all other project stakeholders use BIM in ways that are different from those of contractors.

In addition, Samphaongoen (2010) developed a visual approach for cost estimating using BIM. However, Samphaongoen's work only contains a very small portion of one form of the organisation model representation and is therefore of limited value. Most BIM deliverables were also not discussed. Furthermore, other cost determinants outside the model were not

explored and the accuracy of the components, such as quantities, resourcing and descriptors of work items, which the researcher estimated was not validated.

Other studies have attempted to extend Samphaongoen's work with limited success. For example, Jensen (2011) and Hergunsel (2011) attempted to use BIM for work-scheduling and bidding but the procedures they used were inconclusive. The practice domains to which research finding apply are ill-defined and the conclusions drawn from their studies do not identify whether or not BIM delivers process advantages over conventional estimating processes. These omissions are important because the literature is unclear about the disparity between GDO CAD, 3D CAD, OOP CAD (BIM) and their functional links to estimating and business practices (Anumba, 1996, Goldberg, 2007, Gujarathi and Ma, 2011, Tse and Wong, 2004, Vozzola et al., 2009).

All the studies noted above have argued that all parties must estimate the costs of a project a particular way and this is invariably different from conventional methods. While all the methods used delivered findings and demonstrated some of how their research subjects estimated with BIM, additional work is required to effectively extend what is already known.

5.2.2 Approach to Research Design

In Section 4.3, BIM is described as a knowledge domain for the postmodern AEC industry. Its change potential is evident (see Tse, 2009; Salmasi, 2010; Bleiman, 2008; Brucker et al., 2006). This study seeks to develop workable process models for estimating in different estimating practice domains where BIM has been used. It focuses on activities that lead to acceptable estimating outcomes as estimators shift practice procedures from GDO CAD to 3D CAD, and from 3D CAD to automated procedures in parametric platforms.

Firstly, inspiration was drawn from studies on developing process models. These include Underwood and Alshawi (2006) where the authors developed a process model for integrating estimating and interim valuations. Karhu et al. (1997), Haas et al. (2006) and Jongeling (2006) also used procedures similar to Underwood and Alshawi's to develop process models. All these studies only used computational methods to develop their models. The focus of this study is different even though the outcomes are similar. A comparison between these past studies and the current research is summarised below:

- Those studies used generic themes for their computation whereas the focus of this study is to generate the themes, which are new and relate to estimating practice in the four practice domains.
- The outcomes of those studies are not validated whereas the goal of this study is to test the reliability of the research themes, to measure their relationships in process models and validate the resultant models.
- Those studies viewed estimating as a generic platform without attending to the variability in knowledge constructs across the practice domains, whereas the focus of this study is to discriminate validated views across the four practice domains.

Based on the differentiation above, using different research tools is crucial to achieving the goal of this research. As shown in Figures 5.1 and 5.2, this study uses mixed approaches:

- to explore and correlate the necessary themes involved in estimating construction costs with 3D CAD and BIM – see justifications in Section 5.3.
- to develop process models for estimating with 3D CAD and BIM; firstly, a representative model that is generic to all business models is developed (also referred to as the centroid process model), and thereafter, discriminated models that are workable across the four practice domains.
- to validate the outcomes of the research (i.e. theme exploration, correlation analysis and process models elicited from Sections 6.5 to 6.7) by comparing them to existing practice norms documented in literature.

Additional inspiration was drawn from previous works on learning actions in an expansive learning cycle, particularly that of the progressive learning cycle model described by Engeström and Sannino (2010) which has been used popularly in action research. This approach was deemed appropriate because the identified estimating practice domains are not new, and organizations with functional frameworks for estimating with 3D CAD and BIM appear to possess the attributes of learning organizations (Lowe and Skitmore, 2007). Theorists have shown that it is mainly through learning that organizations have been able to acquire contemporary skills and diffuse innovation outcomes (Lewin, 1948, Kululanga et al., 2001, Kim, 1998, Yang et al., 2004).

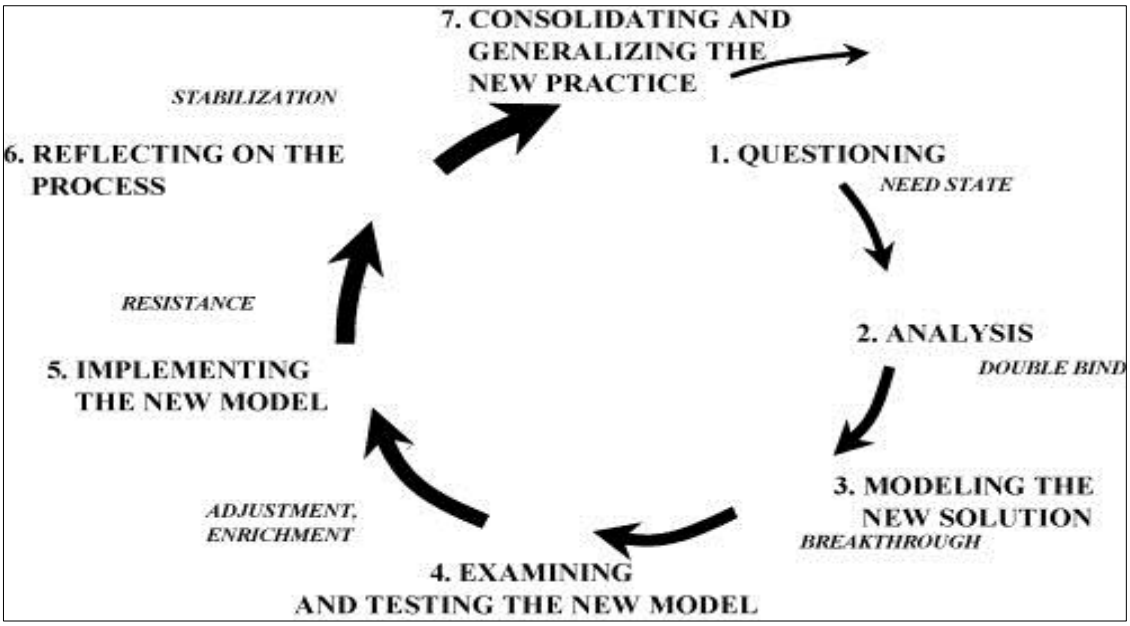


Figure 5.1: Sequence of learning actions in an expansive learning cycle (Engeström (1999), p. 384)

There are seven steps in Engeström's model (Figure 5.1):

1. Questioning i.e. exploring the relevant variable themes (e.g. estimating stages and activities in 3D CAD and BIM)
2. Analysis i.e. quantifying the relevant variable themes identified in Step 1
3. Modelling new solutions i.e. testing the reliability and correlation of the variables in Step 2 to a generic process model
4. Examining and testing the new model i.e. discriminating Step 3 amongst the four practice domains, and comparing them to existing knowledge
5. Implementing the new model i.e. exploring frameworks suitable for an in-depth implementation of Steps 3 and 4
6. Reflecting on the process i.e. triangulating the findings up to Stage 5 with existing knowledge in literature, and
7. Consolidating and generating new practice i.e. drawing conclusions about how the process models apply in the subject practice domains, in the context of estimating with 3D CAD and BIM.

To contextualize and implement these seven steps, the taxonomy shown in Figure 5.2 was deployed. The research instruments shown in the figure are described further in Section 5.3.2. In line with Step 1 (above), the taxonomy starts with *Process Probes*, being guided by

relevant work e.g. Thiollent (2011) and Engeström (1999). *Process Probes* seek to establish how CAE software developers and vendors estimate with BIM. These processes and procedures are triangulated against those used by application end-users in the different practice domains. As indicated in Section 3.2, construction business models are represented as:

- matrix model organisations, which represent the organizational structure of construction clients
- divisional model organisations, which represent the organizational structure of contracting businesses
- functional-unit model organisations, which represent consulting practices
- networked model organisations, which represent specialist and integrated project delivery vehicles.

The target of this approach is to capture richly stratified, nuanced and re-useable data on the dynamic nature of estimating, particularly with 3D CAD and BIM.

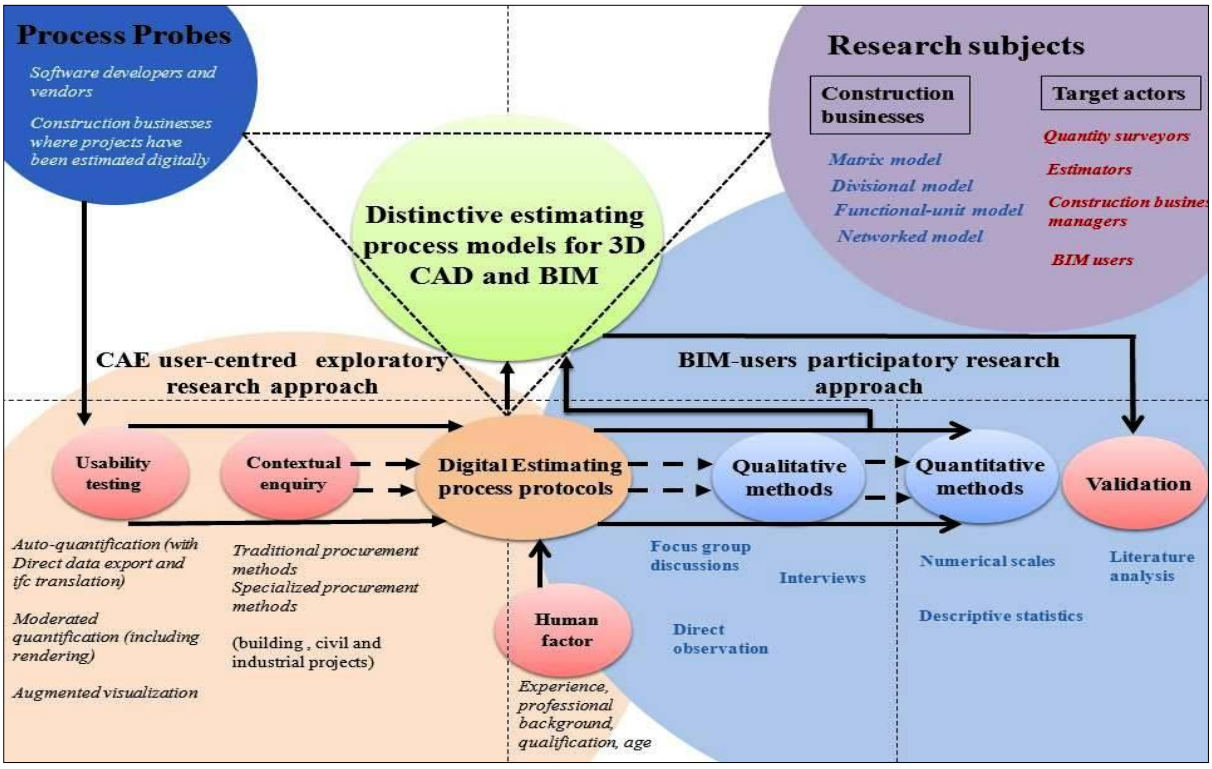


Figure 5.2: A taxonomy of the research design

According to Galliers (1991), several options are suitable for conducting *Process Probes* in both positivist and inductive paradigms. Possible positivist approaches include questionnaire surveys, interviews and case studies. Gaming, reviews and augmentative instruments are possible options to select from qualitative methods. In this study, a focus group discussion is chosen mainly because the target population is relatively small, and none of the other options deliver reliable outcomes. Further discussions (Section 5.3.2) explore the merits of focus groups as one of the approaches for process probes in this research. There are several reasons for this. The use of surveys for a small population has been critiqued by Vreede (1997) as inconsequential. Similarly, Hammersley and Gomm (2005) argue that interviews are not reliable research instruments when the target population is small. To bring this into context, Dainty (2008) summarized positivists' opinions on the weakness of interviewing as the only research method in scenarios as in this study, as follows:

> *"….sees the interview informants as being more focused on self-presentation and the persuasion of others, rather than on presenting facts about themselves or the world in which they exist… Regardless of whether such a radical perspective on the efficacy of interviews is fully accepted, the acknowledgement that they are in any way flawed reinforces the need for data from different sources to triangulate the inferences and outcomes that they provide"* (Pg. 7).

As shown in Figure 5.2, the approach to probing processes used in this research relies on multiple research methods:

- *Initial process probe:* Developers and vendors of software applications with facilities to estimate with 3D CAD and BIM were contacted and observed (Section 5.3 and 5.4).
- *Confirmatory process probe (CAE user-centred exploratory approach):* Secondly, participants were sourced from 3D CAD and BIM conferences to arrange interviews and focus group discussions and to observe their estimation processes (Section 5.3). This was to test how the approaches in each of the practice domains relate to each other.
- *Process probe by Triangulation (BIM-user participatory research approach):* Thirdly, there was specific focus on digital processes for estimating, either as automated or as moderated by human actors.

Ultimately, from the above-mentioned steps, when participants have explained their approaches to estimating; the themes in estimating processes were identified and sorted by stage and activities. The stages are both relative to the lifecycle stages of project development as described by Kagioglou et al. (1999) and summarized in Section 2.2, and as emphasized in participants' discussions. Furthermore, each stage is made of activities which are definite and clearly emphasized. Subsequently, they were parametricized by using rating scales to indicate the importance that research participants ascribed to each of the variables. Finally, the numerical values ascribed to each variable were extended to further rigorous statistical analysis in the following ways:

- Firstly, the reliability of the ratings was tested.
- Secondly, the relationships between the variables were explored; and
- Thirdly, variables with strong correlations were used to develop the processes models which were later discriminated across the practice domains.

Each of these procedures is discussed in detail in Section 5.4. For clarity, the research process was streamlined into four phases which are described in Section 5.3 and Table 5.1. Each phase was designed to address specific research questions corresponding to each research objective. How each of the research instruments was used, and the justification thereof, is discussed in Section 5.3.

5.3 RESEARCH STRATEGY AND INSTRUMENTS

This research seeks to probe estimating stages and activities which lead to workable outcomes in the various practice domains identified in Section 3.2. A summary of these domains is provided in Section 5.2.2 in line with the research design. Furthermore, there are specific research questions and objectives which the study addresses (Sections 1.3 and 1.4). Table 5.1 presents the strategies and instruments that were used in resolving each of the research questions and objectives. They are in four phases, viz:

- *Phase 0,* showing research questions (RQs) that are specific to the research objectives (OBJs) and techniques,

- *Phase 1,* where study methods are initiated for preliminary analyses,

- *Phase 2,* where the outcomes of Phase 1 were prepared for final analysis, and

- *Phase 3*, where the outcomes are extended into practical applications e.g. EXPRESS-G and IDEF0 models.

The research questions (RQs) and objectives (OBJs) have been stated in Sections 1.3 and 1.4. They are summarized below and linked to each other in Table 5.1. For example, the study seeks to identify the impact of BIM on estimating processes. To simplify this, the research questions were broken down into two parts. First, the process leading to workable outcomes in 3D CAD and BIM; second, the required tools and how the outcomes compare to conventional estimates. The first part is divided into three parts:

d. What are the stages and activities of project estimation using BIM?
e. How do 3D CAD and BIM estimating processes mitigate the limitations of conventional estimating processes?
f. What challenges are intrinsic in BIM estimates?

Moreover, the other part is divided into two parts:

g. What are the attributes of software applications that work with BIM and how do they compare with other estimating applications?
h. How do BIM-enabled estimates compare with traditional estimates?

Each of the RQs above was targeted at the research objectives (OBJs). For example:

- OBJ1:- *to explore activities required to develop workable estimates in different practice domains, using 3D CAD and BIM*. This was explored by means of research questions (*a*), (*d*) and (*e*) (adapted in Table 5.1 as RQ1 and RQ2). RQ1 seeks to identify the process themes in 3D CAD and BIM; RQ2 seeks to elicit the relationship between traditional estimating and BIM depending on the importance that participants have ascribed to the themes (variables) in RQ1.
- OBJ2:- *to investigate the statistical association and reliability of the identified activities in OBJ 1*. This was explored by means of research questions (*b*), (*c*) and (*e*) (adapted in Table 5.1 as RQ3). RQ3 seeks to establish whether the relationships between the variables are sufficient to create process models.
- OBJ3:- *to analyse the discrimination of each practice domain. This* was explored by means of research questions (*a*), (*c*) and (*e*) (adapted in Table 5.1 as RQ4 and RQ5). While RQ4 seeks to discover the statistical significance of the discrimination of views

across the practice domains, RQ5 explores the difference between BIM estimating, 3D CAD's and conventional estimating methods.

- OBJ4;- to propose strategies for the technical implementation of Objective 3. This integrates research questions (*a*), (*b*), (*c*), (*d*) and (*e*).

Table 5.1: *An outline of research framework and techniques*

Process particulars	PHASE 0	PHASE 1		PHASE 2		PHASE 3		Research and Statistical Techniques
	Research Questions	***Preliminary Analysis***	***Preliminary Findings***	***Interim Analysis***	***Interim Findings***	***Final Analysis***	***Final Findings***	
Primary Research Theme	***Focus:* Process Modelling**	**Literature analysis and exploratory activities using industry practitioners**	**Identification of process variables (i.e. activities and stages in estimating processes for 3D CAD and BIM)**	**Determine relationships between variables across practice domains**	**Identify activities that generate reliable and workable estimates for both 3D CAD and BIM)**	**Discriminate 'centroid' process models across the four practice domains**	**Elicit degree of association and accuracy of discrimination**	**Observe software developers' demonstrations, discuss potential with estimators**
RQ 1/OBJ 1	What streams of BIM capabilities are deployed for estimating?	Critical analysis of literature on BIM potential with regards to estimating (e.g. the goals and outcomes)	Identification of resources, stages and activities leading to estimating outcomes in 3D CAD and BIM	Explore statistical significance of the data (on stages and activities) across the four practice domains	Elicit reliability, and the basis thereof, of activities' statistical association of the researched themes for both 3D CAD and BIM	Compare outcomes of analysis in both 3D CAD and BIM regimes across the four practice domains	Establish the basis for further discrimination analysis and technical applications of findings	Observe software developers' demonstrations; discuss potential implications with estimators; rate variables
RQ 1/OBJ 1	*What are the attributes* [stages and activities] *in 3D CAD and parametric BIM in respect to estimating?*	*Examination of scholarly materials, technical reports and white papers on 3D CAD and BIM estimating*	*Identification of functional framework of estimating applications, stages and activities in 3D CAD and BIM estimation*	*Exploratory analysis of the variables identified during preliminary analysis*	*Compare BIM estimating regime with the stages and activities in 3D CAD*	*Articulate variables in readiness for confirmatory tests*	*Compare estimating activities in both regimes by mean ranking (based on overall ratings across the practice domains)*	*Mean ranking, univariate ranking*
RQ 2/OBJ 1	*How do participants in the practice domains rate (by emphases) the stages and activities in 3D CAD and BIM estimating?*	*Rate the importance of each estimating activity across the practice domains*	*Rate and rank activities and stages across the practice domains and compare 3D CAD and BIM*	*Subject data from exploratory analysis to comparative statistics*	*Determine discriminations amongst the practice domains, and explore reasons for differences*	*Identify the differences between conventional estimating procedures, 3D CAD's and parametric BIM's*	*Articulation of significant contribution of BIM to estimating processes, both in terms of 3D CAD and parametric BIM*	*Direct observation, explorative and comparative statistics – Mean, SD, ANOVA, scoring factor*
RQ 3/OBJ 2	What is *technical [and statistical]* significance of the ratings in OBJ 1?	Examine the goals of estimators in each practice domains, and the tools they deploy	Triangulation of the ratings in OBJ 1 with the business orientation of each practice domain	Explore statistical association between the variables across the practice domains and design platforms	Determine which practice domain has the most dispersed views and why	Determine which activities have the strongest degree of association	Identify and discount those without significant association	Comparative test, analysis of variance, scoring factor and reliability test – Cronbach' Alpha

Process particulars	PHASE 0	PHASE 1		PHASE 2		PHASE 3		Research and Statistical Techniques
	Research Questions	***Preliminary Analysis***	***Preliminary Findings***	***Interim Analysis***	***Interim Findings***	***Final Analysis***	***Final Findings***	
RQ 4 OBJ 3	How do the outcomes of OBJ 2 discriminate across the practice domains?	Explore statistical basis for comparing ad-hoc and post-hoc data (with respect to OBJ 2) – i.e. whether parametric or non-parametric rules apply	Determine whether parametric or non-parametric rules apply to ad-hoc data or post-hoc data	Measure the degree of discrimination across the practice domains	Determine the accuracy of the discrimination in the measurements.	Develop discriminant analysis functions for each of the practice domains and the centroid.	Compare the discrimination across the practice domains in readiness for technical applications in EXPRESS-G and IDEF0 modelling	Discriminant analysis
RQ 4/OBJ 3	*How significant is the statistical discrimination across the practice domains in both 3D CAD and BIM?*	*Measure the degree of discrimination through key performance parameters e.g. Eigen value, Wilk's Lambda and Pillai test.*	*Identify how ad-hoc data compare to post-hoc data, and both to existing estimating theories*	*Analyse the classification matrix and across the practice domains and centroids*	*Examine and explain the discrimination triggers*	*Develop discriminant models*	*Measure the accuracy of the discrimination across the discriminant models*	*Discriminant analysis*
RQ 5/OBJ 3	*What is the technical application of the statistical significance of OBJ 3?*	*Validate findings in the discriminations with existing body of knowledge in conventional and CAE practice*	*Elicit the gap between conventional estimating theories and the discoveries in estimating practices in 3D CAD and parametric BIM's*	*Compare the gap between 3D CAD estimating and parametric BIM's*	*Articulate the bases for the implementation of the process models in OBJ3.*	*Discuss how the discriminant models apply in practice*	*Elicit methodologies for technical implementation*	*Literature analysis*
RQ6/OBJ 4	What are the technical implications of the discoveries made for OBJs 1 to 3?	Empirical analysis of the difference between BIM estimation and conventional processes	Develop system architecture to underpin the models	Discuss the technical implications of the activities	Elicit an EXPRESS-G model through which the model can be driven	Discuss other factors that could impact on the process models	Recommend an integration definition (IDEF0) platform for implementing the models	*Literature analysis*

5.3.1 The Research process

The four phases that will lead to the research outcomes have been indicated in Table 5.1 and in the introduction to Section 5.3. Each of the four research objectives have been explored in four phases:

(i) research questions – these have arisen from the literature review and stated in Section 1.3

(ii) the preliminary analysis and findings

(iii) the interim analysis and findings

(iv) the final analysis and findings.

As introduced in Section 5.3, exploring answers to each of the research objectives started with specific question(s) which were directed to estimators in the four practice domains. The questions put to participants are adaptations of the Research Questions (Section 1.3). For example, the research question, '*what are the stages and activities of project estimation using BIM?',* was adapted as *'please discuss your estimating processes with 2D CAD, 3D CAD and BIM'* or something similar, depending on the interview situation (the full list of questions put to participants has been deposited in Appendix 1B). In the course of participants' explanations, the process themes were clearly evident. For ease of coding, answers relating to identifying estimating process themes, in respect of 3D CAD and BIM, are articulated for analysis and represented in Table 5.1 as RQ1 i.e. the first part of questions leading to achieving OBJ1. Thus, for Objective 1 which explores *"the activities required to develop workable estimates in different practice domains, using 3D CAD and BIM"*. Two questions were designed to address this:

- firstly, RQ1, *what are the attributes* [stages and activities] *in 3D CAD and parametric BIM in respect to estimating?*
- secondly, RQ2, *how do the practice domains rate the stages and activities in 3D CAD and BIM estimating?* The RQ2 is an adaptation of items (*d*) and (*e*) listed in the research questions in Section 1.3. Specifically, item (*d*) in the research question listed in Section 1.3 seeks to elicit *the attributes of software applications that work with BIM and how do they compare with other estimating applications*, while (*e*) seeks to know h*ow BIM-enabled estimates compare with traditional estimates.*

The relationship between RQ2 and items (*d*) and (*e*) listed under the research questions is not difficult to understand. The main focus of Objective 1 is to identify the variables that lead to

the estimating outcome, and how participants emphasize them, across the four practice domains. In other words, some variables of estimating processes are more important to a practice domain than another. The different groups within each practice domain also have different emphases on the variables, even though the emphases within each practice domain are distinctive enough for analysis. Further to these, the variables can also be distinguished by the type of applications that participants' businesses use and how they put them to use. For example, matrix model estimators use CostX predominantly but those from the divisional model use VICO. These two applications are different in the way they handle quantification and costing; the former translates IFCs and matches with cost databases, the latter allows for the moderation of objects and resourcing. Thus, automatic quantification may be important to both domains, but to a varying degree. Divisional model estimators may replace automation with moderation of object-data while matrix model estimators would find automatic quantification irreplaceable. Therefore, the importance of all variables to each of the practice domains was identified after each group discussion or the interviews and collated such that each variable is represented on a scale ranging from 'not important at all', 'slightly important', 'moderately important', 'very important' to 'very important and inevitable'. As explained further in Section 5.3.2, the judgement on how the variables are rated was based on the emphasis placed on them by the participants in the course of their discussion. Where such emphasis needs clarification, the literature is consulted to determine the most appropriate judgement. Where a conclusion could not be reached via the literature analysis, the researcher's own professional judgement as an experienced estimator was used. In the end, it was possible to compare estimating processes across software applications used in each practice domain. It was also possible to compare estimating in 3D CAD and BIM with conventional procedures used by the participants.

In a similar way, one question was used to resolve Objective 2 (OBJ2), which seeks to *"investigate the degree of association and reliability of the identified activities in each of practice domain (as identified in Objective 1) ...* Items (*b*), (*c*) and (*e*) under the research questions listed in Section 1.3 (and summarized in Section 5.3) were used to formulate how OBJ2 was achieved. As indicated above, item (*b*) seeks to explore how the estimating tools and procedures which were observed in Objective 1 mitigate the limitations of conventional estimating procedures. While item (*c*) also seeks to identify the challenges of estimating with BIM, item (*e*) seeks to determine how the variables in BIM-enabled estimating compare to conventional approaches. These three perspectives were combined into one through RQ3:

"*what is the technical [and statistical] significance of the ratings in OBJ 1"?* Through the literature analysis which was used for triangulation and for rating the variables, it was possible to identify the relationships between conventional estimating methods and the outcomes of OBJ1. The perspective taken by this study is to subject the ratings ascribed to each of the variables to rigorous scientific procedures e.g. to test the reliability of the ratings and relate each variable to existing knowledge in conventional systems.

In the same way, the two questions listed for Objective 3 (OBJ3) in Table 5.1 are targeted at facilitating and strengthening the answers to items (*a*), (*c*) and (*e*) as listed in Section 1.3. What these items stand for has been discussed under previous objectives viz. (*a*) *to identify process themes*, (*c*) *to understand the challenges of BIM estimating*, and; (*e*) *to compare estimating variables in BIM to conventional procedures*. These three items were combined to resolve OBJ3, which seeks to discriminate the outcome of OBJ2 across the four practice models. The combination was used to form RQ4 and RQ5. While RQ4 explores the statistical significance of the discrimination across the four practice domains, RQ5 seeks to identify the technical requirements involved in implementing the outcomes of the discriminations, both for 3D CAD and for BIM. Finally, OBJ4 creates technical constructs for the process models for both 3D CAD and for BIM by using EXPRESS-G Models and IDEF0 models. All the items listed under research questions in Section 1.3 were considered in the course of developing these models.

Providing answers to the research questions (RQs) started with a critical analysis of literature. This is indicated in Table 5.1 as the *preliminary analysis*. In some instances, the preliminary findings achieved on some questions were used as the basis for the preliminary analysis in other questions. In particular, this occurred in OBJ1 and OBJ3 where the target RQs were split into two. In other words, only a part of the research could start from the literature analysis; where an Objective has not been addressed previously, whether in part or in whole, the research started with the literature analysis e.g. OBJ1a, OBJ3a and OBJ4. Where an Objective relies on the outcomes of a previous Objective (e.g. OBJ1b, OBJ2 and OBJ3b), such an Objective commenced with an empirical analysis of the components that had been resolved in the previously completed Objective.

The flow of research activities is such that *findings* from a phase, say Phase 0, led to *analysis* in the next phase, Phase 1. For example, after a research question started with *preliminary analyses* and has led to some *preliminary findings*, they were advanced to *interim analyses*.

In many occasions, the interim analyses were substantially resolved with exploratory methods (through qualitative techniques) and descriptive statistics (through quantitative techniques]. The findings from the interim analyses were extended to the *final analysis* to generate triangulated and confirmatory outcomes. In some cases, there are two research questions per research objective e.g. OBJ1 and OBJ3. In such cases, two research techniques, one for each of Part A and Part B of the questions, were designed to address one Objective. This division was carefully managed to avoid complications in the research process; both parts were designed to be complementary and were re-integrated as the research progressed.

Each of the research instruments used to address the Research Questions and Study Objectives are discussed in Section 5.3.2. The outcomes of this investigation and where they are reported are indicated below:

i. articulation of research themes (i.e. estimating stages and activities in 3D CAD and BIM), first through multiple qualitative approaches, and later, through ratings of the variables (Sections 6.2 and 6.3).
ii. examination of statistical association, including correlation analysis, between estimating activities across the different practice domains (Sections 6.4 and 6.5).
iii. statistical discrimination of ad-hoc and post-hoc data to elicit how the developed process models apply to the different practice domains (Section 6.6).
iv. initiation of specific approaches to the technical implementation of the findings in *i–iii* above (Section 6.7).

5.3.2 Research instruments for data collection

The research instruments for this study were reviewed and approved under the University of Newcastle's *Human Research Ethics Administration Guidelines*. The approval notification, Information Statements, Consent Forms and details of the research questions for the respondents are included in *Appendix 2 (Research method).* As shown in Figure 5.2, a total of five research instruments were deployed to achieve the four research objectives of this study. Out of these, four techniques, viz direct observation, focus group discussions, interviews, and quantisation techniques, were used for model development and response evaluation. The fifth, the literature analysis, was used for model validation. Each of these tools is discussed below.

Direct observation

Recent construction management studies exploring organizational practices and strategies for change implementation have used direct observation and in-depth analysis of case studies as research instruments (Smith and Love, 2004, Zimina and Pasquire, 2011). In some of these cases, researchers have used them to supplement qualitative data from focus group discussions. For example, Zimina and Pasquire (2011) used direct observation to explore how construction companies pursue lean strategies. They combined direct observation with case studies and validated their research outcomes with a literature analysis. Smith and Love (2004) used the same approach to model construction clients' strategic needs analysis (SNA) and developed a unique model, through mixed methods, for managing persistent variability during project implementation. This study follows the same procedure to observe the variables under examination and validate them with literature review.

In this research, direct observation was chosen as a research instrument to model organizational behaviours towards BIM for the following reasons:

- Direct observation combines better with some research instruments than others in a scenario such as this study. In a critical review of the literature on how researchers have explored radical and exponential developments in the experiences of construction business managers, 25 scholarly articles published in the past 10 years were consulted; including Abdelkarim (2010), Karim et al. (2006) and Kristiansen et al. (2005). All these studies focused on the implementation of new technologies including BIM, lean construction philosophies, total quality management and the internationalization of new business concepts in construction. In all the studies reviewed, the change triggered by the abovementioned agents was observed as a complex phenomenon and was explored by combining open-ended instruments such as focus group discussion and interviews with direct observation. In most cases, better outcomes were generated in such scenarios than when they were combined with historical data and structured surveys. For example, where quantitative methods have been used for primary research, participants are limited in the ways they express their views (see Fellows et al. (2003)). In some cases, aspects of participants' responses might require clarification to progress the research. This is difficult if participants have been coded anonymously (Arongo, 1985). An approach used to avoid this was to ask as many questions as possible during the discussions so that the

variables were clear and the importance participants ascribed to them are equally as clear as possible.

In this study, as participants discussed how their organizations estimated using 3D CAD and BIM, it was appropriate to:

- observe how participants usually used their software applications to handle automated quantification and the subsequent steps leading to augmented or automated estimating. This technique was used during software developers' demonstrations and to capture data about how expert-audiences reacted to the presentations of software developers and vendors.
- observe activities that are most important to estimators as they estimate with 3D CAD and BIM. This provides an in-depth understanding on how the views in the four practice domain differ and why.
- understand participants' discussions when supported with evidence e.g. experiences shared on past projects, and an explanation of historical documents.
- explore the peculiarity of each organization by observing them closely e.g. their achievements, challenges, business structure, business culture and corporate mission.
- triangulate interviews and focus group discussions with an in-depth analysis of what was evident in participants' business environments.

Scope and data population in direct observation

The data retrieved from the participating organizations are summarized below:

- In the two *matrix*-structured businesses, estimating departments conducted additional functions such as project management, community services and work-place committee assignments. Eight senior estimators and one architect took part in the research, but the total number of staff in both establishments is unknown. Furthermore, it was possible to observe the nature of corporate policies regarding BIM implementation in both organizations. At the time, a 10-year window period to observe BIM and its deliverable was in place; the research interview took place in the third year of the window period. This observation also helped to understand the roles of large organizations in influencing policy frameworks and setting standards in

estimating practice. It was also possible to observe their roles in improving the capabilities of software estimating applications. These observations made it possible to compare participants' views from these organizations (matrix practice domain) against the views of participants from other practice domains.

- Two large construction companies took part as *divisionally* structured estimating practices. The estimating departments worked side-by-side with other divisions including marketing and business management units. Both companies are publicly listed, and have won many Best Practice awards in Australia in the past three decades. Observations about these companies were that they adapted to change and had continually changed their business practices to survive competition. Four senior estimators took part in the study, although the total number of staff in both companies could not be ascertained.
- The two *functional-unit practices* render estimating services as the main technical core of their organizations' operations. With an average of 19 estimators in both firms, only 4.5% of their staff were non-technical support staff. In one of the two firms, specialized software applications were used to meet their specific business requirements. In particular, *Kinetic* was used to integrate a large number of work stations; it enables distributed users to document their inputs simultaneously. This particular scenario was taken to mean that estimators in this domain, who are supposed to be the most fragmented, have engaged in collaboration and the integration of their estimating resources and processes without having to use BIM.
- In the two *networked* organizations, there was evidence that the firms engage in integrated services within and beyond the scope of conventional estimating practice. They also have extensive alliances with other service organizations. There is an average of 24 staff-members in these firms, 68% of whom are estimators.

<u>Focus Group discussions</u>

Theoretical frameworks and justifications

BIM estimating requires innovative thinking ,as do other practices in parametric modelling (Bailey, 2010, Brucker et al., 2006, Dean and McClendon, 2007). In addition, there is no standard reference or authoritative guide for estimators on how to use BIM to prepare estimates. This is equally true for 3D CAD. Several approaches have been suggested in previous studies, including:

- Using IFCs as the basis for procedural standardization in estimating, either via direct export or by moderating the 'grammars' in IFCs' instructions (Zhiliang et al., 2011).
- Rather than exporting IFCs, cost data can be integrated into object data (Dean and McClendon, 2007, Yum et al., 2008).
- Conventional methods e.g. cost planning methods and SMMs can be used to estimate BIM projects (Olatunji and Sher, 2010a).
- Relying only on the capabilities of estimating applications, regardless of the perceptions of widely accepted standardizations (McCuen, 2009, Samphaongoen, 2010, Sattenini and Bradford, 2011).

Due to the lack of a universal procedure for estimating 3D CAD and BIM projects, estimators' main options are to resort to innovative ideologies that foster quicker and more accurate outcomes in estimating than the case might be in conventional practice. These could involve combining any of the approaches listed above. In addition to these, BIM thrives on multi-disciplinary collaboration and process integration; and these are not limited to design (Ballesty et al., 2007). Thus, the cognitive experiences of estimators within the BIM environment are likely to be similar to those of other professionals on the same BIM platform. For this reason, estimation cannot be treated with isolated instruments like fragmented studies; it should rather be treated in the way that other parametric instruments have been studied. For example, the works of Tang et al. (2011) and Bilda and Gero (2007) provide methodological arguments on protocol analysis and parametricism.

Focus groups (FGs) have been used in many recent studies in construction management and economics (CME), especially involving new technologies, new protocols and studies on knowledge analysis and transfer. Citing Krueger (1994), Ereiba et al. (2004) define focus group interactions as a research method where *"a carefully planned discussion is designed to obtain perceptions* (individuals' views and experiences, through group interaction) *on a defined area of interest in an open-minded, non-threatening environment"* (p. 858). Based on this definition, the approach to a single stage FG process used in this research is characterized as follows:

- It involves dedicated discussions on a subject which prioritises objective opinions of experts (Orlikowski and Robey, 1991).

- Experts who possess appropriate understanding are sourced to discuss a specialist subject in a group such that personal views are objectively analysed and balanced with group views (Elwyn et al., 1999).

- Throughout the research, the researcher took the positions of both a learner and a moderator. While the participants were less constrained in their discussions about the spread and depth of the subject matter, appropriate effort was made to moderate the rigour of their discussions so that conclusions were clear and analysable.

Many studies have used qualitative methods such as FG and Delphi to capture data and explore real life complexities in construction professionals' experience with emerging technologies (see Linstone and Turoff (2002), and Brewer and Thayaparan (2009)). According to these studies, process models can be developed in two ways:

- through pure qualitative analyses such that research themes are explored from respondents' discussions. These themes can then be reverted to another set of participants for validation or for quantitative measurement.
- through interpretivism: According to Currall et al. (1999) and Srnka and Koeszegi (2007), it is possible to explore research themes from qualitative data normatively.

The first approach was not chosen because it is susceptible to the limitations of questionnaire surveys. These limitations have been summarized earlier in this Section, viz the possibility of low return rate (due to inclusion and exclusion criteria of this study), and the fact that the themes being explored are soft in nature. In addition the approach of using questionnaires was considered inappropriate because:

- FGs have been used in many studies as normative tools only to model product attributes. Their outcomes may also be limited by their inability to capture other variables that these models intend to explain. By their subjective judgments, researchers may omit or misinterpret the qualitative data upon which quantitative measurements they intend to achieve are based. Moreover, there is a degree of rigidity in the questions that participants answer quantitatively, if a questionnaire approach is used. According to Ainur and Marioara (2007) and Nounou et al. (2003), such measurements can be confusing. A way to avoid these limitations is by exercising flexibility in identifying and assessing the process descriptors across the concerned stratified domains qualitatively Srnka and Koeszegi (2007).

- The ultimate goal of using FG and interviews is to elicit themes for process modelling; and this has a high exclusion potential. This is because only a small population of estimators had extensive experience with BIM at the time the study was conducted. If only quantitative research methods have been targeted, the outcomes could not have been different. For example, in a survey by Aibinu and Pasco (2008), only 40 valid responses were retrieved on a study about the accuracy of estimates, without delineating the practice domains where the estimators originated from. The goals of qualitative and quantitative studies are different. As indicated in Section 5.2, while qualitative studies explore new phenomena with soft descriptors, quantitative methods are best for hard studies that are focused on single-objective phenomena (Nicholls, 2009). Rather than the numbers, under qualitative paradigms, the unique experiences of a few estimators could represent the practice domains effectively such that the needed themes could be identified, and the importance of such variables to the domains be established. Where a research targets a small population, a very low return rate is a predictable disincentive if quantitative instruments were used (Thorpe and Ryan, 2007a). Thus, it is appropriate to adopt a qualitative approach where valid outcomes can be generated with a small population.

  While qualitative approaches may elicit the dominant themes involved in estimating processes, these themes have to be processed to establish their validity. A reliable approach is to quantise the descriptive themes and analyse them statistically. This may be accomplished in the following ways:

  - Formulate the themes qualitatively and quantise them through quantitative techniques such as questionnaire surveys (Schneider et al., 2002).
  - Formulate the themes qualitatively and quantise them by direct interpretations and literature analysis (Howe, 2012, Onwuegbuzie and Teddlie, 2003, Tashakkori and Teddlie, 1998).

  If a study targets different participants for the quantitative and qualitative aspects of an investigation, the small population size will jeopardize the outcomes. If the same group of participants is targeted for both quantitative and qualitative methods, the variability inherent in the various practice domains can be jeopardized (Flick et al., 2012).

To resolve this challenge, the FG qualitative approach was conducted in two ways. As explained in Section 5.2.2, exploring the primary themes of the research started with software developers. The themes identified at this stage were triangulated with the views of estimators who came from different domains and their perspectives were likely to align with the priorities of their domain. Only the views of estimators in the four practice domains are analysed and reported in this study; the reasons for this are noted in Section 6.2.1. The data collection process and interpretivism approach are described below.

FG data collection process and interpretivism approach

Data collection started with participants who were sourced from CAE software developers and vendors in Australia. These were mainly developers of applications that were described as BIM compliant and were commercially available at the time this research was conducted. Of the five organizations contacted, four took part from three Australian capital cities (Brisbane, Melbourne and Sydney). One organization declined to participate to prevent their *"competitors from knowing our line of action in developing more innovative solutions for BIM"*. However, the view of other participants was different; research and a critical analysis of their products were seen as an impetus for further developments.

Participants demonstrated (i.e. in discussion and by actual use) how their applications work in different design scenarios (e.g. 2D CAD, 3D CAD and BIM). A similar procedure has been described as design-based protocol analysis (DBPA) (Williams, 2000). Using the same procedure, Tang et al. (2011) and Bilda and Gero (2007) researched several topics in parametricism and cognition, with up to 10 students, who collaborated in a design session. Their interactions were reported and analysed qualitatively to generate valid outcomes.

While exploring themes for further analysis, software developers made presentations to subject-experts who were practising estimators. Four of such sessions were attended; the minimum number of subject-experts was two, while other sessions averaged 25 participants. The subject-experts were allowed to ask questions of the estimating processes and the functionalities of the applications. The observed interaction was a significant achievement because, unlike in design-based research, innovative processes for quantity measurement is more dynamic between the practice domains being researched than in design environments. Moreover, this study started with software developers, whose views included interactions with expert subjects. In the case of the sampled DBPA studies (Tang et al. (2011) and Bilda and Gero (2007)), few research subjects (between 4 and 10 students) were used. As shown in

Section 6.1.1, this is a significant advantage indicating the quality of data that were used for this study; both participants who took part at this stage and those who took part from the four practice domains were experienced professionals who had a deep understanding of real life complexities and the subject being studied.

The data from the stage above formed the basis for further interaction with participants in the four practice domains. Before these organizations were contacted, data from the interactions with CAE application developers were coded as shown in Figure 5.3, using an adaptation of the procedure by Srnka and Koeszegi (2007).

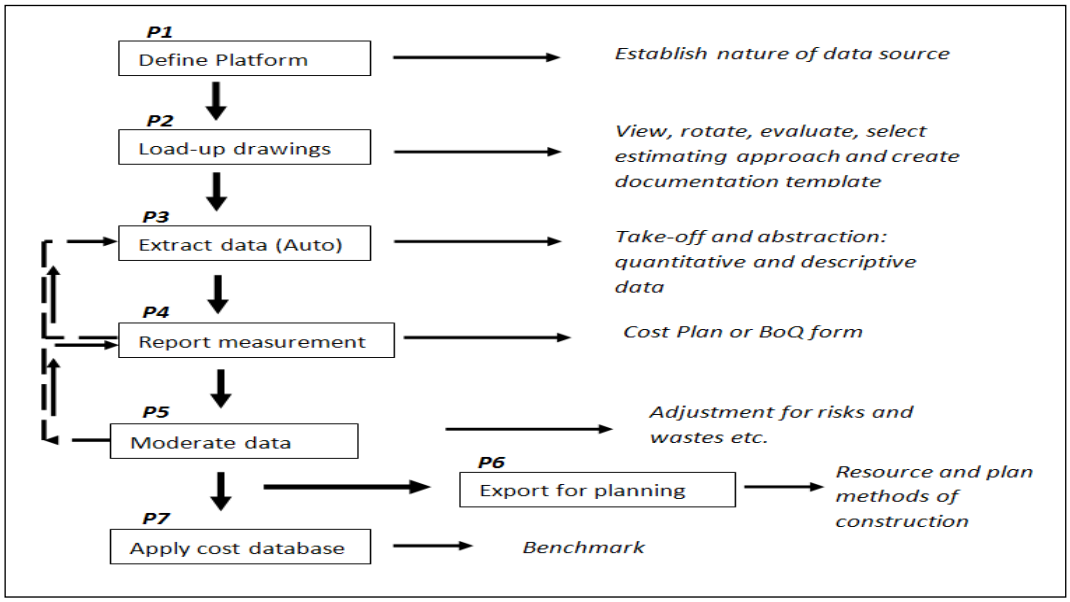


Figure 5.3: The ontology used for coding the data from the first phase of data collection

As indicated in Figure 5.3, the data collected from BIM-CAE software developers were triangulated with the views of estimators who specifically used CAE tools in their regular operations. The underpinning target was to ensure that the process models to be developed had sufficient input from practising estimators. This input was limited to participants' familiarity with 3D CAD and BIM, and the four practice domains covered in this study. These attributes were ambiguous in the first stage of the data collection. The outcomes of the focus group discussions are analysed and discussed in Chapter 6.

Inclusion and Exclusion Requirements

There are inclusion and exclusion criteria guiding what was considered as valid data used for analysis and what does not. Such inclusion and exclusion rules for participants include:

- Participants were practising estimators who had worked for at least the past five years in the Australian construction industry.
- Participants must to have worked on BIM and other design forms on any kind of construction project.
- Participants in a group must be workers in the same organization, and the organization and participants must provide separate written consent to take part in the research.

In summary, participants were carefully sourced from four estimating practice model organisations. Two firms were chosen from each category such that the views of participants could be compared within and across the practice domains. A total of 22 participants were sourced from:

- four software development companies
- four consulting firms
    - two of the four consulting firms operate functional-unit practices,
    - the other two operate within large networks of integrated services.
- two large contracting companies where divisional business structure was evident
- two government offices where the functional structure of their business operation is substantially in the form of a matrix business model

Out of 22 participants, 17 took part in focus group discussions which were conducted in five sessions across the four practice domains. The other five participants were interviewed individually; the discussion of the interviews is presented immediately after this sub-section on FG. Where participants were not estimators or had different levels of experience with BIM, discussions were based on their opinions. For example, on two occasions, an architect (on one occasion) and a software engineer (on the other occasion) were part of a discussion group involving a fairly large number of estimators. The opinions of these people were slightly different as to what an estimate means but such views were complementary to the views of estimators on the potential of BIM. For example, because of the limited

understanding of estimating procedures by these participants, their idea about BIM estimating is an abstract dimension whereas the issues raised by estimators within the groups were more specific and definitive. Moreover, there were instances where some members of the discussion groups had a more developed understanding of BIM than others. In such cases, Powell and Single's (1996) model was adopted:

i. discussants were allowed to express themselves and share their knowledge openly

ii. when this led to distractive arguments, discussions were redirected to the subject of discussion

iii. where people shared different views, the stronger arguments dominated but other arguments were not rejected.

iv. all discussions ended with tangible conclusions to which the majority of discussants agreed

v. where possible for clarity, discussants were informed about new areas; in a few cases, some aspects of discussions from other groups in the research were mentioned.

The number and quality of participants (see Section 6.1.1) were sufficient to deliver valid data and reliable outcomes through focus group discussions. The data were also adequate for transmission into quantitative measures because the themes and the participants explored were distinctive with stratified views across all the practice domains investigated. Additionally, research participants' knowledge about BIM was clear and robust. Thus, the outcomes of the focus group discussions were tangible and implementable. How data from this stage was transformed to a validated outcome in process modelling is reported in Sections 6.3 to 6.7. In comparison, other studies with fewer participants but with a similar scope and research focus have also generated valid outcomes. For example, in Ogunlana's (1989) research, seven organizations were used to analyse the accuracy of estimates using an IBM system called ACCESS. In Brewer and Gajendran's (2009)Delphi study on emerging trends in construction teams, 15 participants took part. From the demographic analysis of these two studies, it was clear that the researchers did not consider the difference in the business practices of the organizations from which participants were drawn.

Interviews

There were instances where participants were only available for interviews and not for focus group discussions. In such cases, the participants were interviewed individually with the same set of questions that were used for FGs. This approach served two purposes: first, to triangulate the outcomes of focus group discussions; and second, to serve as a parallel method of data collection with focus group and direct observation. Five interviews are reported in this study, providing data from four organizations i.e. two contracting and two consulting firms. Whilst the two consulting firms were *functionally* structured, the two contracting firms were *divisionally* structured. Personal interviews are more subjective than FGs where summaries of debated issues were prioritized in forming the themes. This limitation was handled in two ways:

- Interviewees' opinions were compared with the views from focus groups
- Interviews also focused on the personal experiences of participants on different kinds of projects. Therefore, it was easier for respondents to divulge in-depth information confidentially which could be difficult to discuss in focus groups.
- It was also easier to gather personal views on a wide range of issues that are related to this study e.g. some examples of past performance of projects that participants have taken part in and the discussants' opinions on the debacles of estimating practices and processes with 3D CAD and BIM. Such views have focused on personal competencies and limitations.

A summary of participants' discrimination is shown in Table 5.2. By using multiple qualitative research instruments, the nature of participants' organizations' businesses in construction was ascertained. It is also clear from the discussions and observations that the stages and activities leading to estimating outcomes in each of the organization models can be identified and rated. A quantitative approach to the ratings is discussed below.

Table 5.2: *Summary of participants' discrimination*

Discriminators	Matrix Model	Divisional Model	Functional-unit Model	Networked Model	Software developers
Number of organizations consulted/ reported	2/2	2/2	2/2	2/2	4/5
Organizations' business domains	Public clients and regulators	Large contracting businesses, publicly listed, major players in the region, both operate cooperative form of divisional business practices	Large quantity surveying firms	Parts of a large network of firms providing integrated services	Producers of commercial applications for digital estimating (2D CAD, 3D CAD and BIM)
Number of estimators in the organizations	Not known	Not known	38	32	Not known
Number of employees who participated in the research	5	3	2	7	5
Nature of participants	Medium and top management staff	Medium and top management staff	Medium and top management staff	Medium level staff	Medium level staff
Estimating Software in use	CostX, LCA-Design, BEST, Everest, MS Project	Buildsoft, Excel, CATS, MS Project	Kinetics, Buildsoft CostX, Everest, Write Back	CostX, QUBIT, ROSS, Jobpacs, CHEOPS, MS Project, Primevara	CostX, VICO, Primavera LCA-Design
Nature of projects	Institutional and civic buildings; new and rehabilitation	Institutional, civil and industrial; new and rehabilitation	Any form of project, new and rehabilitation	Commercial and industrial projects, new projects only	As long as data can be exported from designs

Discriminators	Matrix business structure	Divisional business structure	Functional-unit business structure	Networked business structure	Software developers
Roles of estimators in the organisations	Construction project estimating and management roles	Construction project estimating and business management roles	Construction project estimating, business and project management roles	Construction project estimating and project implementation roles	Software development, marketing, demonstrations, technical supports to clients
Corporate motivation and recorded achievements	Public regulators	Have many practice excellence awards	Structured leadership in professional practice	Famous for participating in specialized projects	Developers of digital estimating tools
Role of estimators in business outcomes	Dominant, but not conclusive	Dominant and conclusive	Dominant and may be conclusive	Dominant and conclusive	Dominant, but not conclusive
Professional background of estimators/participants	Quantity surveying	Construction management, building, project management	Quantity surveying	Quantity surveying	Quantity surveying
Organizations' commitment to BIM	Ongoing-commitment; still under 10-year evaluation period before final commitment is made	No dominant commitment to BIM, speculating market stimulation	No dominant commitment to BIM, speculating market stimulation	Definitive commitment to digital estimating	Definitive commitment to digital estimating; orientations are moderated by market demand/hands-on innovative practices
Data collection method	Focus group, interview and direct observation	interview and direct observation	interview and direct observation	Focus group discussion and direct observation	Interview and direct observation

Quantisation technique

Several studies have illustrated the ability of qualitative research methods to elicit dynamic and merging research themes (Bazeley, 2004, Sale et al., 2002, Frost et al., 2010). However, the research questions proposed by this study (Section 1.3) cannot be resolved simply by identifying and discussing the emergent themes. In a pragmatic study such as this, the main focus of data analysis is on the views and experiences of estimators, bearing in mind the real world complexities they face when dealing with 3D CAD and BIM. Their views and experiences vary across the four practice domains, and can be measured. According to Flick et al. (2012), Johnson et al. (2007) and Srnka and Koeszegi (2007), it is insufficient to measure pragmatic variables through subjective and contextual generalizations. They argue that this should rather be addressed through objective context-free generalizations through which valid scientific phenomena can be characterized. In the context of this study, each estimating stage and activity has varying degrees of importance to participants from the various practice domains. It is argued that there are logical and scientific relationships within and across the stages that make up estimating processes in both 3D CAD and BIM paradigms. If these parameters are contextualized within the theoretical frameworks of each of the practice domains, the outcomes are not generalizable across all the practice domains. Alternatively, measurements of parameters, such as the importance of variables and the relationships between them, can be used to advance the outcomes of qualitative research into a more robust procedure (Patton, 2002). Specifically, the main focus of this research is to develop process models. It is insufficient to compute models without scientific validity i.e. the variables (emergent themes) must be scientifically reliable and should possess adequate correlation to co-exist in a model.

There are several guides in literature regarding how quantitative methods are integrated into qualitative outcomes. In line with the illustration of Srnka and Koeszegi (2007), this study measures the importance of variables as ‘not important at all’, ‘slightly important’, ‘moderately important’, ‘very important’ and ‘very important and inevitable’ (Section 5.3.1). These measures were translated as ratings of 1 to 5, with 1 being ‘not important at all’ and 5 being ‘very important and inevitable’. In addition, the ratings were extended quantitatively to measure the statistical descriptiveness of the themes, reliability, correlation, regression and statistical discrimination (Section 5.5).

There are fundamental challenges in converting qualitative data to quantitative data. Some of these are:

- *Data population:* According to Maxwell and Delaney (2004), most quantitative purists believe a large data population is an impetus for reliable quantitative outcomes. However, qualitative data can be based on a small data population (Bilda and Gero, 2007, Tang et al., 2011). A reasonable question is how large does a data population need to be if it is to be enough to generate valid outcomes? Routio (2007) argues that:

  > *"There is no formula to determine the size of a non-random sample. Often, especially in qualitative research, you may simply enlarge your sample gradually and analyse the results as they come. When new cases no longer yield new information, you may conclude that your sample is saturated, and finish the job"*

  Taylor-Powell and Hermann (2000) have put this in context; they concluded that data collection may stop once the research objectives have been met.

  In this study, estimators were not selected randomly; four practice domains were targeted and participants' views were stratified along this delineation. A recent study on a similar subject was conducted by Aibinu and Pasco (2008). They delivered a questionnaire survey to estimators in Australia, without identifying their business bases, on issues relating to the accuracy of estimates. Valid outcomes were generated from about 40 respondents. These respondents could fall anywhere across the four practice domains considered in this study; thus their views may only apply to a portion of the categories. In a similar work by Ng and Skitmore (1999), 500 respondents to a survey were reported to elicit stratified views on how six categories of project stakeholders view prequalification criteria. The categories included clients, contractors, architects, engineers and estimators. It proved daunting for the researchers to discriminate between the views of construction clients (i.e. private and public clients), even though the two client categories reported in the research did not agree on most of the variables. These two studies provide evidence that data population may not automatically translate into generally applicable outcomes, even though the research outcomes may be valid.

  The aim of this study is to develop a valid process model that can represent the domains of estimating practice and be used by each of the domains independently. As

indicated in Table 5.2, there were respondents across all the four practice domains. As each practice domain was represented by at least two organizations, participants' views were deemed to represent all the domains. The views of 77 subject-experts who took part during the four presentations by the various software developers were not reported; while the presentation sessions were about quantification using specific applications, estimating practice is far more than using an application. Moreover, while those presentations were limited to very abstract projects and pre-contract estimates only, the research focus is on estimating activities throughout the different components of a project lifecycle. The 17 participants, whose views were analysed, elicited estimating activities in 3D CAD and BIM throughout project life. Such views contained how estimators have used the software applications which the developers have presented before the 77 subject-experts. Moreover, unlike studies where modelling depends mainly on quantitative data, the processes modelling approach targeted in this study relates to themes, not ratings. Throughout the statistical analyses, the number of participants in each domain was not the overriding factor. This means, even though the number of estimators in the categories are not the same as each other, each view was considered on its merit; only the class average for each group was used during descriptive analysis. There are several advantages in this:

- The activities leading to how the dominant themes were elicited were triangulated in several dimensions. Direct observation triangulated the views of software developers, focus group discussions and interviews; focus group discussions triangulated direct observations, while interviews triangulated both focus group interviews and direct observations.
- The ratings were based on generic views about the themes, as emphasized by participants and explored through contextualised philosophies of estimating practice across each practice domain. For example, 'site visit' was identified as a theme necessary to lead to workable estimating outcomes in 3D CAD. This theme was identified by respondents from matrix model organisations as 'very important and inevitable'. However, this is a conditional parameter for estimators from divisional practice domain; it is 'very important' but only becomes inevitable if this activity is mandated by a client or if clients are involved during the design phase.

- When the ratings mentioned above are converted to numbers, only group averages for each domain are adopted. Thus, the thematic ratings are not simply the views of an individual, they represent a class of thought to which many views subscribe and are based on generally accepted principles supported by literature.
- More importantly, all the themes were factored on a unitary basis i.e. no theme was considered to have more importance than another.

- *Integrity of ratings:* The ratings can only be prescribed after participants' views have been interpreted. There are two limitations to this:
  - Participants gave their personal views and those of the organizations they represented. This may not be an absolute representation of every possibility within their domain or that of the whole industry.
  - Where the importance of a variable is not clearly defined in participants' responses, the researcher has used the literature analysis and his personal judgement to rate the importance of the variables. As a trained estimator with industry experience, the research could thus be biased.

Both of these limitations are common to studies in both qualitative and quantitative paradigms (Gruneberg and Hughes, 2005).

After the ratings, the correlations of each activity across the practice domains were established. Further steps taken to identify the activities that contribute more to estimating outcomes than others (Section 6.3 – 6.5) include reliability tests, parametric tests and discriminant analysis (see Section 5.4 and 5.5). The final outcomes are process models that the different practice domain can apply. The procedure for the development of the models is discussed in Section 5.5.

5.4 PROCESS MODELLING FOR 3D CAD AND BIM ESTIMATING

The main focus of this study is to develop process models for estimating 3D CAD and BIM projects, regardless of the estimators' practice domain. This section presents a review of existing knowledge on process modelling, the statistical instruments used for the process modelling and the approaches used for validating the process models that were developed in this study.

Existing knowledge on process modelling

Several approaches to process modelling are well documented. Amongst such works is the work of Green and Rosemann (2000) who explored and modelled the applications of information systems (IS) in organizational improvement approaches. The process model they developed was focused on the dynamic patterns of organization behaviours in the contexts of process improvement strategies such as total quality management (TQM), business process re-engineering (BPR), value-based performance management (VBPM) and enterprise resource planning (ERP). In the end, Green and Rosemann's (2000) work integrates Weber's (1997) and Scheer's (1999) models and applies the outcome as an ERP tool by combining event-driven and object-oriented approaches on the Architecture of Integrated Information Systems (ARIS) platform, a change management tool.

There are a number of issues to note in Green and Rosemann's (2000) work. Firstly, when organizations react to change-agents such as BIM, there are many issues involved. This includes their propensity to adjust their business practice and technical conventions. This will encompass:

- changes to tools i.e. a change from fragmented software applications to applications that work well with the integration and automation of estimating and business processes (Olatunji and Sher, 2010a).
- changes to the pattern of operation i.e. a change from fragmented practices to collaborative behaviours where actors share data across multidisciplinary platforms (Ajam et al., 2010).
- project delivery styles i.e. a change from traditional models of information exchange to bi-directional digital processes, such that outcomes are generated through automated interaction between physical and cyber systems (Akanmu, 2011).
- business behaviours i.e. a change from traditional business practices to platforms where automation, object-oriented simulation, collaboration, value sharing and process integration inform how business frameworks are constructed and implemented. There have been several views on the legal aspects of this (Fairfield, 2005, McAdam, 2010, Mow and Naylor, 2010, Olatunji, 2011c, Speaight, 2009).

- operational philosophies i.e. exponential developments arising from the different between GDO CAD, 3D CAD and parametric BIM (Anumba, 1996, Whyte et al., 2000).

Putting the problem in context

There are two perspectives to the process models targeted in this study, and both relate to the functional difference between 3D CAD and BIM:

- Dean and McClendon (2007) illustrated that, although 3D representation is relevant and popular with BIM, estimating with 3D CAD is limited in parametric capabilities. Hence, it may be possible for estimators to export object descriptive data from 3D models as with conventional CAD. It is impossible for estimators to input estimate data into 3D models.
- Previous studies on BIM have also shown that project models offer robust data to which multi-disciplinary sharing and integration of data is possible (Succar et al., 2007, Succar et al., 2012). A particular illustration on how to integrate cost data into parametric objects has been discussed by Yum et al. (2008).

Thus, estimating in 3D CAD and BIM is structurally different; quantification in 3D largely requires manual augmentation, whereas in BIM purists have argued that quantification is markedly automatic (Bayrak, 2008, Kim et al., 2009b). This evokes several issues:

- Can there be accurate estimates from BIM without estimators' moderation of data from project models?

- In conventional practice where estimators refer to practice standards as process benchmarks, what should be the reference benchmark in the form of a quasi-universal model for estimating BIM?

- So far, four BIM estimating techniques have been discussed in literature:

    - *based on IFC exported into Excel*, where data can be edited, and more items can be added to the imported list.

- *based on automatically translated data that are exported into dedicated estimating applications;* quantities may not be changed as metadata from project models are considered absolute.
- *based on project model remodelling (e.g. using VICO) to create hyper models;* the estimate is visually-based and data can be moderated but such moderation is limited to the content of the model.
- *a combination of automated and manual interactions with BIM metadata;* this takes into account issues to be moderated in project models and items which are not represented in the model.

These approaches are not the same, how do they compare with each other and conventional practice and/or the approach in 3D CAD? The rationale and approach used in developing the process models presented in this study provide answers to the questions above.

Rationale and approach for BIM estimating process models

Section 5.3 has presented the approach to data collection via qualitative techniques and how the data were quantized across the four practice domains. Each of the statistical procedures used in this study has been discussed in detailed in Section 5.5. Below is a summary of how they were used in transforming the data to process models:

- Exploratory focus group discussions elicited the dominant themes as per the stages and activities that participants identified as leading to estimating outcomes.
- Different variables (stages and activities) were collated for using 3D CAD and BIM across the practice domains.
- Each activity and stage was rated on a 5-point scale for each of the four practice domains. Previous research, the participants' emphasis and the researcher's interpretation were combined to determine the rate for participants' views for each of the sessions. Where the group could not agree on a particular emphasis, judgement was based on explicit opinions in the literature. Where such issues are not available in literature, the researcher's interpretation of the direct observation and self-professional judgement (as an estimator) was used.
- For each stage there were up to seven activities; and for each paradigm, there were six stages. All stages and activities have equal weightings but different ratings. The

reason for the equal weighting is based on equality in the validity of the descriptive themes. The same rule has been deployed in many other studies where similar process model descriptors have been identified and applied (Ng and Skitmore, 1999, Underwood and Alshawi, 1997).

- Each activity carried the average of ratings within and across the practice domains. Each stage carried the average of ratings ascribed to the activities within it.
- As the stages are a summary of the activities, they were used for descriptive statistics:
    - Firstly, the data were tested for parametric distribution
    - Secondly, an Analysis of Variance (ANOVA) test was conducted to explore statistical distribution amongst the variables.
    - Thirdly, correlation coefficients and the principal component analyses were used to determine best rater-stages and best rater-activities across the four practice domains.
    - Fourthly, pairwise comparisons were obtained for variables that were statistically significant for the global ANOVA. Adjustments were made for multiple comparisons using Fisher-Hayter method.
    - Fifth, the correlation coefficient and internal consistency reliability (Cronbach Alpha) tests were used to identify "good" and "poor" variables (i.e. stages and activities) leading to workable estimates in each practice domain. This served as the penultimate confirmatory tests while identifying the variables that are statistically relevant to the model and those that are not.
    - Sixth, ultimately, consistency in statistical significance across all the descriptive statistics and reliability tests elicited the dominant themes that formed the estimating models for both the 3D CAD and BIM regimes. In summary, the consistencies of variables across the following statistical instruments have shown that the resultant variables after the procedure are statistically significant and they work well together in a process model.
        - Correlation matrix
        - Item-total correlation
        - Cronbach's Alpha reliability estimate, and
        - A repeat of item-total correlations and Cronbach's Alpha to determine poorly performed variables. ‘Good’ variables (stages) were

consistently significant (positive) across all the statistical procedures, while the 'bad' variables are consistently insignificant (negative). The objective of the statistical procedure for determining the reliability of the variables in forming the process model is to identify variables with negative item-rest values. Such variables have total-item correction values of less than 0.2; thus they are removed as they lack statistical significance as per their contributions to the models. When such items are discounted, the Cronbach's alpha value of the remaining variables increases until a maximum reliability value is achieved. Only the undiscounted variables are considered sufficiently reliable to contribute to the relationships within the process models.

- Seventh, the outcomes of the sixth procedure above are generic to all the practice domains. In order to understand how they apply to each practice domain, discriminant analysis was conducted (the outcomes of the sixth procedure). This is aimed at investigating the reliability of the variables that trigger optimum outcomes where deployed in each of the practice domains. The discriminations were also measured before the reliability test and after the confirmatory reliability tests [sixth procedure]:
    - Wilk's Lambda and Pillai's Trace tests were conducted to measure the degree of discrimination of each of the practice domain, while the outcomes of the sixth procedure were taken as model centroids. The outcome of this stage was compared between values of variables.
    - The Classification matrix (CM) was used to measure the accuracy of the discrimination across the practice domains. This points out whether participants in all the domains think in the same direction or not.
    - Discriminant Analysis coefficients were used to elicit the magnitude of discrimination across group variables. Through this, the mindset of estimators in each of the practice domains can be analysed.
    - 10 discriminant equations were also developed to show the mathematic relations of the process models. The 10 equations were made for each of the four practice domains under both 3D CAD and BIM paradigms.
    - The accuracy of the classifications was also calculated.

- Eight, having explored the discrimination definitively in the seventh procedure above, the technical applications of the process models were developed as followed:
    - The EXPRESS-G approach was used for configuring the system entities to show the relationships between activities and domain subsystems through which the process models to be developed are routed to work. This technique was used in line with the guidelines in previous research (Schenck and Wilson, 1994, Underwood and Alshawi, 1997).
    - The Integration Definition (IDEF0) formats for the two centroid models were also developed to show how the model variables come together during implementation. This followed the illustrations of Karhu et al. (1997).

Instruments for model validation

Approaches to modelling in scientific research are well documented (Al-Hajj and Horner, 1998, Hunter, 2006, Mishler, 1990). In particular, in information systems and organizational behaviour, they have taken the forms of parametric and non-parametric methods and have been used in both experimental and inquiry-guided studies (Mishler, 1990). Contextually, model validation methods have been applied in two ways: the hard and the soft techniques (Macal, 2005, Moss, 2008). 'Hard' techniques are used for modelling environments where validations are based on definitive data; 'soft' techniques are often used for situations where data are somewhat undefined. Unlike situations where the data population is large and the domain of measurement is static, BIM is an emerging technology; methods used by estimators as BIM applications change. Such scenarios of change include continuous improvements in software capabilities and BIM deliverables. Assakul (2003) has identified studies like this as the studies of the future and recommended a validations method to include times-series data, models, brainstorming, scenario writing, simulation, historical analogy, the Delphi techniques, cross-impact analysis, causal modelling, relevance trees, gaming and contextual mapping.

Like most process models, the attributes of the models presented in this study are not quantitative; the uncertainties characterized in them are not reducible and cannot be fully described or delineated. This means that traditional quantitative methods, causal modelling

and simulation cannot be used for their validation (Assakul, 2003). Alternatively, judgemental processes and measures of internal consistency are more reliable (Ritchey, 1996, 2011). Such internal consistencies are explained under model development processes above. According to Ritchey, historical and scientific knowledge develops through cycles of analysis and synthesis. The approach taken by this study therefore is to adapt specific tools of *future* studies to relate BIM to the results of proceeding analyses to verify and to validate its results based on internal consistency through multiple triangulations (see Section 5.3). Few other options were available:

- Quantitative methods e.g. the administration of questionnaires and the analysis of historical data. This method is inappropriate because the number of construction businesses with significant exposure to BIM and 3D CAD is relatively small at the time of the research. Moreover, being a study that focuses on process modelling, the value of the research is better appreciated when the models are demonstrated.
    - If the themes have been sent to participants so that quantitative data can be retrieved for model development and validation, low return rates and conflicts in participants' ratings were obvious disincentives. This view is supported by Bernard (2000).
- Qualitative methods e.g. Delphi techniques and brainstorming.
    - If another set of panels of experts were used for validation purposes only, the outcome is not likely to be valid. This is because the same approach was used during data collection (Harty et al., 2007, Olson, 1986, Soetanto et al., 2006). Moreover, the variables to be validated are not quantitative; thus validation participants can only acknowledge that the themes and the procedures are reasonable. It will be nearly impossible for them to challenge the validity of the models and the procedures leading to them better than the position of literature. Particularly, they will be unable to quantify the accuracy of the models and judge the scientific appropriateness of the variables just be listening to the practical illustration of the models.
    - BIM is an integration platform i.e. it integrates all activities in a project lifecycle. Applying estimating in such a context means the models presented in this study can be fully validated with primary data only if BIM has been used throughout the life of a project. No such projects exist at this time.

Two validation techniques were used in this study: validation by induction and validation based on literature enquiry.

Validation by induction

As indicated in Section 5.3, data for this research were collected in two stages. Estimating procedures used by four major developers of commercial CAE applications in Australia were observed. Four presenters and 77 observers took part in these sessions. After this, 17 senior estimators from eight construction businesses were interviewed to explore their views on estimating processes with 3D CAD and BIM. Validation is substantially evident here:

1. Although estimating practice is not limited to using software applications for quantification (Section 3.1), the research participants were able to triangulate the observations from software developers. Moreover, there were interpretations that were specific to each of the practice domains. This, in itself, is a substantial method of validation (Fielding, 2012).
2. Moreover, all the applications observed are commercially available, and all participants were familiar with them; they have used them on projects involving varying degree of BIM capabilities. Although not biased to specific practice domains, the estimating processes reflected in the estimating applications were validated by the observed developers' interaction with 77 industry experts who were present and were asking questions when the developers made their presentation. With the involvement of experts, the explored themes were confirmed as real and valid as how end-users (estimators) put the tools (CAE applications identified in *1* above) to use.

Validation by literature enquiry

Using the literature for model validation is as valid as any other approach for the same purpose (Assakul, 2003, Macal, 2005, Moss, 2008, Olson, 1986). In the context of this research, the outcomes of the procedure explained above are statistically significant. This is not where it ends; the specific technical implications of such statistically significant outcomes also require further discussion. The procedure leading to the statistical analysis, i.e. the rating of the activities, was based on a literature analysis (Section 5.3). The final outcome was also explored in the context of the existing body of work, particularly, on the subject of integrated estimating. This was shown in three perspectives:

- System architectures for implementing the new paradigms of estimating procedure through 3D CAD and BIM were compared to the work of Underwood and Ashawi

(1997). The outcome is a significant extension of Underwood and Ashawi's work from construction-only estimation to an integrated platform for estimating throughout the project lifecycle.

- The EXPRESS-G model used by Underwood and Ashawi (1997) was also applied to explain how the variables discovered in the research work together.
- The Integration Definition (IDEF0) model was used to explain the process models in both paradigms as per their connection to business behaviours. Literature was used to explain how *'control'* factors and performance *'mechanisms'* apply to each stage and activity in the process models. The rationale behind this is to expose the practical issues (e.g. contingencies, risks, uncertainties, macro-variability, rights and liabilities) that may affect procedural outcomes when the models are applied.

Limitations of the models

In all, 10 models are presented in this study i.e. two models for each of the four practice domains for each of the 3D CAD paradigms and BIM, and a centroid model for each of the paradigms. Numerous studies have had different views on the strengths and weaknesses of process models. Many of these views have been reported by Murthy and Swartz (1975). These authors observe that most critiques of process models have concentrated on how non-parametric models have failed when they are built on limited strengths but are aimed at predicting unlimited real life events. This is especially the case when debating the organizational reaction to change and the change in process architecture and re-engineering of information systems. In the same context, the weaknesses of process models can be:

- *Incompleteness:* This is often the case when model variables are either incomplete or the explanatory relationships between variables are inappropriate. As shown in Section 6.5–6.6, the models presented in this study are between 92 and 96 percent complete.

- *Ambiguity:* When the relationships between variables have limited scientific clarity, model outcomes become unreliable. This could be triggered by multi co-linearity, redundancy in variables or when model descriptors are loaded with unclear attributes. In this study, statistical procedures were used appropriately to limit ambiguity. A total of seven statistical procedures were used before the outcomes of the research

were advanced to further technical implementation. Only the variables that demonstrated consistent statistical significance were used in the model.

- *Fragmentation:* Most process models are targeted at fragmented outcomes. However, this becomes a problem when isolated models are unable to work well in integrated platforms, especially when integrated process models require decomposition. In this study, all practice domains had an equal chance; they can adopt the centroid models or those specifically made for their domains.

- *Functionality:* This is a fundamental limitation of process models. Process models are guides; they are not overarching functional instruments. When target systems are induced to malfunction due to inadequacies in system instruments, the strength of the model could be susceptible.

- *Generalization:* The models developed in this study are based on the views of experienced estimators. However, their views cannot represent the absolute position of the construction industry or all the possible range of views in the domains they represent.

5.5 STATISTICAL INSTRUMENTS USED FOR DATA ANALYSIS

The statistical procedures reported in this study rely on five major methods; they have been summarily described in Section 5.4. Further explanations on the methods are presented below:

Normal Distribution

The data explored in this study occur in discrete form i.e. participants from each of the practice domains have distinct views on the variables leading to estimating outcomes. To make meaning of the various views the data represent, it is expedient to study the nature of the statistical dispersion of the data. When a group representation is to be made, a data cluster can be represented where it is most stable and can represent a substantial portion of the dispersion. In this study, participants' views are stratified. To obtain a representation for the data strata, the arithmetic means are calculated.

For each set of data, arithmetic means are calculated for each practice domain. When this is added across the domains, a representation is made for each variable around the centroid. To

determine how the data are to be treated from this point, it is important to ascertain the nature of their distributions. A set of data is normally distributed when it is certain that if an event within the data band is picked at random, the probability that the event is represented by the centroid is markedly high (Casella and Berger, 2001). Such dispersions from the mean are usually measured by standard deviation (σ) and variance (σ^2). According to central limit theorem, there is about 68% probability that values drawn from a normal distribution are closest to the mean i.e. within 1σ; about 95% within 2σ; and about 99.7% are within 3σ.

Popularly, normal distributions are described as bell curve – see Figure 5.4. When data are normally distributed, parametric statistical methods apply; otherwise, non-parametric methods apply. Contextually, in a stratified study such as this, it is critically important to test the data for normality before they are tested for reliability i.e. it is important to ascertain that the ratings represent participants' views adequately before it is determined whether the variables can deliver reliable outcomes as rated. Other statistical procedures involved in reliability tests are discussed below.

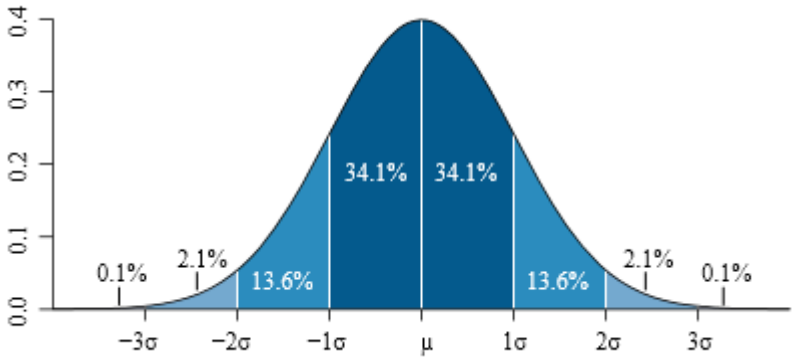


Figure 5.4: Bell Curve representation for normal distribution

Analysis Of Variance (ANOVA)

Analysis of Variance (ANOVA) is used to analyse and validate the significance in the observed dependencies (Myers and Well, 2003). In this study, it is used to clarify:

1. Whether changes in the independent variables (i.e. estimating processes (stages) based on different designs and model data) in each practice domain have significant impact on dependent variables (overall ratings represented by the centroid).
2. Whether interactions between the descriptors of dependent variables are carried forwarded from interactions in independent variable. In order words, it shows the

practice domains that relate more with another than others, and those that contribute more the dispersion than others.

3. Whether interactions in *2* above can be reverted or transferrable.

4. To test dispersion within and across clusters i.e. stages and practice domains.

ANOVA is the product of model variance matrix and inverse of the error variance matrix

$$\sum_{res}^{-1} \text{x} \sum_{model}$$

.....**equation 5.2**

Where Σ_{model} equals $\Sigma_{residual}$, A tends to Invariance *(I)*. However, generally, eigenvalues (λ_p) of the A matrix are reported to show the statistical significance in the transitions between the variables.

In this study, ANOVA was applied in two dimensions:

- Global ANOVA, also called F-Test, was used to compare the group mean of each of the variables across the practice domain to the centroid. It measures the statistical points or variables at which participants' views are most associated or dispersed. When such views are understood, it will be possible to theorize the factors behind such association or dispersion.

- Pairwise comparison was used to compare the ratings of the variables within a pair of practice domain. Thus, rather than comparing the ratings to the centroid, this analysis helps to determine the relationships between the ratings in every pair of practice domain. At the end, this shows the appropriateness of using the variables for a process model based on a matrix of link between the variables from one practice domain to another.

<u>Principal Component Analysis</u>

Principal component analysis (PCA) is a popular multivariate technique that analyses a set of data in which observations are described by several inter-correlated variables (Abdi and Williams, 2010). The goal of PCA is to determine the variables (stages) that are most important (Best raters) in the ratings and represent them as a set of new orthogonal variables called principal components. Thus, from a pairwise comparison, PCA helps to identify the

variables that are most important such that their critical contribution to the process models can be noted (Myers and Well, 2003).

Correlation Analysis

Correlation coefficient is a measure of association between two measured quantities. In this study, different perspectives of correlation analysis were used:

- *Correlation coefficients:* Variables within a model often have strong correlation within themselves. To explore this correlation between each estimating stage and another, scoring factor (F1) method was used. The purpose for this is to compare and identify the practice domain that most discriminate across the variables (estimating stages).
- *Correlation Matrix and Item-Total Correlation:* As each estimating stage is made-up of variables, the correlation within and across each stage can be understood. Multiple Comparison technique was used to determine whether the relationships within and across the activities are adequately consistent in lead up to reliability analysis. Where an activity has a weak correlation (less than 0.2 at $p<0.001$), it is discounted so that the value of the total item correlation of all the variables can improve

Cronbach Alpha

Cronbach Alpha measures the reliability in variables' covariance through item-total correlation (Myers and Well, 2003). Where variables have strong correlation, they are retained; when the correlation is poor, such variable is dropped until the optimum Cronbach value is achieved. The value of the combined correlation of the variables equals the combined strength of the variables in a process model. Moreover, if the Test Scale value and Cronbach Alpha co-efficient is closer to 1, the relationship between the variables is fit and reliable to predict workable outcomes when the model is put to use.

Discriminant Analysis

The outcomes of Cronbach Alpha procedure have helped discounted some activities that weaken the internal strengths of the processes models. Moreover, the activities that have been formed through item-total correlations only represent the centroids i.e. a representative view of all the practice domains combined; one for 3D CAD estimating process, another for BIM. A further step was taken to discriminate the categorical dependencies in the variables, one

model per paradigm for each of the practice domains.

Due to the reliability test, two sets of data are available for the discriminant analysis: data before reliability test (ad-hoc data) and data after the reliability test (post-hoc data). Ad-hoc data contain all the variables that were identified by participants as valid and able to lead to workable estimating outcomes. Some of the variables were however discounted for lack of strong correlation – the undiscounted variables are the post-hoc data.

For each set of data, discriminations across the categorical variables were identified. First, to determine the most appropriate approach to discrimination, post-hoc data were also tested for normality. The strength and accuracy of the discriminations are reported in detail in Section 6.6

5.6 SUMMARY OF THE STUDY METHODOLOGIES

This chapter reports a multiple and mixed method approach for developing and validating non-parametric models. It relies on ontologically stratified approaches for data collection: the procedure starts with direct observations where the researcher and 77 observers took part in four sessions during which software developers demonstrated how to use their 3D CAD and BIM compliant applications. The aim of the observations was to identify how the tools presented apply to estimating processes. It was possible to discriminate participants' questions by practice domain. Moreover, participants have applied the tools precisely as demonstrated by the developers. Furthermore, as estimating is not solely limited to using software applications for quantification, other research methods were used:

- to explore how the different estimating practices identified in Section 3.1 assist in preparing estimates using BIM.
- To triangulate the outcomes of direct observation with focus group discussions and interviews
- To use focus group discussion and interviews to map out experts' views on estimating activities and their suitability to generate workable estimating outcomes. The views of 17 participants from 8 estimating practices were reported.
- Quantitative techniques were used based on the emphasis that participants had put on each of the activities. Where this emphasis was not evident, literature analysis and researcher's professional judgment were used. In the end, each estimating activity and stage was rated across the four practice domains.

A procedure by Brynjolfsson et al. (1997) was used to sort and prime the data for analysis. The statistical procedure has been detailed in Section 5.5. It included a normality test,

correlation analysis and a reliability test. While measures of central dispersion and global ANOVA were used for normality, a multiple comparison method was used to analyse consistency in the correlation between the variables (estimating stages). Later, the data were subjected to a reliability test (Cronbach Alpha) to discount variables that added limited or no value to the system. Those retained formed the centroid models which were discriminated across the practice domains. The entire data analyses procedures and interpretations are presented in Chapter 6.

6 DATA, ANALYSIS AND INTERPRETATIONS

6.0 DATA, ANALYSIS AND INTERPRETATIONS

6.1 INTRODUCTION

This chapter analyses data collected from the interviews and focus group discussions. It presents interpretations of these data that explore the impact of BIM on estimating practice. These interpretations are based on two premises:

1. There has been a paradigm shift in the way design data are generated and used. A shift has occurred from conventional GDO 2D CAD to 3D CAD, and to relatively more sophisticated parametric capabilities in BIM designs. This has impacted on the ways in which estimates are prepared.
2. The approaches used to generate construction estimates are linked to specific attributes which relate to construction business structures (Chapter 3), including the following:

   - Matrix model (MModel) is used to represent clients' behaviours during estimating. Client organizations differ in size and business philosophies. Particularly, the term is used in relation to private and public organizations where estimating functions are in-sourced or outsourced with the emphasis on estimates' firmness, accuracy and value for money (Potts, 2004).
   - Divisional model (DModel)is used to reflect the attributes of contracting organisations, regardless of their size and peculiarities. The main business focus of this category of organisations is to control production costs and maximise profit, and where they take responsibility for project risks (Aje et al., 2009, Akintoye, 2000, Holland and Hobson, 1999).
   - Functional-unit model (FModel) reflects the business behaviours of consulting organizations where estimators are responsible for defending or moderating the commercial interests of clients or contractors (Odusami and Onukwube, 2008).
   - Networked model (NModel) organizations are "virtual" and provide integrated services in accordance with the details described by Thomsen et al (2010). Estimators in this business model integrate at least two of the roles stated above for integrated projects using IPD, PPP and PFI lenses (Akbiyikli and Eaton (2004), Rutter and Gidado (2005) Swaffield and McDonald (2008)).

Overview of Statistical Methods

Exploratory focus group discussions provided data which were used to explore the stages and activities leading to estimating outcomes using 3D CAD and BIM across the practice

domains indicated above. Participants' discussions of the dominant themes (stages and activities leading to workable estimates) were classified based on the emphasis that each group of participants put on the activities. Subsequently, each activity and stage was rated on a 5-point scale for each of the 4 practice domains to identify participants' views on estimating with BIM and 3D CAD. Normality tests, first scoring factor, correlation analyses and the principal component analyses were used to determine the highest-rated stages and activities across the four practice domains.

Preliminary analysis indicated that the data were normally distributed. Following this, an Analysis of Variance (ANOVA) test was used explore the four practice domains under parametric BIM and 3D CAD regimes. Pairwise comparisons were then obtained for variables that were statistically significant for the global ANOVA, with adjustments being made for multiple comparisons using Fisher-Hayter. Correlation coefficient and internal consistency reliability (Cronbach Alpha) tests were used to identify "good" and "poor" variables (i.e. stages and activities) leading to workable estimates in each practice domain as penultimate confirmatory tests. In summary the following parameters of descriptive statistics and reliability tests were consistently statistically significant, prior to the discriminant function analysis:

a) Correlation matrix
b) Item-total correlation
c) Cronbach's Alpha reliability estimate, and
d) A repeat of item-total correlations and Cronbach's Alpha to determine poorly performing variables. 'Good' variables (stages) were consistently significant (positive) across all the statistical procedures, while the 'bad' variables are consistently insignificant (negative).

The statistical procedures for determining the outcome of the reliability test in 'd' above are:

(i) To identify variables with negative item-rest values.
(ii) Following (i) above, variables with total-item correction values less than 0.2 have been removed as they lack significance.
(iii) When items in (ii) above are discounted, the Cronbach's alpha value of the remaining variables increases until a maximum reliability value is achieved. Only the undiscounted variables are considered sufficiently reliable to contribute to the relationships within the process models.

(iv) The outcomes of (iii) above are generic to all the practice domains. In order to understand how they apply to each practice domain, discriminant function analysis is conducted. This is used to investigate the reliability of the variables to trigger optimum outcomes where deployed in each of the practice domains.

e) Following the outcomes of (*d*) above, undiscounted variables were subjected to discriminant analysis to elicit the statistical dispersion of estimating activities across the practice domains.

Overview of chapter

This chapter comprises the following:

- Section 6.1 continues with further analysis of the demographic background of participants.
- Section 6.2 presents exploratory data on 3D CAD estimating procedures across all the practice domains.
- Similarly, Section 6.3 presents exploratory data on BIM estimating procedures.
- Section 6.4 provides summary statistics comparing the overall ratings of variables in 3D CAD and BIM paradigms.
- Section 6.5 presents confirmatory statistics of the variables (stages and activities) of estimating processes already determined in Sections 6.2 and 6.3.
- Section 6.6 provides the discriminant function analysis across the four practice domains with respect to 3D CAD and BIM paradigms.
- In Section 6.7, technical applications of the estimation process models in both paradigms are presented.
- A summary of this chapter is provided in Section 6.8

6.1.1 Demographic Background

An overview of participants' professional background and experience

Table 6.1 shows that 22 participants from 12 organizations took part in this study. 87% of them had worked as construction estimators for an average of 20 years. Participants had worked in more than ten countries including Australia, UK, Singapore, Malaysia, Vietnam, Fiji and Brunei. Where participants were not estimators, they took an active roles in project

management, worked with estimators and were conversant with BIM and BIM-based estimation. All participants had professional backgrounds including estimating, architecture, software engineering and computer science.

Table 6.1: *Demographic background of research participants*

	No. of participants		**Total**	**Years of experience of participants**		**Cumulative Average**
Professional Background	***Estimators***	***Others***		***Estimators***	***Others***	
Structural Models						
MModel	4	1	5 *(22.7%)*	36	15	30
DModel	3	-	3 *(13.6%)*	22	-	22
FModel	2	-	2 *(9.09%)*	24.5	-	24.5
NModel	6	1	7 *(31.8%)*	12	20	14
Software developers	4	1	5 *(22.7%)*	16	8	14
Total	**19** ***(86.4%)***	**3** ***(13.6%)***	**22 (100%)**	**20.8** ***(90.2%)***	**14.3** ***(9.8%)***	**19.9 (100%)**

Importantly, approximately 90% of participants were senior and principal employees in their respective organisations. In addition to their estimating responsibilities, some were employed in a mixture of roles in organizational management and professional practice. Moreover, although approximately 32% of participants were from NModel organizations, their views were considered as valid as those of estimators from FModel organizations who comprised 9% of participants. This is due to the length of the latter group's experience, which was almost twice that of the former group's. Both groups provide detailed and perceptive data across the four practice domains.

Figure 6.1 shows that the MModel estimators were the most experienced and had also worked in a range of other business models. Before joining the public service, most of them had worked in consulting, contracting and software development firms. Participants from

DModel organizations were from large public-listed construction companies. Some of them had also worked for other organizations of a similar size in Australia and overseas. Those from software development companies demonstrated major BIM estimation applications in Australasia, including CostX, VICO and Primavera 6.

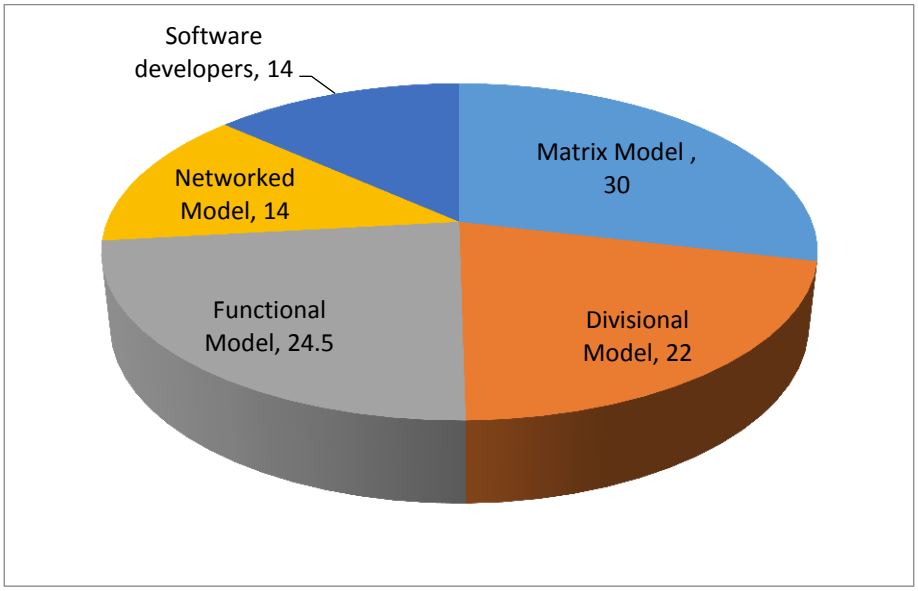


Figure 6.1: Years of experience of participants from the different organization models.

Inclusion and Exclusion Criteria

All participants in this study met the inclusion and exclusion criteria (Section 5.3.2). Six participants were Fellows of AIQS/RICS whilst all others participants had extensive experience and had worked in a wide range of organizations and on a variety of projects. They had used different estimating tools and had a well-developed understanding of BIM and the construction estimating practice and procedures discussed in Section 6.1.2. Their views may thus be considered to be valid representations, indicative of the possible approaches the various organization models might engage in. Thus, their views are relevant to similar organizations wishing to generate similar business outcomes.

6.1.2 Participants' background in CAE, CAD and BIM

Participants' experience with CAD

All 22 participants had extensive experience of CAD, had informed opinions about BIM. Participants were asked to describe estimation processes and their experiences while estimating with CAD and manual drawings. The purpose of this question was to establish whether estimators' patterns of transiting from manual systems to CAD and from

conventional CAD to nD and BIM were influenced by their practice domains. Answers to this question also helped to understand the specific activities included in the estimation approaches that each organization and participants prioritised in their manual, CAD and BIM regimes.

Responses to this question indicated that drawings prepared using CAD had been the main basis for construction estimates in Australia for over three decades. Only one participant from the public service (MModel) had seen and worked with manual drawings four decades previously. All other participants had worked only with CAD drawings (in CAD file formats, vector and scalar portable document formats (pdf), and jpegs). Therefore, this study has viewed computer-aided estimating both as a metamorphosis of manual procedures and as a culture that is entirely new.

Participants' utilization of CAD and BIM Data

36% of the participating organizations (about 32% of participants, mostly from DModel and FModel organizations) only used computer-aided methods to measure quantities from drawings and prepared their estimates manually i.e. they printed off drawings and measured quantities manually into estimating software. The other 68% of the participants (mostly from MModel and NModel practice domains) use automated processes to quantify and estimate, but fragmentally. Moreover, they had to moderate these data by including parameters which are either absent in the CAD drawings and project models or may not be captured accurately through automatic quantification. This finding is contrary to some views on automatic estimating, (e.g. (Goldberg, 2007) and (Jiang, 2011), where project estimates are based on direct data exports from CAD and BIM, and deployed "as-is". Where this group of estimators does not moderate data from automatic quantification, resource planning and costing were carefully initiated manually. In other words, as yet, none of the organizations contacted produce 'automatic' estimates, either from CAD and parametric models or by automatic interaction between databases and quantified work items.

The interface between automation and manual handling of data identified above has been noted in previous studies as one of reasons for estimators' reluctance to adopt and use digital innovations. Best et al (1996) and Hardie et al (2005) note that estimators' views have not changed significantly. Rather than criticizing these observations, this study interprets estimators' nuanced approach to estimating as a considerable strength in estimating

outcomes. This is because there is no evidence to suggest that fully automated estimating procedures guarantee estimating outcomes.

It is quite a usual procedure in estimating to rely on design data, either a manual drawing, CAD or BIM. As argued in Section 4.1, these three paradigms are functionally different from each other, and so are the approaches to estimating using them. While IT-enabled estimation popularly relies on auto-quantification and process automation, existing theories of estimating practice have focused exclusively on manual estimating procedures. As pointed out in the paragraph above, the practice of automated quantification and process automation deployed by the research participants is not as simplistic as considered by Goldberg (2007) and Jiang (2011). However, the procedures are not entirely conventional (Section 6.2) and have led to the evolution of new roles for estimators. Presented below is preliminary evidence of a change in the roles that estimators play, as has been triggered by the proliferation of IT (particularly BIM) in the construction industry.

Preliminary evidence of role change

The data collected in this study provide preliminary evidence that estimators are migrating their skills from those that service core estimating to those which involve more IT applications, especially BIM. 18% of participants have developed IT management roles or changed their role from core estimating roles under manual and CAD estimation regimes to software and IT management roles under 3D CAD and BIM. 50% of the role changes were targeted at "re-making" design data, both in 3D CAD and BIM, to reflect an appropriate economic representation of projects. This work involved making clearer descriptions, remodelling data in line with transparent cost descriptors and providing delineators of value. This finding confirms aspects of previous studies (such as (Tse, 2009, Succar, 2009)) where BIM has been presented as having the potential to trigger role changes.

Participants' views on estimation under different regimes – manual, CAD and BIM

The relationship between manual estimating procedures and electronic procedures based on direct data extraction from CAD were investigated. Most traditional estimating texts focus on manual processes. For example, Ashworth and Hogg (2007) and Seeley and Murray (2001) have described estimation as a process involving quantity measurement, resourcing and pricing. As described in Chapter 2, the basis for estimating resources and costs involved the manual quantity measurement involves taking-off, abstraction, working-up measured

quantities and final drafting. These two procedures (i.e. quantification, and resourcing and costing) are the main components of estimating processes. However, are these procedures the same under CAD regimes? Data from this study shows otherwise; IT has changed estimating procedures significantly over the past two decades.

More importantly, unlike manual methods, there are several approaches to estimating with CAD ((Norbert et al. (2007), Serror et al. (2008), Jadid and Idrees (2007)). In addition, their CAE applications do not have similar properties nor do they deliver the same outcomes. This critical topic has not received attention since Arditi and Suh's (1991) work on software selection models. This study advances these authors' work by exploring workable methodologies that different organizations deploy while transitioning from CAD to BIM estimation processes, without compromising workable outcomes.

The approaches of participants to estimating with 3D CAD and BIM in each organization model are understandably different. Participants from contracting organizations (DModel) frequently outsourced quantity measurement to fabricators, subcontractors and independent quantity surveyors. This does not mean these contractors do not measure quantities while estimating and tendering. They do this by way of moderation e.g. bolt checking and risk analysis, construction cashflow and resource risks. In contrast, these aspects were not identified as crucial to estimation procedures in the opinions of participants from MModel organizations. Furthermore, participants from DModel organizations and MModel organizations expressed little concern about tax depreciations and associated allowances, while these are considered crucial on integrated projects by estimators in networked organizations.

Estimating tools and projects undertaken by participants

Participants' views were analysed based on the profile of projects they estimated and executed with CAD and BIM. Participants from MModel organizations used *LCA Design*, *Best* and *CostX* for automated quantity measurement from CAD files, driven on PC and digital design platforms. As shown in Table 6.1, there two groups of participants represented each practice domain. In one of the groups that represented MModel, the majority of projects undertaken by the participants are "*a part of a programme of work of government for government agencies"*. The participants described their involvement as having "*designed and built hundreds of primary and high schools, technical colleges"*, as well as several *"health projects, correctional centres, court houses, government office buildings, landscaping*

projects and civic centres". These projects have been delivered as new works and maintenance projects (e.g. rehabilitation, modernization, conversion and alteration). Other projects which participants from this group have worked on include the CH1 building (Melbourne), the KPMG building (Amsterdam) and the Sydney Olympics projects. When the participants from both groups in the MModel practice domain were interviewed, BIM was under '*Strategic Implementation'* i.e. it was being observed for 10 years prior to full adoption depending on a satisfactory impact.

Participants from FModel organizations were interviewed as two groups. One group use Kinetics software (an integrated platform for several estimators to work on the same document simultaneously) and had worked on many projects in the past five years, including the state-of-the-art Trip 2 project at Monash University, an intelligent building project valued at $75 million. The other group used Everest, Buildsoft and Write Back, and had worked on many projects in Asia, the UK, the Middle East, Vietnam and Australia. Both groups represented quantity surveying firms with networks in all the major cities of Australia and in several countries.

There were two groups of participants from NModel organizations. One used Dim X of CostX, ROSS, QUBIT, MS Project, Primavera, CHEOPS and Jobpacs, all of which are driven by RYPAC, a multiuser system. This group had worked on major projects including the Sydney Opera House, Sydney Olympics projects and CSIRO projects. Participants in the other organization had worked on several commercial projects and mainly relied on CostX for estimation, although Calculus and Buildsoft had been used previously by some of the participants in this group.

The three participants from DModel organizations are from two major construction companies in the Hunter region. Both are publicly-listed companies with large networks throughout Australia, and have won several best practice awards. Buildsoft was the main estimation tool used by these participants who had taken part in many major projects including health facilities, rail projects and airport projects.

6.2 EXPLORATORY DATA ON CAD ESTIMATION PROCESSES

Data collection on estimating processes involving CAD and BIM were conducted in two stages. Firstly, software developers were asked to explain the performance framework of their application as this will serve as a reference to estimators' testimonies on how they put such tools to use. In the second stage, software developers were asked how they generate their

outcomes. Only the views of estimators in the four practice domains are reported because it was difficult to establish substantial evidence that the software developer companies:

- provide services, in the form of central database system, which enable end-users of their applications to deposit actual data on cost and resources as expended on past projects;
- work as consultants on projects such that they assess, possess or build their database based on real projects;
- stimulate or demonstrate multiple levels of data manipulations as situations operate in a real life situation, especially in an industry where project estimates are reported in different styles (see Cattell et al.'s analysis of bid unbalancing models (2010, 2007b))
- supply cost data or resource management services in support of their end-users' numerous approaches to costing and resourcing.

This section explores how estimates based on CAD data are arrived at and how estimating procedures differ between organizational business models. The stages in CAD estimating processes are reported in Sections 6.2.1 to 6.2.5. In Section 6.5, the correlation between these activities across estimators' organizational business models is reported. The same procedure is repeated on BIM in Section 6.3.

6.2.1 Estimating processes based on direct export of data from CAD designs

Section 6.1.2 demonstrated that participants used the potentialities of CAD and BIM for estimating in different ways; they either:

- auto-measured quantities from drawings and used these to prime estimating applications as they deemed fit; or
- used manual techniques to input estimate descriptors such as dimensions, quantities, units and descriptions of work items into estimating applications

Once the descriptors of work items have been primed into estimating applications, the processes leading to estimating outcomes are automated. There could be different approaches to the above-mentioned methods e.g. exploring the integrity of model-data before priming them into estimate format, data moderation to compensate for inadequacies in drawings and project models, and defining methodologies for integrating quantity and cost data. Consequently, participants were asked to describe their approach to estimating based on quantities derived from the direct export of data from 2D and 3D CAD systems, and process automation through estimating software applications. The manual approach was de-

emphasized because it has been given extensive attention in the existing literature ((Ashworth and Hogg, 2007, Brook, 2008, Harris et al., 2006, Seeley and Murray, 2001).

Preliminary findings (Table 6.2) indicated that different organizations used different tools and approaches for both quantification and estimating; and this resulted in different outcomes. The disparity is caused by:

a. different estimating goals e.g. to win a bid or to control costs

b. different styles of resourcing and pricing

c. construction method design i.e. software applications are trained to translate data from product models to a designed process of project execution.

d. different styles of risk definition and cashflow planning.

Table 6.2: *Software applications used by participants for estimating processes*

	Software Applications used by participants for estimation processes		
Estimators' business models	**Quantity Measurement**	**Cost Estimation**	**Planning**
MModel	CostX[$,#], LCA[^,#], BEST[#]	Everest	Everest, MS Project
DModel	Buildsoft, Excel	CATS[+,**]	MS Project
FModel	Kinetics[+], Buildsoft CostX[$,#]	Everest, Write Back	--*
NModel	CostX[$,#], QUBIT[#]	ROSS[+], Jobpacs, CHEOPS	MS Project, Primevara

Legends

*	Not usually within scope of work/services
**	Networked database pricing system, not targeted at building construction
^	Used for indirect cost estimation e.g. environmental impact assessment
+	In-house applications
$	Can be extended to cost estimation
#	Exports data from CAD

From the above, the research began by exploring the approaches software developers used in turning direct data exports from CAD drawings to estimates. Thereafter, their views were

triangulated with how estimators in the various practice domains actually put the applications to use. In both cases, demonstrations were made using the applications listed in table 6.2. Where this was not possible, participants gave comprehensive descriptions of how they handled their estimating procedures. From participants' discussions, a 5-stage estimation process was clearly identified when participants measured with CAD i.e.

1. Preliminary data mining from outline attributes of a project.
2. Feasibility appraisal of projects, including site visits, value analysis, risk assessment and elementary cost planning.
3. Cost Planning, involving detailed cost planning, Development Approval (DA) submissions, provisional estimation and preparation of tender documents.
4. Estimation and Tendering, which includes outline planning, final benchmark pricing, call for tender, tender analysis and contractor selection.
5. Project Execution and handing over, which involves contract management operations.

Each of these stages is discussed below.

6.2.2 Stage 1: Preliminary data mining

This section describes the different styles of data mining used by participants from the four practice domains where estimators are confronted with real life complexities arising from estimating, construction management, contract management and project management in Australia:

- When designs were in scalar mode (e.g. .jpeg, .pdf and .png), project descriptors were sourced through a process called re-calibration. Rather than adopting the dimensions in scalar images, re-calibration activates the capability of quantification software to understand the scale by which the drawings should be measured.
- Where designs were in vector mode, project data (e.g. length, area, volume) were captured quasi-automatically, and related to embedded descriptions or improvised ddescription libraries.
- Projects cannot be described in their entirety by drawings. For estimates to fully represent projects, missing items were included by either adding to exported data or by creating an addendum.

The four data export styles described above were applied differently in each of the practice domains. Some (65% of participants) used direct export data on the basis of approximate

quantities (for conceptual estimation and cost planning purposes), while others (45% of participants) assumed that these data were accurate enough to form the basis for comprehensive estimates. In the former case, pricing was generous so as to cover possible inadequacies in the adopted data; whereas in the latter, no such differentiation is made.

In MModel organizations, participants have a particular stream of projects, and project delivery styles, where their professional practice is focused. As indicated in Section 6.1.2, these are new institutional buildings, and, less commonly, new construction and the rehabilitation of civic projects. Moreover, because they are client organizations, the estimates are taken to reflect the mindsets of constructors. Nonetheless, how are such estimates arrived at? A group of participants described this by saying

"... we have [and use] *a fairly comprehensive* [cost] *database."*

Such cost databases are usually developed from market surveys and past project documents e.g. contractors' previous tenders and valuation records. Participants from NModel and FModel organizations have a similar style of estimating as the one described for the MModel practice domain. However the approach of DModel organizations is different; their cost databases are based on newly estimated costs while price data from past projects are used as secondary data; in the other aforementioned practice domains, data from past projects can serve predominantly as primary estimating data. Exported quantity data were also re-modelled and moderated to reflect risk and the merit potential of the project.

This stage is made-up of definitive activities, summarised at the end of this sub-section. First, there are explanations on how these were arrived at. When asked about estimating activities at this stage, participants in all categories agreed that all projects started with team formation and role distribution. Although there could be exemptions, participants from MModel practice domain did not indicate that they had performed other roles apart from estimation. Moreover, even when their mainstream practice was repetitive, they said project teams always interacted to discuss project components and peculiarities. Specifically, this activity is important to estimators to enable them have a multi-disciplinary view costs might be impacted by risks. Moreover, this scenario was observed to be common to all the practice domains under observation.

Furthermore, team formation is an activity that primarily depends on clients. Thus, further exploration on the nature of this variable started with the views of participants from MModel practice domain. For example, a group of participants stated that:

> ..... *"Because* *<u>in the main we have this programme of projects</u>, in particular for schools, we have basically standard designs, what we call <u>the component design range</u>. So the various functions we have a particular design which can go up for different sizes".*

From the excerpt above, two activities are identifiable. First, *"because in the main, we have this programme of projects"* means the participants are within the team project teams who have been used consistently for a particular nature of projects. It is therefore inferred from the quote that estimators' work starts from when they are selected as part of the project team, and of course, when interaction within the team begins. The first variable in this stage therefore is *"team formation and interaction between the project team".* Secondly, the quote clearly shows *"definition of component design range"* as an estimating activity at the very early stages of project development. Moreover, these activities have varying importance to participants from the different practice domains. For example, unless a project involves a contractor's input during the design phase, "*team formation and interaction…"* during early design stages is not an activity that participants from DModel organizations considered as 'applicable or 'important' to their roles at this stage. Meanwhile, they also have to constitute their teams while estimating. This is considered at a later stage, Stage 3 – estimating and tendering.

Although the two above-mentioned variables are considered 'important' by participants from MModel, NModel and FModel, they also have different views about the emphases (importance) they put on each of these activities. For instance, NModel organizations required team members with experience in integrated project delivery costing. Therefore, constituting teams around the core values of their projects, and engaging estimators early in the design phase are both crucial. In the MModel, participants had little influence on how project teams are constituted; whereas, participants from FModel organizations could choose who to work with, the projects to take part in and how the form they want their collaboration within project teams to take.

The second variable, "*definition of component design range",* was interpreted the same way across all the organization models. Furthermore, there are other crucial activities in this stage.

The excerpt below was obtained from two groups of participants from MModel and FModel practices.

> *"… we have a fairly comprehensive database and when we first prepare the feasibility budgets for projects, we don't actually have a completed design…."*
>
> *.."We don't necessarily know exactly where on the site the building is going to be located or its orientation".*

The themes expressed above complement other variables that have been identified in this stage, e.g. "*feasibility budgeting"* and deploying a "*comprehensive database".* However, there are many activities in feasibility budgeting (see Section 6.2.3). Estimators across the various practice domains deploy their databases by "*exploring and applying base data"* i.e. by limiting how historical data are used only in previous projects which share similar attributes and circumstances as new the project being estimated. These two activities are also important to all practice domains where:

- estimates are taken to reflect the mindsets of constructors (e.g. MModel), base data are adopted with minimal manipulation. Thus, this activity is not crucial to estimating outcomes in the Model practice domain because they may be different from actual occurrences during construction.
- design data are remodelled to replicate the proposed construction situation (e.g. DModel), application of base data requires critical manipulation. Thus this step is very important to estimating outcomes.
- design data are considered as approximate quantities (e.g. in NModel organizations), application of base data is conceptual. Thus, this activity is important to estimating outcomes but only for goal setting.

Furthermore, there are other activities in this stage. Participants say that, based on databases, estimators are involved in reviewing client requirements and inventing solutions to meet them. Following the *"preliminary reviewing of clients' requirements"*, outline project attributes extracted from client requirements are used for "*conceptual cost planning".* Cost planning has different uses across these organization models. Participants from MModel and FModel organizations use it to guide project cost (to keep design within cost limit), while DModel participants viewed this in terms of dealing with risks and optimization of

commercial interests. To participants from NModel organization, all the uses in other models are possible, but the focus of cost plans was flexible.

As a result of feasibility budgeting and cost planning, estimators end this stage with a "*preliminary determination of the construction process and cashflow management methods"*. This variable is of varying importance. For example, estimators of contracting organizations (DModel) expressed their clear understanding of a particular construction process while estimating, whereas clients' estimators (MModel) may have a wide margin for variability.

In summary, there are six variables in this stage:

- *The formation and interaction between the project team*
- *The definition of component design range*
- *Exploring and applying "base data"* based on previous projects (with similar attributes and circumstances)
- *Preliminary reviewing of client requirements*
- *Conceptual cost planning based on outline project attributes*
- *Preliminary determination of the construction process and cashflow management methods*

As explained above (also see Table 6.3), a scale of 1 to 5 was used to represent participants' emphases on activities in this stage of estimation processes per practice domain. The importance given to each activity was rated according to the views of each group of participants so that an average for each practice domain was collated:

- 1 represents *'not applicable'*,
- 2 represents '*not important'*,
- 3 represents *'fairly important'*,
- 4 represents *'important, but not compulsory',*
- 5 represents *"highly important and inevitable"*.

Table 6.3: *Variables of estimation process in Stage 1 - Preliminary data mining*

Stage 1 - Preliminary data mining	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Formation and interaction between the project team	3.5	3.3	4.5	4.0	3.8
Definition of component design range	4.0	4.7	4.5	4.5	3.7
Data mining/applying "base data" based on previous projects	5.0	4.0	4.0	4.7	3.7
Preliminary review of client's requirements/project attributes	4.6	4.7	4.5	4.7	3.8
Cost planning based on outlined project attributes	3.8	4.3	4.0	4.5	3.5
Preliminary determination of construction process and cashflow management methods	4.0	4.7	3.3	4.0	3.3

Table 6.3 shows that the variables in this stage have different importance ratings in each of the practice domains. For example, although estimators across all the business models consider *"Preliminary review of client's requirements/project attributes"* as the single most important variable in the stage, other variables are not viewed in the same way. The *"Definition of component design range"* and the *"Preliminary determination of construction process and cashflow management methods"* are more important to estimators in contracting organizations (DModel) than *"Data mining/applying 'base data' based on previous projects".* Estimators from MModel considered the latter more important than the former.

Furthermore, participants from the FModel practices consider *"team formation and interaction with team"* as more important than those in MModel because the latter focus on repetitive projects. Similarly, participants from NModel organizations consider *"cost planning based on outline project variables"* as not very important because their estimates

are based on an integrated project basis, while others who value this approach more are based on fragmented components of project life.

6.2.3 Stage 2: Feasibility Budgeting

After exporting data from CAD, all participants from software development firms adopted the following procedure:

- sort data according to their preferred presentation styles; and
- upload these to in-house databases for estimating as they prefer.

This may take different forms including conceptual estimates (based on gross floor areas and the number of hospital beds or floors), cost planning (based on project elements) and comprehensive estimates (such as a bill of quantities). The data they used for estimating are either resource-based or sourced from industry databases such as Rawlinsons' and Cordels' handbooks of construction costs. Each of these estimating approaches applies to the practice domains in different ways, but first, the views of participants from MModel should be considered (See Section 5.3.2). A summary of the both groups of participants in MModel is quoted below:

> *"We usually visit the site to assess and to speak to local asset management personnel to find out what the status is of things like the power supply, whether it's currently at maximum demand or whether it needs augmentation. Availability of water services, both incoming and stormwater and sewage going out etc. We try and assess the nature of the grounds conditions and the degree of the slope etc. so that when we return to the office we can prepare a feasibility budget based …on a design but just on an accommodation brief along with what we've gleaned from the site visit."*

From the above, *"site visit"* is a variable and it serves at least two purposes. Firstly, the nature of the site such as slope and ground conditions may require considerable surveying and geotechnical details. Secondly, the proposed project might have an impact on the existing facilities and vice versa. These two purposes are treated as separate process variables.

Do estimators from other business models also visit the site before developing estimates? Comments from participants from other models show that conducting a site visit is important prior to a feasibility estimation but it is not compulsory. When estimators from FModel firms are engaged as consultants, site visits are imperative for making informed judgments on site-associated risks, construction methods, site plans and resource planning.

Where estimators from DModel organizations are not involved in the design process, a site visit before tendering could be a matter of company policy on how they do business, e.g. some may visit the site only if they are advised to do so by the client or only when they have time before submitting their tenders; others may not bid unless they make provisions for variability that may arise from site issues. If DModel organizations elect to outsource the measurement of quantities from drawings, site conditions may not be reflected in this measurement, but can be compensated for during pricing.

Estimators from NModel organizations often visit the site but, until the construction stage, such estimates are based on conceptual data.

After a visit to site, a budget is set for the proposed project. For example, a group of participants from a MModel organization said:

> *"… then assessed against the budget that the client has set for the project. If that is comparable with the budget then we move on. If not, then we have to look at ways of bringing it down. It may mean reducing the accommodation or finding some alternative means or perhaps a different location or site which is cheaper, less major runs of services, things like that. Once we have established a feasibility study that the budget can support the scope of work we then move on and designs are then produced in sketch form. Usually two or three concepts for the client to look at and confirm which one they prefer".*

Although the procedure described above is an integral part of clients' in-house services, estimators from other organisation models also conduct similar activities but in different ways. Estimators in DModel organizations indicate that feasibility budgets are set to establish commitments for cashflow forecasts, predict exposure to financial risks or identify whether a project complies with their company policies on bidding. Moreover, estimators in FMmodel organizations may either adopt the approach explained by estimators in MModel organizations (if they are hired by clients) or the approach explained by estimators in

contracting organizations (if they are hired by contractors). The approach used by estimators in NModel organizations is a combination of both.

As indicated in the quote above, "*feasibility budgets"* are produced after "*site visits"* and "*feasibility appraisals"*. As noted in the quotation above, elemental cost plans reported in feasibility budgets are instrumental in "*schematic designs"* as they indicate the "*cost limits*" for each project component. Estimators compare the value of each component across all possible options based on *"two or three concepts"*. To guide client's choices (or contractors' bid plans or decisions), parametric methods are used to develop conceptual estimates for the different approaches. Consequently, the variables of this feasibility stage of the estimating processes, as sourced from participants' discussions, can be summarized as:

- *Site investigation, including geo-technical investigation*
- *Feasibility appraisal* – to determine the economic impact of project around its proposed location
- *Feasibility budgeting* – establishing cost limit through preliminary elemental cost planning
- *Production of schematic de*signs to create options within cost limit
- *Value analysis* based on proposed project components
- *Conceptual estimation*, using parametric methods

As indicated in Table 6.4, each variable was rated in line with the levels of '*importance'* that each of the groups ascribed to it.

Table 6.4: *Variables of estimation process in Stage 2 – Feasibility Budgeting*

Stage 2 – Feasibility Budgeting	***MModel***	***DModel***	***F Model***	***N Model***	**Average**
Site visit/investigation; including geo-technical investigation	5.0	2.7	3.5	4.8	3.4
Feasibility appraisal: assessing factors that contribute to the economic life of the project	5.0	2.3	4.0	4.8	3.4
Preparation of feasibility budget (in line with cost limits)	4.6	4.0	4.5	4.8	3.7
Involvement in the production of schematic designs (based on cost plans)	4.2	4.0	4.0	4.8	3.6
Value analysis (identifying potential value streams)	4.8	4.0	4.0	5.0	3.8
Conceptual estimation (parametric methods)	5.0	4.0	4.8	5.0	3.9

Working to a cost limit is the most important role of estimators in the early stages of the design process (

Table 6.3). However, this is not usually a role of contractors' estimators unless they are involved in the design process. Moreover, participants from DModel organizations stated that contractors usually have limited time to prepare estimates. Consequently, there is often little time to visit the site. Furthermore they rarely have the chance to ask questions about existing site facilities and the orientation of projects. Similarly, when consultant estimators (FModel's) are not involved in project conceptualization they simply prepare estimates based on design drawings. They frequently only ask questions about components of proposed designs rather than site conditions.

Meanwhile, the views of estimators in NModel organizations are different from those from DModel and FModel. While the functions of estimators in the latter are fragmented (being limited only to the feasibility budgeting stage of a project) estimators in NModel organizations often consider this stage of estimation as crucial to the economic life of projects. They are involved in taking decisions about what adds value to the lifecycle of projects rather than short-term economic goals. As such, they are involved in determining what is included in designs as well as keeping the project within cost limits. To estimators in FModel practices, clients determine costs; estimators' professional roles are limited to providing advice. Keeping a project within cost limits is usually important, but estimators do not have the ultimate power to control project outcomes.

6.2.4 Stage 3: Cost Planning

Participants made it clear that the cost planning stage is aimed at providing details about a project that accord with the milestones created in Stage 2 (particularly those that relate to cost

limits). Consequently, after the feasibility budgeting stage, drawings are submitted for development approval (DA) and enable cost plans to be prepared in readiness for construction. The overarching question that participants addressed in this section was how automated measurement from 3D CAD and BIM affected cost planning. The unanimous opinion of participants was that automated measurement from CAD improves accuracy and speed, but these gains are easily compromised if cost data are of low quality.

Furthermore, the culture of cost planning in the construction industry is similar across different business models, and has not been challenged by design platforms. With or without CAD, this involves attaching costs to project elements without compromising project goals and other items detailed in the course of preparing estimates. Consequently, participants' views were matched with existing theories on cost planning (e.g. Seeley (1996)) to establish whether estimators across the different models perform the same activities while planning costs, or whether they attribute the same level of importance to the variables in this stage.

To ascertain whether estimators for public clients have advantages over estimators in other business models regarding cost planning processes (e.g. by relying on comprehensive guidelines, more robust data and being accountable to the public), this study considers the views of estimators from MModel organisations as a reference point. This does not mean their views are more important than others, but rather whether other estimators view cost planning variables in a similar way to those in public practice, particularly with or without CAD. Some excerpts of participants' views include:

> "*Once the concept is accepted, and at that concept stage we may use just cost per square metre rates by function, individual rooms or departments, or we may go to a very quick elemental cost plan.*
>
> *The equivalent of a DA, development application submission stage where we would have probably 1:100 plans, elevations, the old cross section etc. and indicative estimates from the services engineers, we would prepare an elemental cost plan. Again, that would be checked back against the budget. Assuming everything was still on budget, we would move on then.*
>
> *If it was a large project or a complicated one we might do a subsequent cost plan, but usually it would just be a cost check and then roughly 90 to 95 per cent of tender documentation we prepare another cost plan which is also the pre-tender estimate".*

Based on the quotes above, the variables of estimation processes in this cost planning stage can be summarized as:

- *Preparation of cost elemental plans based on detailed drawings*
- *Collation of provisional estimates for specialist components and services*
- *Cost analysis and checking based on detailed design – to ensure that project is within budget*
- *Project documentation for public planning purposes*
- *Client's final cost checking prior to going to tender*
- *Tender documentation, in readiness for 'call to tender'*

As shown in Table 6.5, the importance of these variables is rated differently by estimators in the various domains identified in this research.

Table 6.5: *Variables of estimation process in Stage 3 – Cost Planning*

Stage 3 – Cost Planning	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Preparation of elemental cost plans based on detailed drawings	4.4	4.5	4.5	3.5	3.3
Collation of provisional estimates for specialist components and services	4.0	2.0	4.5	5.0	3.9
Cost analysis based on detailed design – to ensure that project is within budget	4.0	3.5	4.5	5.0	3.7
Project documentation for public planning purposes	4.0	3.2	3.0	5.0	3.4
Clients' final cost checking prior to going to tender	4.4	3.0	5.0	4.5	3.8
Tender documentation in readiness for 'call to tender'	4.8	3.0	5.0	5.0	4.1

As can be seen in Table 6.5, clients often want to get things right before inviting bidders to tender. Consequently, unless contractors are involved at this stage, they only perform some of the activities that occur during tender preparation (Section 6.2.5). For example, when clients or their agents source data for provisional and prime cost items, contractors are not involved unless they are part of project packaging processes. Thus, when provisional estimates are being collated and clients are preparing tenders, the active participation of estimators in DModel organizations are important (but avoidable). However, the roles of estimators in other models are both important and unavoidable at this stage.

Furthermore, estimates in integrated project delivery (IPD) systems require consistent updating as estimates develop. Consequently, estimators in NModel organizations do not require definitive data from comprehensive project designs for cost planning. Instead, an appropriate level of information about project components is enough. Table 6.5 also shows that clients' pre-tender estimates are important but not the ultimate yardstick for determining project cost; these need to be established from post-tender analyses. Therefore, *"tender documentation in readiness for tender",* according to participants, is more important than clients' pre-contract estimates in Australia.

6.2.5 Stage 4: Estimating and Tendering

Participants viewed this stage of estimation as being comprised of the following:.

1. Contractors' actions on tender documents: According to participants from DModel and NModel (integrated-service) organizations, these take several forms, including working up a contract price based on:

    a. *CAD drawings only* – contractors measure quantities from drawings, propose tender price and take responsibility for this. Contractors, either individually or in teams, consult independent quantity surveyors for quantity measurement, and subcontractors for quotations. These quotes are rarely for a single item. They are usually for a number of items of work (and resources) and include prices for each item.
    b. *Descriptive data captured automatically from CAD drawings* –contractors are expected to propose contract prices using this. In other words, work items may be described accurately in respect of the data in the design; however design data seldom contain all the information an estimator requires to develop a workable estimate. In addition, construction methods are the prerogative of

contractors. Thus, estimators from the different domains are likely to have different descriptors in their estimates, depending on how they consider the estimate appropriate for their chosen construction approach. Thus, contractors estimate and compete by means of:

i. Qualification – by modifying the descriptive document described above and in the client's template for estimating and pricing (e.g. BoQ).
ii. Discretionary estimation – by putting a price on the items as they are without qualification.

c. *Data which are moderated by clients from CAD drawings* and presented in the form of a bill of quantities upon which contractors are expected to compete and plan for a proposed project. Clients take responsibility for such documents. According to the participants, outsourcing is a common approach; quantification and small portions of the estimate are outsourced to independent estimators and sub-contractors. They also utilise expertise from the pool of specialist resources with whom the organizations share long term relationships.

d. *Contractors' involvement in project conceptualization processes*. In this approach, activities already identified in Stages 1 (*Preliminary data mining*) to 3 (*Cost Planning*) are completed by the contractor on behalf of the client. This could be supplemented by some activities in Stage 4 (*Estimating and Tendering*), as per items (*a*) – (*c*) above.

2. Clients' actions on contractors' submissions: As per Chapter 2, clients' estimators are involved in analysing contractors' bids. Generally, this involves checking for errors and comparing basic components between bidders. A group of participants from MModel described how this task was handled, stating

> *" .... We <u>receive the tenders back</u> in, review the tenders. We have a fairly bureaucratic procedure for tender reviews to make sure property is met and to make sure that the decision is made because we don't necessarily accept the lowest tender for various reasons. I would say probably about 10 to 15 per cent of the tenders that we do accept are not actually the lowest ones that have been submitted".*

3. Tender Negotiations: where tenders are negotiated, the terms of negotiation, and the legal ramifications, are the same as 1 and 2 above.

Using Items 1 to 3 above, work items or outlined quantities are resourced and planned to determine project durations. Participants indicated that estimators across the different organization models plan in different ways:

- Participants from MModel organizations relied on data from past projects to predict the duration of new projects. Their estimated durations are not binding on contractors unless the latter assume this as part of their contract or there are appropriate incentives to adopt the plan.
- Participants from DModel organizations rely on current data e.g. projections from subcontractors and calculations based on in-house resources. Unless moderated by clients, these projections are contractually binding.
- Where participants from FModel organizations take-up roles from either of the above, a suitable approach is adopted as identified.
- Participants from NModel organizations based their planning on outline and approximate quantities. These might create limits (and incentives) for contractors' timelines.

Based on the parameters described above, estimators' roles during estimating and tendering can be summarized as:

- *Clients' call for tenders, including prequalification*
- *Measurement (by manually interacting with drawings), direct export from CAD / BIM and moderation of data based on project designs*
- *Solicitation, collation and moderation of data (quotations) from subcontractors and outsourced specialists*
- *Resourcing and finalization price surveys for works to be executed by the contractor*
- *Construction planning, process scheduling and cashflow planning*
- *Conversion of estimates to tenders, and submission*
- *Tender analysis, contractor selection and contract documentation*

The variables shown in Table 6.6 have different importance ratings across the organizational models. For example, in normal circumstances, quantity measurement during tendering is not applicable to estimators in MModel organizations because that step was completed in Stage 3. Similarly, when estimators in FModel organizations represent clients, their efforts align with MMmodel organizations' procedures. However, participants from DModel organizations indicated that contractors usually have technical strengths to draw on at this stage, particularly in strategic alliances with independent quantity surveyors and estimators from FModel organizations.

Table 6.6: *Variables of estimation process in Stage 4 – Estimating and Tendering*

Stage 4 – Estimating and Tendering	*MModel*	*DModel*	*FModel*	*NModel*	Average
Clients' call for tender, including prequalification	4.4	2.0	4.0	4.0	3.0
Measurement (by way of manual interaction with drawings), direct export and moderation of data from project designs	1.0	5.0	5.0	3.0	2.8
Solicitation, collation and moderation of data (quotations) from subcontractors and would-be outsourced specialists	1.0	5.0	3.0	4.0	3.0
Resourcing and finalization price surveys for works to be executed by the contractor	2.0	5.0	4.0	4.0	3.2
Conversion of estimates to tenders (including cost checking), and submission	1.0	5.0	3.0	5.0	3.4
Construction planning, process scheduling and cashflow planning	1.0	5.0	4.0	5.0	3.5
Tender analysis, contractor selection and contract documentation	5.0	2.0	5.0	4.0	3.2

The role of estimators in NModel (IPD) organizations is quite different from those of other practice domains. Depending on the nature of the procurement method selected, they can act both as clients and contractors. For example, where they bid for PPP, PFI, BOT and BOOT projects, they are usually required to present their overall bids at Stage 2: *Feasibility Budgeting* or Stage 3: *Cost Planning*. However, these projects may be refined at a later stage. Thus, activities such as construction planning, moderation of in-coming data and measurement of quantities (which are considered as unimportant to clients at this stage), are relatively important to IPD estimators as they are to estimators in DModel and FModel organizations.

6.2.6 Stage 5: Post-Tender Estimating and Contract Management

Estimators' involvement in contract management is crucial; they defend clients' interest by ensuring clients receive value for money whilst they also facilitate contractors' commercial interests. Participants' views therefore depend on the service estimators provide. As contract performance depends on clients' requirements, this stage starts with the views of participants from MModel organizations. Participants were asked to explain their estimation roles once construction contracts had been awarded. The following is an excerpt:

> *"After that stage the project is basically handed over to another department … who supervise the construction phase. So we don't really get involved in that phase, only if there is a particularly awkward variation which the authorised person or the superintendent's representative under the contract feels that he needs a measure on price."*

Estimators are thus involved in "*project supervision and valuation",* and "*resolving issues"* arising from variations. These activities relate to project attributes that are measured from drawings and included in contract sums, and the actual work completed as supervised, re-measured and ratified for payment. These activities are all executed manually.

Nonetheless, estimators are involved in establishing what is due to contractors at this stage. Their work involves documenting progress (including taking notes of change orders) and variation claims. Estimators from FModel organizations may support either the project owner or the contractor. Those in NModel organizations assume their roles as an integration of perspectives – as a partner-client who is responsible for taking design and operational decisions, and as contractor to their partner who ultimately owns the project. A portion of an interview session with participants this organization model is quoted below:

> *"…is a complete system. We can do anything from early conceptual estimates through to full bills of quantities, through to progress claims, variations, financial reporting, tax depreciation, cash flows; we can all run it through this system and it all links together so you can carry a job basically all the way through from concepts through to basically tax and operational life cycle costings."*

Regardless of the organisational model an estimator serves, their roles at this stage include:

- *Project supervision to maintain compliance with pre-contract terms, including physical measurement, preparing, agreeing and ratification of interim valuations for payment.*
- *Financial reporting and contract administration, including valuation documentation, accounts' reconciliation and finalization of project accounts.*
- *Cost controlling and management*
- *Participation in attenuating disputes arising from variations.*
- *Post occupancy evaluation and project documentation in respect to cost (including database updating).*
- *Facilities management, including tax depreciation and lifecycle costing.*

The importance of activities in this stage is rated differently across organization models (Table 6.6). For instance, estimators in MModel organizations have no control over contractors' resources, and by extension, controlling contractors' own cost. In other words, as long as contract parameters are not violated, they may show little concern over contractor's production cost and profit; whereas, this is the priority of an estimator in DModel organization. Estimators are partly responsible for project supervision and dispute management in all organizational models, but the frameworks for performing such roles are different under each regime. For example, a group of participant from a MModel organisation said:

> *"…we are a little bit different from quantity surveying practices in the private sector in that we have the standard designs and we have a fairly rigid system."*

Table 6.7: *Variables of estimation process in Stage 5 – Post-Tender and Contract Management*

Stage 5 – Post-Tender Estimating and Contract Management	***MModel***	***DModel***	***FModel***	***N Model***	**Average**
Project supervision to maintain compliance with pre-contract terms, including physical measurement, preparing, debating and ratification of interim valuations for payment.	4.6	5.0	5.0	4.0	3.7
Financial reporting and contract administration, including valuation documentation, accounts' reconciliation and finalization of project accounts.	4.8	5.0	5.0	5.0	4.1
Cost controlling and management	4.0	5.0	4.5	4.0	3.5
Participation in attenuating disputes arising from variations.	5.0	5.0	5.0	5.0	4.1
Post occupancy evaluation and project documentation in respect to cost (including database updating).	5.0	3.0	5.0	5.0	3.8
Facilities management, including tax depreciation and lifecycle costing.	3.0	3.0	5.0	5.0	3.5

As shown in Table 6.7, "*financial reporting"* and "*dispute attenuation"* are the highest rated activities in this stage. This is followed by "*project supervision" and "post-occupancy evaluations".* These activities are performed to support clients to facilitate value for money, and to support contractors to improve commercial interests. However, these focuses are

synchronous but not congruent. The inability of pre-contract estimating processes to accurately reflect what actually happens during construction has been a major factor in determining the accuracy of judgements in both focuses. With BIM's virtual design and construction (VDC) facilities, this phenomenon can be controlled (see Section 6.3).

6.2.7 Summary of estimating stages based on 3D CAD Data

The calculated average of participants' ratings of estimating activities per stage based on 3D CAD data have been reported in

Table 6.3 to

Table 6.7. Furthermore, these tables are summarized in Table 6.8 to provide an overview of the stages in 3D CAD estimating. The rating for each stage is the average of the ratings within the stage. Of all the 5 stages, "*post-tender estimating and contract management"* is rated highest. As explained earlier (Stage 4), the activities in this stage rely on actual project data rather than automatically captured data from CAD or databases from past projects or improvised data.

Table 6.8: *Importance rating of stages in estimating processes under 3D CAD regime*

Variables of Estimating Processes	*MModel*	*DModel*	*FModel*	*NModel*	Average
Stage 1 - Preliminary data mining	4.2	4.3	4.1	4.4	4.3
Stage 2 – Feasibility Budgeting	4.8	3.5	4.1	4.9	4.5
Stage 3 – Cost Planning	4.3	3.2	4.4	4.7	4.3
Stage 4 – Estimating and Tendering	2.2	4.1	4.0	4.1	3.5
Stage 5 – Post-Tender Estimating and Contract Management	4.4	4.3	4.9	4.7	4.6

How does automated data export contribute to the accuracy of a pre-contract estimate? As established in Sections 6.2.3 and 6.2.4, estimators have different views on this; e.g. styles, representations and reliability of descriptive data embedded in CAD. Participants viewed estimates as robust when stakeholders were able to visualize construction processes. Meanwhile, as described in Chapters 1 and 3, BIM provides more explicit visualisations than conventional CAD. The procedures followed by participants in estimating BIM projects are reported in Section 6.3. Furthermore, in Section 6.5, correlation analyses of estimating processes based on the importance that participants ascribed to the variables in 3D CAD and BIM are reported. Analyses of these data provide a pattern of differences between the two regimes across the organization models. They show whether the differences are the result of a metamorphosis or are independent of the regimes.

6.3 EXPLORATORY DATA ON BIM ESTIMATION PROCESS

Like CAD (Section 6.2), the procedures for capturing estimating processes in BIM are based on demonstrations provided by vendors of BIM software and how participants put those tools to use (Table 6.2 for details). The demonstrations were based on four approaches, namely:

- Direct export of IFC data
- Remodelling design models to reflect an estimator's own representation and style of reporting
- Direct export by using model translation application 'as-is'
- Estimation based on VDC simulation model

The question put to participants was:

> *'Could you please explain or demonstrate how your product handles BIM for estimating and planning?'*

All the applications observed (CostX, LCA Design , VICO and Synchro) have different approaches for estimating and planning, but fall within the scope identified above. In particular, LCA Design uses IFC data export (see Figure 6.1). VICO is a modelling or remodelling software which is targeted at object-based cost representation (see Figure 6.2). CostX is a translator application (see Figure 6.3). Snychro is a virtual design and construction (VDC) simulation application (see Figure 6.4).

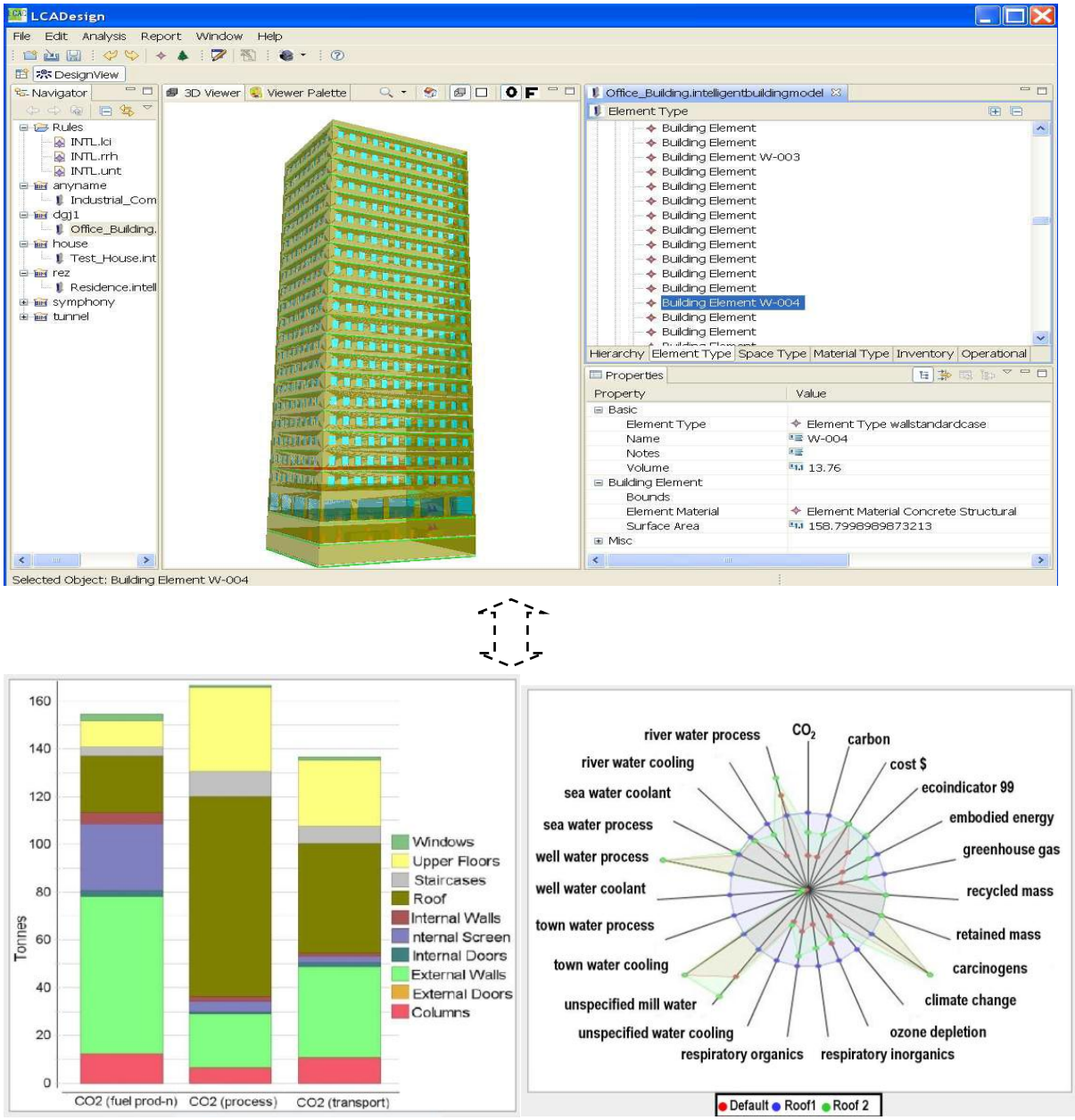


Figure 6.2: LCA Design Software

LCA Design is used to estimate lifecycle environmental impact cost of project components. It is more commonly used by public sector estimators during the project planning stage than in other practice domains. LCA Design exports IFC data from BIM object; when costs are put to this, the resultant estimate is an abstract implication of construction materials on the environment. Unlike other estimating procedure, using LCA design does not require conformity to any standard method of measurement.

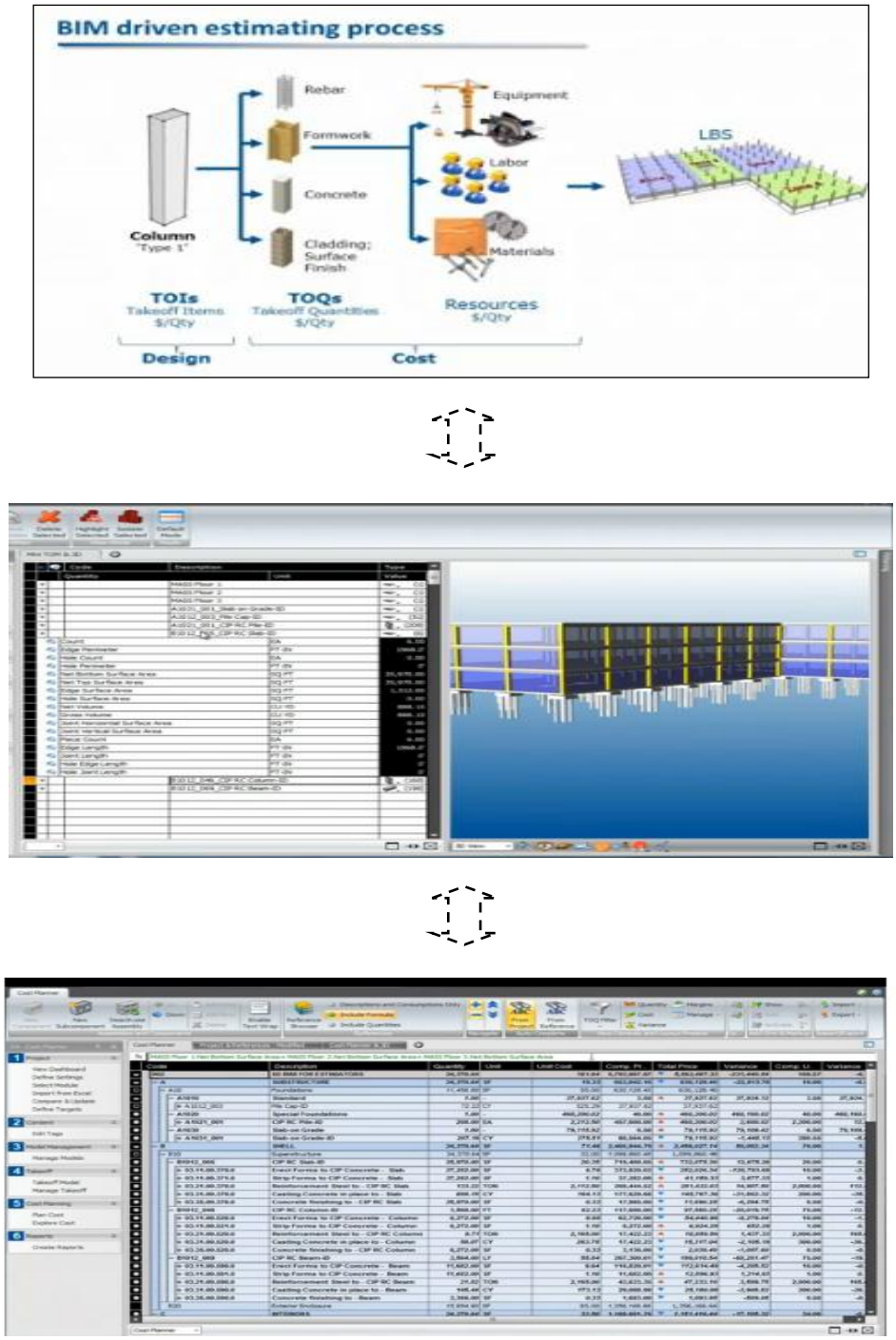


Figure 6.3: VICO Software

VICO is a model-based estimating application that allows estimators to modify model objects in ways that are most suitable to estimate reporting. It allows estimators to decompose model objects, augment and render them in the best way by which workable estimates are most conveniently represented. With VICO, estimates can be engineered by the location of components (LBS), project zones, sections, trades, elements and in other formats. It also

integrates estimating processes from cost planning to detailed costing and scheduling. Other applications might only be able to do these tasks separately.

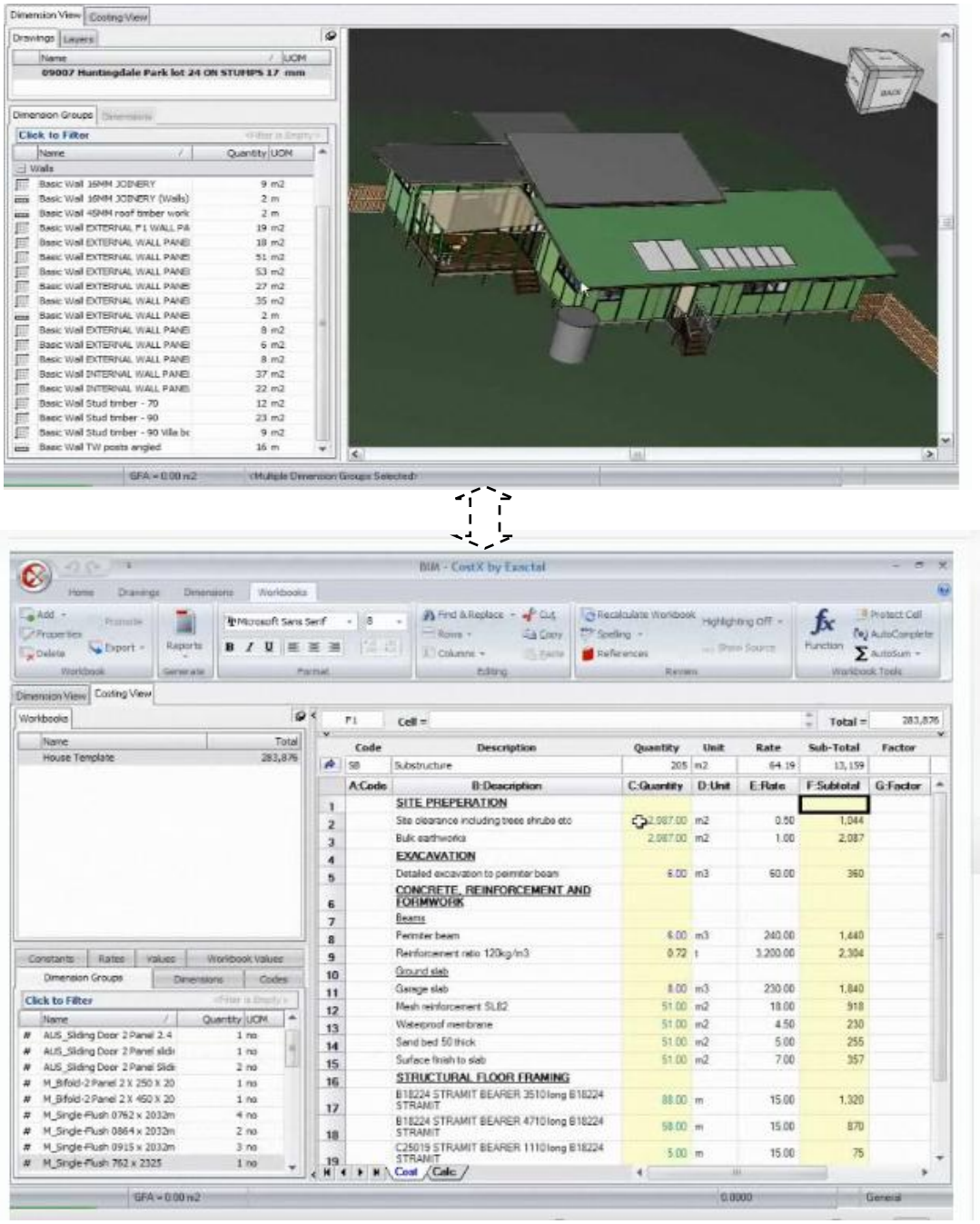


Figure 6.4: CostX Software

CostX is used to translate BIM model's IFCs to an estimating template e.g. cost plan or BoQ. In such templates, estimate parameters (quantities, units and descriptions) are as contained in the IFCs. After exporting items to estimating applications, data from cost databases are applied to the items to generate the required estimates. IFCs data exports (e.g. quantities)

could be adjusted (e.g. to cater for omissions in the models, wastes and lappings), unlike in the case of VICO, such adjustments do not translate as modifications to the BIM objects.

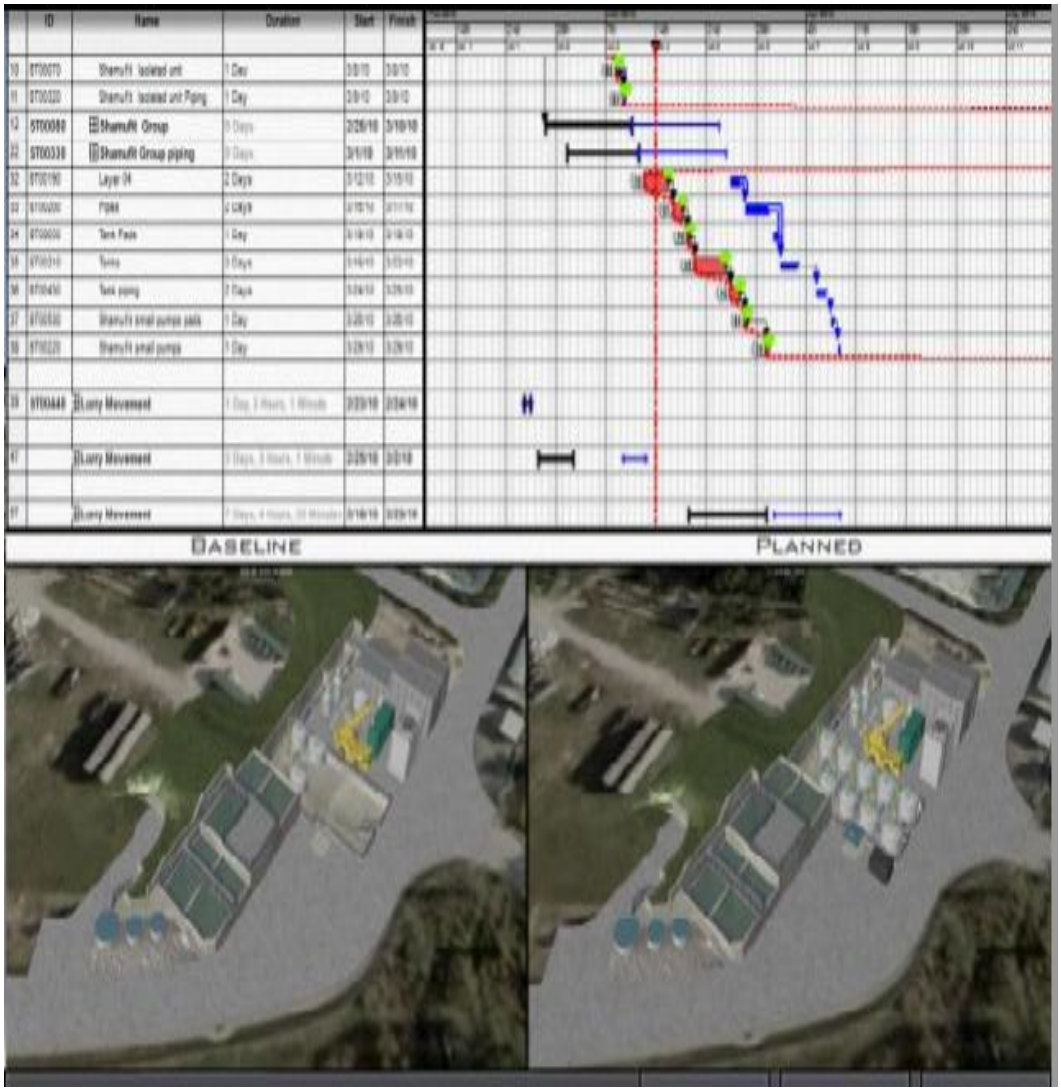


Figure 6.5: Snychro Software

Synchro is used for virtual construction simulation. It uses parametric objects as active agents in simulating different approaches to construction. Unlike in other applications where estimates are based on static representation, Sychro presents construction as a process. The resources and duration required in completing every object are collated to form time-lined hyper-models for an entire project. Unlike other applications, rather than reporting quantities, descriptions, units and costs, Synchro estimates on the basis of resources, duration and construction risks; and its presentation augments construction cost values with visualizable process models.

Figures 6.2 to 6.5 show different ways that estimators can use these BIM applications for different purposes. In the same way that software developers explained how they estimate using BIM, research participants from different organizations were asked to explain or demonstrate how they deal with BIM projects using whatever tool they have access to. The stages and activities that participants engage in while producing estimates through BIM are reported in Sections 6.3.1 to 6.3.5.

Several findings were drawn from the question indicated above (where participants were asked to demonstrate how they handle BIM with their CAE tools):

1) Estimators were highly aware of BIM. All the participants interviewed had heard about BIM. There was no concern that BIM would jeopardise or replace estimators' work, whether at present or in the future. Participants were not sceptical about the use of BIM for estimating nor what estimators could offer in a more integrated regime of multidisciplinary interactions within a project team.
2) The organizations represented fell within different scales of the BIM maturity index (BIMMI) (see Section 4.3). Nonetheless, notwithstanding some rhetorical claims by software developers, there was no major suggestion that estimates which were derived from higher-order BIMMI perform more (in terms of accuracy and robustness) than estimates that were derived from lower-order BIMMI. This does not mean that achieving more capabilities in BIM provides little incentive; rather the deliverables of the former add more to the estimation process in terms of data integration, time savings and additional incentives for digital innovation (see discussions in Sections 6.5 and 7.3).
3) BIM initiates two domains of change, viz a change in estimating processes and a change in business behaviours and philosophies. All the construction organizations that participated in the research consistently identified BIM as an instrument that provided competitive advantage. New policies were being made, new roles were being created or assumed, while documentation practices were also changing.
4) Generally, the participants' understanding of the potential of BIM was fairly limited, although they all had high expectations in BIM and the future of the construction industry. For example:
    a. some participants (about 30%) have handled BIM-based projects conventionally;

b. the actions of some participants (about 47%) were limited to the capabilities of the software applications which they used for conventional CAD;
c. as BIM favours process integration, all the participants thought large projects and clients' demands were the main market drivers for BIM;
d. BIM components such as IFCs and schemas do not replace the existing ways in which individual disciplines handled project information. In the case of estimating, these components contained a wealth of information out of which estimators selected the portion they required. These were then applied in a range of ways to develop outcomes that best worked for them.
e. Most organizations (about 92%) had changed from conventional 2D CAD and were currently transiting from 3D object-based collaboration to fully integrated parametric platforms. The main drivers for this transition included the rate of advancement in existing knowledge in BIM, especially in terms of progress made on policy frameworks and technical limitations such as interoperability and legal ramifications of model ownership.

Of all the organizations researched, MModel organizations had a structured 10-year policy on BIM implementation. All other organizations used BIM on the basis of market demand and were not answerable to government policies (like MModel organizations) about the outcomes of their commitment to BIM. The approach taken in this study is to compare estimating processes across all organization models with reference to MModel cases where such reference is required (Section 5.3.2).

As indicated earlier, two public organizations participated in the research as MModel organisations. In one, CAD intelligence (parametricism) has not been achieved substantially; 2D and 3D CAD were the basis for multi-disciplinary collaboration within project teams, while the other uses full BIM capabilities to estimate the indirect cost of projects on the environment. Below is a quote from a group of participants from one of the organizations:

> *"We have looked at generating information from 3D files and from 2D files and we use that to varying degrees of success. The predominant method of operating is more traditional where it's not using either BIM or CAD intelligence. That's something that we're hoping to change in the short term"*

In the second organization however, the situation was different, as stated below:

"…We import building information models from any of the major CAD software vendors ArchiCAD, Bentley. Allows us to import models from most of the major CAD software suppliers and then do an environmental impact assessment".

From these quotations, the "*varying degrees of success"* and ability to *"import BIM models…"* referred to above are viewed in relation to BIMMI, a scale for measuring the degree to which Australian construction businesses to BIM:

- *'Pre-BIM' regime*, which is based on manual and conventional non-parametric CAD (2D or 3D CAD)
- *Object-based modelling regime,* which is the single disciplinary use of intelligent 3D application
- *Model-based Collaboration,* a regime of sharing project data as object-based model and model-based information across two or more disciplines
- *Network-based Integration,* a situation whereby several multi-disciplinary models are integrated on model servers or other network-based technologies.

Consequently, based on the BIMMI parameters above, the organizations' alliances with BIM are as follows:

- Organization 1 is a *"transitioning organization"* where 3D is used as the basis for collaboration between design and estimating disciplines. The perceived *'absence'* of *'intelligence'* in the 3D platform is not an indication of participants' lack of exposure of how BIM works or their lack of understanding of BIM deliverables. The challenge is mainly an interoperability problem as the following quote shows:

  ".... we are using MicroStation and there is an export issue regarding from MicroStation into IFC formats".

  Moreover, interaction with this organization revealed that the estimating tools used by their estimators are able to deal with 3D as well as BIM designs:

  "…we have used Best and CostX for our 3D and BIM projects. If drawings possess full intelligence of the CAD functions then obviously measurement to the format in CostX is far better and far easier. With CostX you don't need to have an AutoCAD programme so you cannot manipulate the drawings the way you do in Best because in Best you need

to have a AutoCAD programme. So the function of CostX is all dependent on the way the architects publish the drawings basically.

We have tested drawings, 3D [CAD] drawings, but because it's not BIM-based we cannot generate quantities, whereas we have tested it on our base model, Revit file and we find it works. It works fine actually. So we can see and as far as we get the IFC running or we get a programme that can convert with MicroStation drawings into Revit through IFC or some other means, then we can see the use of it".

In the other organization in this group (a MModel organisation), interoperability did not present a problem, as the following quotation illustrates:

"It allows us then to look at the building information model, look at the actual building in terms of every element that makes up that building and what we do is we import the IFC file into LCA Design, and in the importing process we take every building element, work out its volume, work out its surface area. When we have that within LCA Design we have a three-dimensional model we can look at and tag with the materials that we want to assign to that building. We can use brick walls or double brick walls or concrete walls or whatever or there's a whole range of different building products that can be defined within LCA Design. Once we have all those building elements identified then we can work out the total volumes of concrete, the total volumes of cement and we can put a cost factor to it in such a way that you can do a cost estimating."

The various stages in BIM estimating processes are described and discussed in Sections 6.3.1 to 6.3.5.

6.3.1 Stage 1: Project conceptualization and design planning

According to the participants, estimating processes start with understanding clients' requirements in line with project goals. The challenges experienced by some estimators at this stage are highlighted in the following quote:

"Many clients can't read plans. They might think that they can. A lot of architects can't read plans very well too. The main benefit of 3D/BIM is that clients understand the building better which gives them more realistic expectations of what they're getting".

The estimation process therefore starts with the estimator's "*interaction with the client and the project team"* as each party attempts to align their understanding of the project goal with that of the other parties involved. This variable is similar to the corresponding variable under the CAD regime. However, different teams have different priorities. In the latter, individual disciplines claim ownership for their input to project conceptualization; in the former, clients reserve ownership to the outcomes of disciplinary inputs while the duty of care on input is exclusive to individual disciplines (Olatunji, 2011c). Moreover, the former is based on short-term relationships while the latter operates in integrated platforms and to service long-term responsibilities of stakeholders.

The next step, relating to what estimators do with the data they capture automatically from designs, is described in the quote below:

> *" ....if you just get the raw dump of data from a 3D file with everything inside, that information is useless. Quantities have to be organised in what we call a cost plan situation, a format that makes sense. The cost of a building can be dissected into elemental areas to be analysed…"*

This means that models have to be "*decoupled"* into elements that *'make sense'* to an estimator (e.g. element commonly found in cost planning exercises). If these procedures stem from the automatic export of project data, estimators may compensate for inadequacies in the model through 'condensed costing' (as explained in Stages 4 and 5). If estimates are to reflect all the primary activities involved in the construction process, whether indicated on the model or otherwise, a remodelling approach is required. In both processes, estimators need to be able to *visualize* project elements and *analyse* their interactions:

> *"…able to quickly look at different morphings of the building shape and configuration so that <u>we can immediately give the architect and the rest of the design team some indication as to how it's affecting the budget</u>."*

The underlined portion of the quote above implies that the feasibility of a construction project depends on how construction processes are resourced and modelled by estimators. Once the construction processes have been resourced and planned, IFC data, based on the de-coupling and remodelling, can be exported for extended applications. Such applications include cashflow planning, preparation of cost plans and preparation of tender documents. Unlike conventional estimating where a clients' estimate relates only to the data in a project model

(without specifying any method of construction), BIM requires a method of construction to be specified that can be demonstrated through virtual simulation.

In summary, estimating activities during this stage are shown below and rated in Table 6.9.

- *Interaction with the client and the project team*
- *Model decoupling*
- *Visualization of design components*
- *Design analysis*
- *Resource planning and modelling*
- *Export of meta-data for extended uses.*

As with CAD, these activities have different importance ratings for different organizational models. For example, estimators in MModel organizations seldom pay attention to errors and construction risks; instead they usually export model data based on the product model. Thus, model decoupling is an important activity; however this is not as important as it is to estimators from DModel organizations. To this group, risks occur in multiple forms, construction waste and commercial advantages must be modelled into every workable estimate; however, in the former, these parameters are a matter of competition. Therefore, either the lowest cost or the proposed contract price that is most relative to client's benchmark would win regardless of the lack or excess of risk consideration in such estimates.

Estimators from FModel consulting organizations may adopt either approach, depending on who they work for (clients or contractors). The views of participants from NModel organizations are unique; they often consider the best interest of the project on a long term basis, beyond the construction phase, as the ultimate focus. To this group, models are not only decoupled to reflect an elected style of estimating; projects can be analysed in line with a range of parameters. These include elements (for value analysis), sections (for cost planning), locations (for finance planning) and timelines (for cashflow planning) and other ways of estimating.

Table 6.9: *Variables of Stage 1 of BIM estimation processes – Project conceptualization and design planning*

Stage 1 – Project conceptualization and design planning	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Interaction with the client and the project team	3.8	4.0	4.5	5.0	3.7
Model decoupling and reorganization to reflect estimators' elected construction approach	3.2	5.0	4.5	5.0	3.8
Visualization of design components	5.0	5.0	5.0	5.0	4.1
Design analysis	4.2	5.0	4.5	5.0	4.0
Resource planning and modelling	3.0	5.0	3.5	5.0	3.7
Export of meta-data for extended uses	4.2	4.3	4.3	4.5	3.6

6.3.2 Stage 2: 3D visualisation and Virtual Reality

Virtual reality (VR) is a simulation platform whereby real life scenarios are replicated. VR is inherently three dimensional and is thus confined to BIM and 3D CAD. A range of VR's benefits are listed in Chapters 1 and 3. In addition, participants from different organization models had different approaches to VR (e.g. to simulate construction approaches, to simulate facilities use and management, and for communication and training). When applied to different platforms, estimating outcomes are different.

Participants from the two MModel organizations observed that estimation using VR starts with "*use scenario simulation, using active agents"*, as described below:

> *"Virtual walk throughs, ties in with the client being aware. One tool that I've been using a hell of a lot recently is Adobe have in their free reader, the ability to view 3D files which can be spun around. They can also be cut in a section and that section line can be adjusted in any plane and moved along.*
>
> *Clients love it. It means they can understand something. It's simply for them to use. They don't need proprietary software and it's quick. Designers can send them a plan. They can see where their office is and they can walk through that with no hassles at all" .*

The views of participants from other organizational models are summarized in the quote below:

> *"We have a national life cycle inventory database for Australia, which was actually developed originally for the Sydney Olympics as part of their process in*

satisfying the requirements of being the green games if you like. Our estimation tool allows a user to import the model, identify the resources that the building will be constructed of and also the alternatives such that costs could be compared".

From the quotes above, the estimating variables based on 3D Visualization and VR can be summarised as follows:

- *Facilities use scenario simulation, using active agents in order* to demonstrate clients' requirements so that informed choices can be made on clients' priorities during design and procurement.

- *Construction scenario simulation,* which shows how construction activities are 'layered'. It may be used as basis for bid competition in large and highly risky projects.

- *Cost control:* Based on simulated models, design and project costs can be controlled to conform to cost targets. While clients usually control total project costs, from a contractor's perspective it is necessary to control production cost. For IPDs, the focus is on long term value for a project – i.e. to prevent wastage, avoid risks and to promote social value. In summary, there are different perspectives on cost control at this stage (and different cost control tools are used to achieve appropriate outcomes in each domain). Clients may focus on cost reduction, while contractors and IPD stakeholders focus on making a profit and best value (not necessarily lower cost) respectively.

- *Model-based value engineering;* based on facilities' use and construction scenarios, this application facilitates the integrated utilization of knowledge while making informed decisions on value-adding design and procurement alternatives.

- *4D/5D hyper-modelling:* 4D involves putting nD on a timescale, and 5D results in taking 4D and overlaying costs on the time dimension.

- *Finalising project models for estimating and tendering:* When models are decoupled, they are re-arranged in approaches that support the outcomes that estimators require. Like conventional CAD regimes, an important aspect of the economic feasibility of projects is for stakeholders to decide how to advance with costing from project conceptualization. For contractors, this 'bid-or-not-to-bid' decision requires some in-

depth analyses. It was indicated clearly in participants' discussions that visualization and VR simulation help project stakeholders to take final decisions on what they require, the associated risks and in readiness for tendering.

The importance ratings of the variables described above are shown in Table 6.10. Participants views were allocated different importance ratings for the variables of this stage. For example, despite technical issues (e.g. interoperability and lack of policies on public procurement that favour modelling), participants from MModel organizations showed a considerable understanding about hyper-modelling. However, they were still able to prepare reliable estimates without hyper-models. Moreover, as clients generally do not specify a particular construction approach, participants from the same group indicate a 'not important' rating for "*construction scenario simulation"*. Instead, *"use scenario simulation"* was rated as *'important, but avoidable'*.

The views of participants from DModel organizations are different to those of MModel organisations. Unless contractors are involved in model development, their priority is limited to devising construction methods during pre-contract estimation. However, 3D visualization and VR gives contractors a competitive edge when it is used to support clients making their decisions. Thus, this item was rated "*important, but not compulsory".* It is determined by clients who wish to know when to engage a profession, how and what the basis of their appointment will be. This also applies to 4D/5D hyper-modelling; as these facilities are not used until they are required.

Table 6.10: *Variables of Stage 2 of BIM estimation processes – 3D Visualization and Virtual Reality*

Stage 2 – 3D Visualization & Virtual Reality	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Use scenario simulation, using active agents	4.2	3.0	4.5	5.0	4.4
Construction scenario simulation	2.2	4.7	4.5	5.0	4.1
Model-based value engineering	3.6	3.7	5.0	5.0	4.4
4D/5D hyper-modelling	1.0	3.0	3.5	4.5	3.1
Cost controlling and scheduling	3.6	4.3	4.0	5.0	4.4
Finalising project models for estimating and tendering	2.8	4.0	4.5	5.0	4.1

As participants from FModel organizations can be engaged by clients or contractors, they were able to promote the goals of whosoever hired them. Despite the fact that object-based cost representation is not yet very common at the time of this research, all other variables were considered as very important by participants. It is interesting to compare these views with conventional practices involving 2D CAD. With CAD, estimators from this organisational model print off drawings to assist them visualize the project. However, with VR presents interactive facilities that extend viewers' understanding and appreciation of projects that exceed 2D drawings.

There are limitations regarding hyper-modelling e.g. software applications are few and the knowledge to drive the practice is limited (Huang et al., 2009b). Meanwhile, participants from NModel organizations ranked all the activities as very important. This means the limitations faced by estimators in other models could be a result of the challenge of transitioning from fragmented practices to integrated systems. As BIM becomes more widely accepted as a platform for integration, and organizations make significant progress in embracing integration, these limitations are likely to diminish.

6.3.3 Stage 3: Estimation and Tendering

All participants agreed that traditional estimating practices are still prevalent in the industry. They are largely textual and paper-based, making minimal use of CAD. This applies whether or not data are sourced directly from CAD models. As stated in the introduction to Section 6.3, there are at least four ways BIM data may be used to generate estimates:

a) Data can be exported in IFC and CSV file format, and can be adjusted and re-arranged to enable estimators to prepare estimates of cost, time and tender price.
b) Using applications such as VICO to remodel project model data, work items can be exported or considered using an approach that the estimator has chosen. Relevant approaches include location-based systems (LBS), timeline-based and section or element-based approaches.
c) Using translator applications such as CostX, models' descriptive data can be exported automatically into BoQ templates 'as-is' (Figure 6.4).
d) Using simulation applications such as Synchro, it is possible to extract and process representations of a project the way the estimator wanted it, and upon these all items in the estimates are related. Such flexibility could be missing in either *(a)* to *(c)* above.

The challenge of approach (*d)* is that conventional estimates are based on product-representations noted in *(a)* to *(c)*; there is limited standardization on what could be presented in virtual process representation in digital estimating platforms. Is this a unique contribution of BIM to estimating or a furtherance to activity-based construction (ABC) estimating? Participants' comments provide an answer to this question as shown below.

As outlined in previous sections of this Chapter, and supported in other Chapters (2 and 3), the approaches which estimators take in each business model align with stakeholders' interests. Clients wish to achieve their project goals; contractors want to maximize their commercial interests; and other parties (consultants) wish to support both views and drive long term project goals.

Meanwhile, each of the approaches labelled as *(a)* to *(d)* indicates the culture of each business domain. Traditionally, clients focus on product data, explicitly or otherwise, leaving bidders to adopt a construction approach they deem suitable for the project. Those working from this perspective (e.g. estimators from MModel and FModel practices) focus mainly on direct data export from project designs or models, as shown in the quote below:

> *"You push a button and quantities are generated. So in terms of, if [drawing side] in 2D it is not as easy to visualise if you do it in 3D, but even better if you've got BIM. You can virtually measure all the elements if it is there. You can pick up all the dimensions rather than measuring it. If you've got a wall, you don't have to measure it. If you want internal walls, external walls and everything else it would still be a lot simpler if we have got BIM information, a Revit file or IFC or whatever. It would be a lot simpler to measure and once it's measured, you know it's accurate because it's been produced using BIM functions. So we spent less time measuring, more time evaluating and helping to formulate the way the project should be going. The counter argument to the [one button] is that when you are stepping through the measurement process, you are coming to understand the building … If you are just presented with a file and you press a button and all these quantities come out, you are no wiser than five minutes previously as to what's the building …*"

The approach described above is not exactly the same as the estimating process used with conventional CAD-based drawings. BIM adds more value to the estimation processes which the conventional CAD-based approaches grapples with. With BIM, estimates are generated

with considerable understanding of (and interaction with) project stakeholders, and design visualizations are no longer based on estimators' own imagination.

Meanwhile, both CAD and BIM estimating have similar problems. Firstly, BIM models cannot fully represent construction methods, and where items such as temporary works and preliminaries usually left out in the models are 'masked' into costing, the challenges that go with this can overshadow clients' interest and project goal. For example, there are transparency issues when cost variables are 'enveloped' within only the items that are represented in clients' list of parameters as shown in BIM models. Secondly, there are no perfect project models. Thus, when data from product models are adopted for costing and planning 'as-is', estimates are susceptible to such omissions. This is an important reason for estimators to put project models in the perspectives of project execution rather than automated adoption of product data. Thirdly, translators can leave out items in the model and such issues can trigger critical problems in the outcomes of estimates. Moreover, it is a waste of time for estimators to have to manually check quantifications that were exported automatically from BIM models; they would have obtained similar outcomes if manual procedures were adopted in the first place.

From the arguments above, the bases for estimating using quantities generated from BIM include:

- Auto-export of BIM data in a format that can be imported into CAE systems. This involves 'manual handling' the descriptions that are exported from BIM so that they are interpreted by estimators and aligned with terminology they are familiar with (i.e. using descriptions similar to standard method of measurement or equivalent).
- Model moderation in the context of project economics e.g. timeline simulation and evaluated risk assessments (ERA) with a focus on specific project components which may be arranged as line items, elements, zones, locations, sections, interim report stages and finance engineering.

Estimators in other business model organisations use approaches other than applying costs databases to data which were exported automatically from BIM models or a moderated of same. There are platforms such as Syncho where estimates are based on simulated construction processes. In such simulation, alternative construction approaches are explored and analysed before the approach that is most suitable to project goals is selected and priced. While estimates are conventionally represented in a single data format, this approach

provides visual aids for alternative construction methods with demonstrable analysis of risks involved as well as the estimation process. This is impossible with conventional CAD. Moreover, instead of text-only estimates, estimates could be presented in form of motion and clients can visualize a range of value streams in the project. The way it works is as follows:

a) Site conditions are simulated in a virtual environment; this could be created on GIS platform.
b) Based on the information in the BIM model, construction approaches are created in as many formats as the estimator desires e.g. elemental, sectional, trade, zonally, according to timelines, location or interim reports. An example of this is the conventional operational estimating approach, shown in a visual form (see description on Synchro).
c) Thus, when models are resourced using *active* (virtual) agents to represent process inputs (see description on Synchro), such actors can be auto-measured and monitored in as many forms as the estimator requires.
d) Based on *(c)* above, the style of reporting can take many forms:
    i. Project-based representation (e.g. location-based, based on cashflow or based on evaluated risk method)
    ii. According to the prescriptions of Standard Method of Measurement (SMM);
    iii. Clients' prescribed method of presentation e.g. motional and visual, which may relate to clients' own style of reporting with or without recourse to the two options above; or
    iv. A combination of some or all the options above.
e) When construction activities have been captured in line with *(a)* – *(d)* above, appropriate costs can be apportioned to each item.
f) Item *(e)* can be moderated to further for tendering purposes.

Process hyper-modelling is predominantly practiced by estimators from NModel and DModel organizations. Estimators who focus on BIM models (e.g. those from MModel and FModel practices) rely on a small portion of metadata from IFCs and schemas to drive their estimates. However, those who rely on process hyper-models (e.g. estimators from NModel and DModel practices) work with customized application software where data engineering through models IFCs and schemas are not the primary concern.

As shown in Table 6.11, the activities in this stage have different importance ratings. MModel estimators rate auto-import BIM product data as *'very important'*, whereas those of other business models are different; they preferred process hyper-modelling and model reconstruction. Moreover, while the former considered *'auto-pricing based on past project data'* as *'very important'*, the latter favoured *"costing by ERA, prevalent market conditions and customized operational process benchmarks"*. The views of estimators from NModel organizations supported more of the perceptions of those from DModel organizations. Meanwhile, the opinions of participants from FModel were shared within the two domains – client and contracting organizations.

Table 6.11: *Variables of Stage 3 of BIM estimation processes – Automated Estimation and tendering*

Stage 3 – Automated estimating, Hyper-modelling and tendering	**MModel**	**DModel**	**FModel**	**NModel**	**Average**
Auto-quantification of BIM product data, including 'manual handling' of allied descriptive parameters	4.2	3.0	4.5	4.5	4.1
Model moderation or reconstruction in the context of project economics	3.4	5.0	4.5	5.0	4.5
Process hyper-modelling, including resourcing and costing by ERA, prevalent market conditions and customized operational process benchmarks'	2.8	5.0	4.0	5.0	4.2
Application of base costs, including provisional estimation and market surveys	5.0	4.3	4.5	5.0	4.8
Conversion of estimates to tender	3.4	5.0	4.0	4.5	4.2
Tender documentation, including augmented packaging and submission	4.6	5.0	4.5	5.0	4.8

6.3.4 Stage 4: Contractor Selection based on Virtual Models and estimating

According to the construction management literature, contractor selection approaches in different business models have remained unchanged for decades (Aje et al., 2009, Hatush and Skitmore, 1998). These involve checking for errors and discrepancies in bids. Most importantly, they relie on price and descriptive data in contractors' data to judge whether this agreed with the clients' term or not. Participants were of the opinion that BIM adds to this as shown in the quote below:

> "*Many clients can't read plans… The main benefit of 3D/BIM is that clients understand the building better which gives them more realistic expectations of what they're getting.*"

Thus, instead of the conventional practice of showing estimates in texts, BIM promotes the use of virtual construction process models where clients can visualize and analyze the construction methods that underlie the estimates:

> *"…So the idea is via an iterative process or via looking at and changing and varying the material structure of the building and also varying the operational energy considerations involved with operating the building we can compare it to other buildings and also then we can make judgements as to how the construction will go."*

As mentioned in Section 6.3.3, estimators use different approaches to explore BIM data, viz through direct data export, manipulation of product models and conversion of product model to process hyper-models. The onus is therefore on clients to specify the required approach for competition during bidding. If competition is not essential, the next focus of clients is to outline the requirements that bids must address and decide whether BIM has a role to play. Whether clients elect e-tendering or the conventional approach, BIM also provides bidders with the opportunity to bid graphically i.e. make BIM a part of contractual documentation such that a monetary value is attached to each digital object. This usually takes different forms, as outlined below:

a) Object pricing on product model: in the same way as object data are embedded into BIM objects, cost data can be included on model object as:
    - Predicted cost of object as bid for prior to construction
    - Notes on negotiations where applicable
    - Actual construction costs
    - Notes on procurement specifications, guides and embellishments
    - Notes on amendments and change decisions

b) Object pricing on process hyper-model: Unlike *(a)* above where prices are embedded into models, the platform**s** which support process hyper-models allow them to include resources (labour, plant and materials) and duration. Where neither of these is possible, manual judgments are made to supplement them; this is referred to later in this section as model moderation. However, where such is possible, the resources are

imported into BIM platforms or estimating templates and arranged according to either of the following:

- Clients' chosen styles of estimate format e.g. any form of BoQ (trade, sectional or elemental), builders' BoQ or any other format.
- A project-based approach chosen by a contractor e.g. showing the cost of a project by model timelines, by project zones or location, or by cashflow targets.
- A qualification to clients' chosen format

In this study, all the participants agreed that bidders had a very high competitive value when they augment their tender documentation with process models; 68% of participants had done this for large projects and won, or have participated where BIM was used for bidding. In all such cases, there were 'obvious' additional costs spent by the contractors on bid documentation. However there was no significant change in clients' tender costs. Regarding speed and accuracy, participants gained about 65% of the time spent on quantity calculations when the direct data export approach was used. However the time spent in expressing estimates in hyper-model is relative to this gain; the experience may vary depending on handler and platforms through which hyper models are generated.

Across all business models, participants indicated that the accuracy of their estimates did not change significantly when their estimates were based on BIM. However quantity measurement was faster, more reliable and more accurate than with manual and 2D CAD design regimes. In other words, while participants could not quantify the extent to which BIM lowered the costs of a project to their clients, they argued that clients benefited from the openness, control, project value and knowledge-based decisions that BIM facilitated. Nonetheless, there were cost savings to contractors as BIM improved communication intrinsically and extrinsically.

In addition, as pointed out in Section 1.2, estimators are responsible for ensuring that contract bids are workable. As described in Chapter 2, the actions of clients' estimators during tender analysis and contractor selection are as important as pre-tender activities; they are rigorous, and involve substantial action by both clients and contractors. For clients, the *best* bid must give the client the *best* value, as judged on the quantitative and qualitative parameters in the bid. To contractors' estimators, the commercial interests inherent in proposed projects must

be '*secured in good faith*' i.e. they must account for the effort put into bidding, and regardless of competition, the reputation of the organization must not be jeopardized.

The question put to participants at this stage was *'how does BIM affect tender analysis and contractor selection?'* The overwhelming view of participants was that BIM supported e-tendering. However, whether this is adopted as the tender approach or not, tender analysis and contractor selection in BIM are both still relatively unchanged as they were under conventional practice; contract price and contractors' values are the main determining factors.

Another approach to this question is to explore BIM's contribution to tender analysis in terms of:

- automation (e.g. auto-reporting)
- error detection (e.g. omissions in model or item pricing, erroneous pricing and violation of bidding rules),
- data management (e.g. whether data is transmittable, re-usable or error-proof)

In all of the business models represented in this study, BIM has had very limited impact on the issues noted above. Although BIM's visualization helps decision-making, it was found that BIM's capabilities have not replaced human judgments when selecting contractors. This involves reviewing the merits of bids and determining whether contractors are able to support BIM during construction. Below are excerpts from participants from FModel organizations:

> *"They're* (software developers) *going (to) bring together GPSs, they're going to bring about 3D modelling and then once they can build a machine that can handle all this as well and is portable and you're able to take it with you it might just be a matter of projecting something in front of you and you could see it then yes I could say so. It's definitely going to be like that, where you're still going to need the labour to put it together to analyse it, to submit it. Yes, definitely, we use it as much as we can now".*

> *"Our progress claims used to have to go on site and do everything, come back to the office, produce the complete percentage to be done; you can do that all on site now with either your laptop or your PDA and tell the builder you're claiming $600. I'm going to give you $580 based on this; he knows what he's getting even before you come back to the office. And again, it's a two or three hour job instead of two or three days where you had to come back to the office to look through all your bill of quantities and so these are changes as well."*

Based on the above, estimating activities at this stage include:

- *Decoupling of BIM models to form virtual representation of the construction process and alternatives*.
- *Tender analysis based on visual, quantitative and qualitative data* on proposed prices of primary items, contractors' organizations and their proposed approach for the job. Rather than limiting tender analysis to the construction stage, BIM promotes an analysis of the construction price in tandem with the value on project life.
- *Moderation/integration of work-process models*. At some point, it will be necessary to integrate client's and contractor's models. This could be by way of feedback on proposals, negotiations or deliberate intent to articulate co-ordinated views.
- *Organization of software platforms for the integration of on-site and offsite systems* – for cost management and project supervision purposes. This includes progress monitoring based on the cyber-physical system (e.g. remote capture of photographs and videos, RFID and other remote access technologies).
- *Object-based communication (and analysis) of project finance matters* – a replacement of text-based interim valuation system, final accounts and accounts' reconciliation.
- *Parametric documentation of project's financial data*, including embedding project model with valuation or actual project data, and reconciliation on project's financial data.

The importance ratings of the activities in this stage of estimating processes are shown in Table 6.12. Analysis shows that participants from MModel organizations view the use of virtual models for bidding and reporting as *fairly important*. Due to the culture of competition (during bidding) and the risks contractors face during construction, participants from DModel organizations are of the view that virtual representation helps contractors to establish and prove the value of solutions. They saw that this also provided clients with the opportunity to fully visualize and understand the choices they made. As a point of interest, participants revealed that using BIM for tendering was a priority business strategy for some contractors, and this has paid off.

Furthermore, while participants from MModel organizations viewed the integration of process models between clients and contractors as *important but not compulsory*, estimators from contracting organizations did not view this variable with the same importance. The latter preferred the freedom to interpret clients' requirements in line with the strategy they chose for a project.

In the views of participants, FModel and NModel organizations support virtual model representation and reporting. Although estimators from FModel practices identified some challenges (e.g. lack of practice framework and motivation from clients), participants from NModel organizations thought that BIM adoption was self-driven and its value was all-encompassing.

Table 6.12: *Variables of Stage 4 of BIM estimation processes - Contractor selection and construction based on a virtual construction model*

Stage 4 – Contractor Selection thru' Virtual Models and estimation during Construction	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Formation of virtual representation of the construction process, and possible alternatives	3.2	4.3	4.5	5.0	4.3
Tender analysis based on visual, quantitative and qualitative data on contractors and bid proposals	4.8	4.3	5.0	5.0	4.8
Moderation/integration of work-process models	4.0	3.7	4.0	5.0	4.4
Organization of platforms for the integration of on-site and offsite systems	4.0	4.2	5.0	5.0	4.6
Object-based communication (and analysis) of project finance matters	3.4	4.0	4.0	4.5	4.3
Parametric documentation of project's financial data	4.8	4.3	4.5	5.0	4.8

6.3.5 Stage 5:Post-construction cost management and extending estimate data into facilities management model

Unlike traditional practices where design, construction and facilities management data are fragmented, BIM provides a platform for data integration. Regarding Stage 4, although some participants have not had extensive experience with facilities management operations, the information that was provided by others, especially those from IPD (NModel) firms, on this stage is useful. Based on construction cost data, estimators still need to take decisions on taxation depreciation of construction (and the constructed) facilities, monitoring the cost

implication of project performance and updating model data (as lifecycle phenomenon) in terms of maintenance works (e.g. alterations, replacements and conversions). An excerpt from a participant from NModel organizations is provided below:

> *"We operate a complete system; it allows us to do anything from early conceptual estimates through to full bills of quantities, through to progress claims, variations, financial reporting, tax depreciation, cash flows; we can all run it through this system and it all links together so you can carry a job basically all the way through from concepts through to basically tax and operational life cycle costings..... the challenges would be integrating the new software with this automated – for want of a better term – measurement, particularly seeing with our existing software doesn't integrate. One reason that we went down the path of the software that we've got is that it's a database based system rather than spreadsheet based systems. So, our system gives us the ability to manipulate and report on our information, our costing, our data in different ways in all sorts of things."*

Following up on an earlier comment from participants from MModel organization on database management, and in line with the excerpt above, it is evident that post-construction models contain cost information up to when the project was handed over. When this model is extended to facilities operations, the data they contain can be used for the different components of lifecycle costing. It will also be used for updating asset inventories and as an auto-alert system when items require replacement or corrective attentions.

From participants' interactions, the following variables are indicative of estimating processes leading to FM operations (see Table 6.13):

- *Integration of project models into asset inventories* – design and construction
- Where necessary, *establishment of basis for asset tracking*
- Ditto *management intelligence for future procurements*
- *Consistency in updating cost data in lifecycle product models*
- *Value analysis of space usage in order to draw lessons for future projects*

Table 6.13: *Variables of Stage 5 of BIM estimating processes - Extending construction estimate data into facilities management model*

Stage 5 – Post-construction estimate and extending estimate data into facilities management model	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Integration of project models into asset inventories' models – design and construction	*3.4*	*2.0*	*2.0*	*5.0*	*3.6*
Establishment of basis for asset tracking	*2.2*	*3.0*	*1.5*	*5.0*	*3.4*
Management intelligence for future procurements, including estimating for maintenance, replacement, conversion, alteration and rehabilitation works	*4.2*	*3.0*	*4.0*	*5.0*	*4.3*
Periodic tax depreciation procedures	*1.0*	*1.0*	*5.0*	*5.0*	*3.1*
Consistency in updating cost data in lifecycle product models	*3.0*	*2.0*	*4.0*	*5.0*	*3.8*
Value analysis of space usage and cost modelling – to draw lessons for future projects	*3.4*	*1.0*	*3.0*	*5.0*	*3.6*

6.3.6 Summary of BIM estimating processes

The activities in BIM estimating processes have been identified and rated in Tables 6.8 to 6.12. In Table 6.14, a summary of these ratings is presented to show how each stage is represented by the arithmetic means of the activities within it.

Table 6.14: *Estimating stages and activities in BIM regime*

Estimating Stages and Activities in BIM regime	***MModel***	***DModel***	***FModel***	***NModel***	**Average**
Stage 1 – Project conceptualization and design planning	3.9	4.7	4.4	4.9	3.8
Stage 2 – 3D Visualization and virtual reality	2.9	3.8	4.3	4.9	4.1
Stage 3 – Automated estimating, hyper-modelling and tendering	3.9	4.6	4.3	4.8	4.4
Stage 4 – Contractor selection thru' virtual models and estimation during construction	4.0	4.1	4.5	4.9	4.5
Stage 5 – Post-construction estimate and extending estimate data into facilities management model	2.9	2.0	3.3	5.0	3.6

On the overall, Stage 4: *Contraction selection through VDC* is rated highest amongst all the stages leading to successful BIM estimating. \Stage 3: *Automated estimating and hyper modelling* is next, while Stage 2: *3D Visualization and virtual reality* was rated third highest. The reasons for this can be ascribed to:

- The skills required to use virtual reality are new to estimators: VR is neither a part of most professional or academic teaching curricula nor yet a mandatory requirement for bidding. Thus, estimators currently use their conventional skills to estimate while they seek skill development in the area of VR.
- VR is a tool for simulation; its outcomes may be different in real situations. What is shown on screen during a simulation might not be what actually occurs. Thus, the correlation between VR and accuracy in estimating is debatable. Data from VR are neither exportable nor do they make estimating activities faster or more accurate.

Overall, participants viewed *"model decoupling, visualization and application of base costs"* as the most significant activities, while "*hyper-modelling", "construction simulation"* and *"establishment of basis for asset tracking"* are rated lowest. There are clear inferences to draw from this:

- Estimators found it difficult to manipulate BIM models to the appropriate state where they can support accurate estimates.

- Rather than guessing, visualization helps to clarify a designer's mindset during design, thus leaving a limited margin for guesswork and variability arising from uncertainties in design information.

- Estimators rely on historical data as the most important determining factor in estimating. Deploying historical data for BIM estimating only becomes expedient once the two points above have been determined appropriately.

- Like VR, hyper-modelling requires new skills, some of which are not yet popular in estimators' roles. Clients also make little demand of hyper-models; thus the market incentive for estimators to use these tools is still weak at the moment.

- At the moment, depending on how BIM is put to use, asset tracking is still an outlier in estimator's roles. Practitioners with skills in VR and simulation may extend their skills to this area; however, now, the market incentive for this activity is still weak.

6.4 SUMMARY STATISTICS ON THE RATINGS FOR ACTIVITIES AND STAGES IN 3D CAD AND BIM ESTIMATING

A summary of the ratings for activities and stages leading to estimates in 3D CAD and BIM has been presented in Tables 6.3 to 6.14. The next question to explore is how the activities compare. For example, as shown in Table 6.16, *model decoupling, visualization and application of visit base cost data* are the most significant variables in BIM; whereas *site visit, feasibility appraisal and application of bases data* are the most significant items in 3D CAD. In particular, a feasibility appraisal is not a mandatory exercise in all estimating; it is only provided when clients request it. With much less effort, several aspects of feasibility studies can be simulated or strengthened using a BIM model. For example, building components (BIM objects) can be analysed to explore constructability, financial feasibility and viability of contract or commercial interests. Nevertheless, contrary to participants' views, the correlation between the aim of feasibility studies and the functional framework of CAD is still debatable.

With the pressure on construction businesses and project stakeholders to use BIM, the transition from CAD estimating to BIM's is widespread. Such a transition means estimators would gain the time spent on activities that have been integrated into automated outcomes rather than spending time on individual process fragments in CAD. Depending on the perspective of estimators in each of the practice domains, the implementation of the themes in BIM estimation means estimators could take an advantage of the new skill areas in BIM to improve their participation in the industry. As explained later in this Section, there are new horizons in BIM estimating which are likely to expand further in the future and would propel an evolution of new skills and new roles.

Table 6.16: *summary of statistics on overall ratings for activities leading to estimates in 3D CAD and BIM*

BIM Estimation Stages and Variables	Ranking	CAD Estimation Stages and Variables	Ranking
Stage 1 – Project conceptualization and design planning	**1**	**Stage 1 - Preliminary data mining**	**3**
Interaction with the client and the project team	11	*Formation and interaction between the project team*	26
Model decoupling	1	*Definition of component design range*	15
Visualization of design components	1	*Data mining/applying "base data" based on previous projects*	1
Design analysis	8	*Preliminary review of client's requirements/project attributes*	8

Resource planning and modelling	11	*Cost planning based on outlined project attributes*	20
Exportation of meta-data for extended uses.	25	*Preliminary determination of construction process and cashflow management methods*	15
Stage 2 – 3D Visualization and Virtual Reality	**5**	**Stage 2 - Feasibility budgeting**	**1**
Use scenario simulation, using active agents	8	*Site visit/investigation; including geo-technical investigations*	1
Construction scenario simulation	27	*Feasibility appraisal: assessing factors that contribute to the economic life of the project*	1
Model-based value engineering	18	*Preparation of feasibility budget (in line with cost limits)*	8
4D/5D hyper-modelling	29	*Production of schematic designs (based on cost plans)*	14
Cost controlling and scheduling	18	*Value analysis (identifying potential value streams)*	5
Finalizing project models for estimating and tendering	25	*Conceptual estimation (parametric methods)*	1
Stage 3 – Automated estimation and tendering	**2**	**Stage 3 – Cost planning**	**3**
Auto-quantification of BIM product data, including 'manual handling' of allied descriptive parameters	8	*Preparation of elemental cost plans based on detailed drawings*	11
Model moderation or reconstruction in the context of project economics	20	*Collation of provisional estimates for specialist components and services*	15
Process hyper-modelling, including resourcing and costing by ERA, prevalent market conditions and customized operational process benchmarks'	1	*Cost analysis based on detailed design – to ensure that project is within budget*	15
Application of base costs, including provisional estimation and market surveys	11	*Project documentation for public planning purposes*	15
Conversion of estimates to tender	20	*Final cost checking prior to going to tender*	11
Tender documentation, including augmented packaging and submission	7	*Tender documentation*	5
Stage 4 – Contractor Selection and Construction based on Virtual Construction Model	**3**	**Stage 4 – Estimating and Tender Action**	**2**

Formation of virtual representation of the construction process, and possible alternatives	24	*Measurements from detailed drawings*	5
Tender analysis based on visual, quantitative and qualitative data on contractors and bid proposals	4	*Construction planning, process scheduling and cashflow planning*	20
Moderation/integration of work-process models	11	*Resourcing and finalized price surveys*	22
Organization of platforms for the integration of on-site and offsite systems	11	*Conversion of estimates to tenders*	22
Object-based communication (and analysis) of project finance matters	20	*Call for tender, including prequalification*	8
Parametric documentation of project's financial data	4	*Tender analysis and documentation*	11
Stage 5 – Extending construction estimate data into facilities management model	**4**	**Stage 5 – Post-tender and contract management**	**5**
Integration of project models into asset inventories	4	*Contractor selection*	24
Establishment of basis for asset tracking	28	*Project supervision*	26
Management intelligence for future procurements	11	*Contract administration*	26
Consistency in updating cost data in lifecycle product models	11	*Dispute management*	25
Value analysis of space usage – to draw lessons for future projects	20	*Post-occupancy evaluation and project documentation*	29
		Facilities management	30

When the variables in 3D CAD estimating and BIM's are compared, analysis shows that estimators' ability to integrate estimating roles into facilities management (i.e. *asset tracking and post-occupancy documentation*) was rated lowest for 3D CAD platforms. In BIM, *4D/5D hyper modelling* and *asset tracking* were rated lowest of the variables. There are other low-rated activities, which are not popularly used by estimators across board but are crucial. These include simulation and VR. Estimating activities in simulation and VR may not translate as automated quantification; they contribute to stakeholders' understanding (through visualization) of the factors that influence cost.

Another important finding was the paradigm shift towards multi-disciplinary integration. With BIM, it is increasingly possible to integrate estimating skills throughout a project's lifecycle. Regardless of the emphasis placed on these variables by the participants, the importance and relevance of a theme which was rated poorly, and the new horizons they create, cannot be underestimated. Thus, rather than concluding the analysis of the variables (stages and activities) based on participants' views, additional steps were taken to explore the relationship between the variables within and across the stages. Further statistical procedures were also undertaken to determine how the activities add value to the estimating outcomes across all the practice domains. Statistical correlations of all the variables were conducted and are reported in Section 6.5.

6.5 COMPARATIVE STATISTICS ON STAGES AND ACTIVITIES LEADING TO ESTIMATING OUTCOMES IN CAD AND BIM

Section 6.5.1 presents the activities in 3D CAD while Section 6.5.2 focuses on activities in BIM estimating. As a prerequisite to comparative statistical procedures, descriptive statistics were used to examine whether the variables are normally distributed. When variables are normally distributed, parametric procedures are used to initiate reliability tests on the variables. The descriptive statistics reported in this section include means and standard deviations for the practice domains, arranged by estimating stages in both 3D CAD and BIM regimes. These are presented in Tables 6.17 and 6.18.

Table 6.17: *Means and standard deviations of practice domains by stages in 3D CAD estimating*

Measure of stages in CAD estimating	**MModel**		**DModel**		**FModel**		**NModel**	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Preliminary data mining	4.15	*0.55*	4.28	*0.56*	4.13	*0.48*	4.48	*0.26*
Feasibility Budgeting	4.77	*0.32*	3.50	*0.78*	4.13	*0.45*	4.87	*0.10*
Cost Planning	4.27	*0.33*	3.20	*0.81*	4.42	*0.74*	4.67	*0.61*
Estimating and Tendering	2.20	*1.75*	4.14	*1.46*	4.00	*0.82*	4.14	*0.69*
Post-Tender Estimating and Contract Management	4.40	*0.78*	4.33	*1.03*	4.92	*0.20*	4.67	*0.52*

In Table 6.17, the normal distribution of the data is evident. The standard deviations of most variables are less than 1. This means the margin of variability in participants' opinions is very small. In the very few cases where the standard deviation is more than 1, the margin for variability could be fairly significant. For example, during *Estimating and Tendering* (where

the standard deviation is 1.75), variability in estimators' views are most evident. Estimates could be based on the direct data export from BIM models, on the basis of process models; based on prevailing market conditions or based on historical data.

Table 6.18: *Means and standard deviations of practice domains by stages in BIM estimating*

Measure of stages and activities in BIM regime	MModel		DModel		FModel		NModel	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Project conceptualization and design planning	3.9	*0.7*	4.7	*0.4*	4.4	*0.5*	4.9	*0.2*
3D Visualization Virtual Reality	2.9	*1.2*	3.8	*0.7*	4.3	*0.5*	4.9	*0.2*
Automated estimating, hyper-modelling and tendering	3.9	*0.8*	4.6	*0.8*	4.3	*0.3*	4.8	*0.3*
Contractor selection thru' virtual models and estimation during construction	4.0	*0.7*	4.1	*0.2*	4.5	*0.4*	4.9	*0.2*
Post-construction estimate and extending estimate data into facilities management model	2.9	*1.1*	2.0	*0.9*	3.3	*1.3*	5.0	*0.0*

The same situation applies in Table 6.18; participants from MModel organizations had divergent views about VR, perhaps because of the skills gap in this area. The views of participants from FModel organizations are moderately distributed. This is because the services rendered by this organization are freelance in nature and depend on the requirements of their clients. Overall, participants' views have reliably shown normal distribution. This provides preliminary confirmation of the validity of further steps to determine the relationships between the variables.

Tables 6.19 and 6.20 report the correlation coefficients and the principal component analysis (using the first scoring factor (F1) for each of the variables for each of the practice domains). The importance of these combined procedures is to determine the practice domains with the highest scoring factor. This signifies the practice domain that has had the most consistent views on the variables. As indicated in Section 5.3.2, participants from MModel organisations were clearly the reference point in some of the stages. Thus, the MModel organizations have the highest F1 value of 0.64 under 3D CAD regime. The scoring factors of the NModel and the DModel are the next highest. The correlation coefficients between these three are the most significant out of the four ($p < 0.05$).

Table 6.19: *Correlation and first scoring factor (F1) of the 4 practice domains in 3D CAD*

Measure	Factor 1	MModel	DModel	FModel	NModel
MModel	0.64	1			
DModel	-0.55	0.3734*	1		
FModel	0.37	0.3303	0.3782*	1	
NModel	0.40	0.1258	-0.0091	0.0561	1

* $p < 0.05$

In Table 6.20, the MModel, FModel and DModel also report F1 scores of about 0.6 and the correlation coefficients between these practice domains are significant ($p < 0.05$).

Table 6.20: *Correlations and first scoring factor (F1) of the 4 practice domains in BIM*

Measure	Factor 1	MModel	DModel	FModel	NModel
MModel	0.57	1			
DModel	0.58	-0.4402*	1		
FModel	0.57	0.3723*	-0.1111	1	
NModel	0.13	0.2950	-0.2489	-0.0388	1

* p <0.05

In Tables 6.21 and 6.23, analysis of variance of the views across the 4 practice domains for CAD and BIM regimes, respectively, are reported. In Tables 6.22 and 6.24, multiple comparison factors were determined for the practice domains across both CAD and BIM regimes. Why are these important? The overarching reason is to determine whether the relationships across the practice domains can be sustained consistently and significantly.

Table 6.21: *Analysis of Variance of CAD domains*

	Sum of Squares	df	Mean Square	F	P-value
Between Practice Domains	9.6364	3	3.2121	3.68	0.014
Within Practice Domains	104.7245	120	0.8727		
Total	114.3609	123	0.9298		

Table 6.22: *Multiple comparisons of CAD domains*

Domain vs. Domain	Domain Means		Mean Difference	FH-test
MModel *vs.* DModel	3.90	3.90	0.00	0.0000
MModel *vs.* FModel	3.90	4.31	0.41	2.4417
MModel *vs.* NModel	3.90	4.55	0.65	3.8836*
DModel *vs.* FModel	3.90	4.31	0.41	2.4417
DModel *vs.* NModel	3.90	4.55	0.65	3.8836*
FModel *vs.* NModel	4.31	4.55	0.24	1.4419

Fisher-Hayter pairwise comparisons for variable studentized range critical value (.05, 3, 120) = 3.3562154

An analysis of variance shows that the overall effect of the measured variables (stages of estimating) across the practice domains in the CAD regime is significant ($F(3,120) = 3.68$, p-value = 0.014). Comparison analyses using the Fisher-Hayter (F-H) procedure also indicate that the practice domains (MModel *vs.* NModels) and (DModel *vs*. NModel) contributed to

the significant differences reported in the analysis of Variance (ANOVA) (indicated by asterisks in Table 6.22).

Table 6.23: *Analysis of Variance of BIM domains*

	Sum of squares	df	Mean Square	F	p-value
Between Practice Domains	32.2803	3	10.7601	13.98	<0.001
Within Practice Domains	89.2913	116	0.7698		
Total	121.5716	119	1.0216		

Table 6.24: *Multiple comparisons of BIM domains*

Domain vs. Domain	Domain Means		Mean Difference	FH-test
MModel *vs.* DModel	3.52	3.84	0.32	1.9769
MModel *vs.* FModel	3.52	4.16	0.64	3.9954*
MModel *vs.* NModel	3.52	4.92	1.40	8.7192*
DModel *vs.* FModel	3.84	4.16	0.32	2.0185
DModel *vs.* NModel	3.84	4.92	1.08	6.7423*
FModel *vs.* NModel	4.16	4.92	0.76	4.7238*

Fisher-Hayter pairwise comparisons for variable studentized range critical value (.05, 3, 120) = 3.3576694

The ANOVA in Table 6.24 shows that the effect of the measured variables (stages of estimating processes) across the four practice domains in the BIM regime is statistically significant ($F(3,116) = 13.98$, p-value < 0.001). Using the Fisher-Hayter (F-H) post-hoc procedure, the differences between the 4 practice domains (MModel *vs.* FModel), (MModel *vs.* NModel), (DModel *vs.* NModel) and (FModel *vs.* NModel) are significant (indicated by asterisks in Table 6.24).

The implications of the statistical procedure is that it elicits internal consistency within the variables that translates into the strength of process models. This consistency is established in how the domains relate to each other in their views of the variables. Thus far, analyses have shown respondent's views on all the stages in both CAD and BIM regimes are relatively close across all the 4 practice domains. Furthermore as explained in the FH-Test indicators (in Tables 6.22 and 6.24), the thinking of participants on the utilization of 3D CAD for estimating, using these stages, is relatively close in a number of cases (between MModel and DModel organisations, and between DModel and FModel practices). However, this is not the case between MModel and NModel and between DModel and NModel practices:

- Where participants' views about variables are similar, estimating outcomes across the practice domain are relative in terms of the outcomes they generate i.e. most clients' estimates are based on contractors' (past) estimates. Thus, contractors can predict the clients' mindset quite easily. Moreover, contractors often outsource the measurement of quantities from drawings to consulting firms; therefore, consultants can predict contractors' management of this stage.

- Where there is a significant gap in the practice philosophies of the practice domains (e.g. between MModel and NModel and between DModel and NModels), estimating outcomes may not be close. For example, while estimates of NModel organizations are focused on the long-term performance of projects, most clients and conventional contractors still traditionally hold views that strongly favour fragmented relationships. In reality, this position is further explained by the reason why the costs of IPD, PPP or PFI projects are not often the same as the costs of conventional projects (Campbell and Harris, 2005, Sakal, 2005).

The same interpretations as above apply to the BIM regime, although with BIM, participants from most business models think more similarly on the stages. This is not where the outcomes of the analyses end; while all the stages are rated with some degree of significance (whether stakeholders think of them in the same way or not), the most important aspect is to determine how the variables in these stages behave in both regimes. The final outcome of the statistical procedure in reliability tests shows whether all the activities in all the stages are statistically significantly associated in generating workable outcomes across all the practice domains or not.

To achieve this, correlation coefficients of all the variables were determined. The reliability of each of the variables was then confirmed by applying the Cronbach Alpha Reliability procedure. Using this test, the variables that strengthen the bond between all the variables leading to the outcomes will stand out as 'good'. Those with negative Alpha values do not support the bond (they stand out as a 'bad' variable); thus they do the bond between the variables more damage unless they are discounted. Once such 'bad' variables are discounted, the optimum strength of the process models is the aggregate Alpha value. The outcomes of the statistical procedures are reported in Tables 6.25 and 6.27 (for correlation analysis) and Tables 26 and 28 (for the Cronbach Alpha reliability estimates) for 3DCAD and BIM regimes respectively.

In Tables 6.26 and 6.28, the highest overall Cronbach's Alpha values are indicated as 0.96 and 0.95 for 3D CAD and BIM regimes, respectively. These figures indicate that the undiscounted variables account for 96% and 95% of the potential predictive strength when combined to model estimating processes in 3D CAD and BIM, respectively. To get to this point, only items with significant correlation coefficients were considered. Thereafter, the Item-Test and Item-Rest correlation were adjusted to improve the overall reliability or Alpha scale of the model by removing variables with negative Item-Rest values.

In 3D CAD regimes, the Item-Rest values of variables 2, 3, 11 and 20 – 23 were negative. When removed, the reliability estimate, as per Table 6.26, increased to 0.96. This means only variables 1, 7-12, 14-19, 25, 30 and 31 (detailed identities are provided in Tables 6.25 and 6.26) can reliably lead to satisfactory estimating outcomes when applied to 3D CAD. This finding has limited statistical relationship with how each variable was ranked in the exploratory procedures.

Table 6.25: *Correlation coefficient for estimating activities in 3D CAD estimating*

Activities in 3D CAD Estimating processes	var1	var7	var8	var9	var10	var12	var14	var15	var16	var17	var18	var19	var25	var30	var31
Formation and interaction between the project team **(var1)**	1														
Site visitation/investigation; including geo-technical investigation **(var7)**	0.267	1													
Feasibility appraisal: assessing factors that contribute to the economic life of the project **(var8)**	0.464	0.956	1												
Preparation of feasibility budget (in line with cost limits) **(var9)**	0.681	0.888	0.951	1											
Involvement in the production of schematic designs (based on cost plans) **(var10)**	0.481	0.677	0.584	0.737	1										
Conceptual estimation (parametric methods) **(var12)**	0.591	0.897	0.986	0.967	0.555	1									
Collation of provisional estimates for specialist components and services **(var14)**	0.841	0.731	0.869	0.959	0.619	0.932	1								
Cost analysis based on detailed design – to ensure that project is within budget **(var15)**	0.927	0.567	0.683	0.872	0.750	0.759	0.933	1							
Project documentation for public planning purposes **(var16)**	0.298	0.785	0.651	0.733	0.968	0.585	0.558	0.625	1						
Clients' final cost checking prior to going to tender **(var17)**	0.786	0.569	0.784	0.814	0.262	0.873	0.920	0.768	0.205	1					
Tender documentation in readiness for 'call to tender' **(var18)**	0.745	0.754	0.909	0.933	0.462	0.966	0.972	0.824	0.438	0.966	1				
Clients' call for tender, including prequalification **(var19)**	0.538	0.845	0.962	0.904	0.390	0.983	0.889	0.667	0.433	0.904	0.963	1			
Tender analysis, contractor selection and contract documentation **(var25)**	0.515	0.669	0.844	0.762	0.125	0.891	0.807	0.548	0.156	0.934	0.922	0.957	1		
Post occupancy evaluation and project documentation in respect to cost (including database updating) **(var30)**	0.677	0.793	0.936	0.930	0.440	0.980	0.951	0.775	0.440	0.952	0.995	0.985	0.943	1	
Facilities management, including tax depreciation and lifecycle costing **(var31)**	0.992	0.159	0.353	0.594	0.458	0.485	0.768	0.894	0.254	0.707	0.654	0.426	0.408	0.577	1

Meanwhile, variables 4 – 6, 12, 13, 24 and 26 – 29, regardless of previous ratings, are discounted because their total item correction is less than 0.2, which means they do not contribute significantly to the strength of the bond between the variables when combined to form a process model.

As per Table 6.25, there is a significant correlation between most of the variables (estimating activities). Only 5 out of the 15 retained ('good') variables show few relatively weak correlations with other variables. For example:

- *var1* (team formation and interaction) strongly correlates with all other activities except *var7* (*site visit and investigation*) and *var16* (*project documentation for DA approval*). This can be interpreted as meaning that the overall assessment of the participants is such that estimators' site visits have a different direction to the interaction they had had with project teams. Moreover, when proposing estimates during project documentation for DA approval, such estimates are not likely to reflect near-actual project costs, even more-so that the project is at a proposal level.

- *Var7* (*site visit and investigation*) correlates strongly with all other variables except *var31* (*facilities management*) and *var1* (*team formation and interaction*). This means that site investigation is taken by participants only as a factor for consideration during the construction phase. The weak correlation between *var1* and *var7* was explained above.

- *Var16* (*project documentation for DA purposes*) is weakly correlated with *vars 17, 19* and *25* (*final cost checking prior to tender, call for tender* and *tender analysis* respectively). This means that estimates prepared for the purpose of DA approval have limited relationships with further steps taken by estimators to finalize their procedures for tender action. On many occasions, estimates contained in DA documentation are not conclusive or fully representative of actual project costs (at the time of submission); these are rather some projections based on approximate quantities or assumptions on preconstruction scenarios.

Table 6.26: *Cronbach Alpha Reliability estimates of activities in 3D CAD estimating*

Estimating Activities	Item-Test Correlation	Item-Rest Correlation	Average Inter-Item Covariance	Alpha
Formation and interaction between the project team **(var1)**	0.75	0.72	0.61	0.96
Site visit/investigation; including geo-technical investigation **(var7)**	0.82	0.78	0.57	0.96
Feasibility appraisal: assessing factors that contribute to the economic life of the project **(var8)**	0.94	0.92	0.54	0.96
Preparation of feasibility budget (in line with cost limits) **(var9)**	0.98	0.98	0.63	0.96
Involvement in the production of schematic designs (based on cost plans) **(var10)**	0.61	0.59	0.64	0.96
Conceptual estimation (parametric methods) **(var12)**	0.98	0.98	0.61	0.96
Collation of provisional estimates for specialist components and services **(var14)**	0.99	0.98	0.52	0.96
Cost analysis based on detailed design – to ensure that project is within budget **(var15)**	0.88	0.86	0.60	0.96
Project documentation for public planning purposes **(var16)**	0.58	0.53	0.61	0.96
Clients' final cost checking prior to going to tender **(var17)**	0.91	0.90	0.58	0.96
Tender documentation in readiness for 'call to tender' **(var18)**	0.99	0.98	0.56	0.96
Clients' call for tender, including prequalification **(var19)**	0.94	0.93	0.55	0.96
Tender analysis, contractor selection and contract documentation **(var25)**	0.85	0.81	0.54	0.96
Post occupancy evaluation and project documentation in respect to cost (including database updating) **(var30)**	0.98	0.97	0.56	0.96
Facilities management, including tax depreciation and lifecycle costing **(var31)**	0.66	0.60	0.59	0.96
Test scale			**0.58**	**0.96**

As shown in Table 6.26, with an inter-item average covariance of 0.58, the following activities have explained 96% of activities required to project reliable estimating outcomes in 3D CAD:

- In Stage 1: *Preliminary Data Mining*, the only important variable is *interaction between the project team*. This variable ranked among the bottom 5 in participants' discussions on estimating activities. Surprisingly, the highly ranked variable, viz *Data mining/applying "base data" based on previous projects* turned out during reliability analysis as making no significant contribution to estimating outcomes. This is justifiable because such data can confuse clients as all projects have individual unique properties that cannot be predicted, especially when the available information on a project is scanty. In other words, the databases that estimators relied upon at the earliest stages of design conceptualization are only provisional; actual project costs are determined after construction.
- In Stage 2: *Feasibility Budgeting*, all activities, from *site visit* to *conceptual estimation by parametric model*, are significant.
- In Stage 3: *Cost Planning*, all items except *preparation of elemental cost plans* stood out as significant.
- In Stage 4: *Estimating and Tendering*, *measurement of quantities* is the only significant variable. The technical implication of this is understandable; the articulation of cost data (as provisional sums, cost analysis based on detailed design and final cost checking) were completed in Stage 3; *Cost Planning*. Thus, the definitive quantity measurement will only reinforce the outcomes of Stage 3.
- In the Stage 5: *Post-Tender and Contract Management*, only two activities, *post-occupancy evaluation and project documentation* and *involvement of estimators in facilities management processes*, are the most significant in adding value to the overall outcome of the activities involved in generating estimates.

There are few things to draw out from this:

i. Analysis shows that estimators currently engage in more activities than are necessary to optimize estimating outcomes in the 3D CAD regime. According to the analysis, only about 50% of the activities listed by the discussants are statistically significant as value-adding activities leading to reliable outcomes.

ii. There is no evidence from past studies to suggest that a conclusive correlation between the accuracy of pre-contract estimates and contractor selection activities,

project supervision and the involvement of estimators in dispute management. Thus, these activities may be important to the participants in relation to their business assignments. However, they do not improve estimating outcomes significantly.

Understandably, these activities mean different things to estimators in different practice domains. While the activities listed in Table 6.26 represent a systemic view of variables in a process model that is applicable to estimating with 3D CAD, the variables can be further discriminated for specific application in the different practice domains. This is reported in Section 6.7.

In the same process as 3D CAD, the variables identified by participants as leading to reliable estimates in BIM, as per Table 6.13, are subjected to correlation analysis and Cronbach's Alpha reliability estimate. As shown in Tables 6.27 and 6.28), only four items (*vars 3, 16, 17, 18 & 19*) are discounted. Although, the correlations between the variables are substantially significant, there are a few cases where analysis shows weakly positive and weakly negative correlations. For example:

- *Var2* is strongly correlated with all other variables except *vars 7, 13, 20, 21, 24, 25, 29 & 30*. This means that when estimators decouple product models in ways that best represent their construction approach, their primary focus is on construction goals rather than VR simulations *(var7)* or by taking an advantage of auto-quantification *(var13)*. Project models are also not decoupled to reflect an approach to tender analysis *(var20)* or how contractors may integrate clients' construction models into their construction model *(var21)* or to represent how data will be transmitted into asset inventory models *(var25)*.
- *Vars 4 & 5 (Design analysis and, Resource planning and modelling respectively)* strongly correlate with all other variables except *vars 7, 9, 24, 25, 27-30*. Design analysis conducted by estimators, and resource scheduling are targeted at optimising clarity on project constructability rather than VR simulations *(var 7)* or value engineering *(var 9)*. In other words, design analyses are used to query omissions, conflicts and complex details rather than querying design forms and components' functions. Moreover, design does not support asset tracking *(var 25)* or facilities management functions *(vars 27-30)* i.e. lifecycle costing, tax depreciation and value analysis of facilities spaces.

Table 6.27: *Correlation coefficient for estimating activities in BIM estimating*

	var1	var2	var4	var5	var6	var7	var8	var9	var10	var11	var12	var13	var14	var15	var19	var20	var21	var22	var23	var24	var25	var26	var27	var28	var29	var30
var1	1																									
var2	0.625	1																								
var4	0.522	0.936	1																							
var5	0.474	0.889	0.993	1																						
var6	0.924	0.740	0.755	0.739	1																					
var7	0.717	-0.096	-0.181	-0.205	0.506	1																				
var8	0.715	0.984	0.869	0.806	0.764	0.037	1																			
var9	0.919	0.486	0.262	0.181	0.704	0.750	0.626	1																		
var10	0.905	0.893	0.774	0.714	0.900	0.360	0.944	0.812	1																	
var11	0.826	0.821	0.875	0.869	0.975	0.307	0.809	0.562	0.881	1																
var12	0.915	0.866	0.723	0.656	0.878	0.398	0.931	0.853	0.997	0.845	1															
var13	0.560	-0.272	-0.408	-0.442	0.278	0.964	-0.120	0.691	0.190	0.059	0.245	1														
var14	0.618	0.999	0.949	0.906	0.746	-0.105	0.978	0.466	0.886	0.832	0.856	-0.288	1													
var15	0.581	0.983	0.985	0.959	0.760	-0.143	0.939	0.376	0.845	0.863	0.805	-0.348	0.989	1												
var19	0.886	0.912	0.795	0.735	0.890	0.318	0.958	0.790	0.999	0.880	0.994	0.148	0.905	0.865	1											
var20	0.624	-0.187	-0.339	-0.379	0.341	0.970	-0.031	0.753	0.274	0.124	0.329	0.996	-0.204	-0.270	0.233	1										
var21	0.843	0.278	0.338	0.349	0.851	0.813	0.329	0.649	0.598	0.748	0.590	0.629	0.286	0.314	0.568	0.653	1									
var22	0.925	0.570	0.345	0.261	0.730	0.682	0.701	0.995	0.861	0.606	0.897	0.612	0.550	0.461	0.843	0.681	0.619	1								
var23	0.899	0.891	0.840	0.800	0.957	0.346	0.918	0.733	0.981	0.956	0.964	0.140	0.891	0.878	0.980	0.219	0.675	0.782	1							
var24	0.489	-0.246	-0.122	-0.078	0.469	0.826	-0.201	0.337	0.109	0.336	0.108	0.721	-0.235	-0.185	0.071	0.698	0.859	0.265	0.203	1						
var25	0.560	0.003	0.183	0.238	0.649	0.689	0.007	0.302	0.270	0.573	0.245	0.510	0.022	0.098	0.240	0.502	0.916	0.257	0.399	0.946	1					
var26	0.618	0.523	0.721	0.767	0.854	0.296	0.467	0.259	0.576	0.890	0.522	0.032	0.547	0.636	0.570	0.062	0.796	0.279	0.721	0.570	0.804	1				
var27	0.674	-0.117	-0.098	-0.089	0.564	0.956	-0.025	0.600	0.303	0.394	0.320	0.868	-0.116	-0.109	0.262	0.865	0.903	0.532	0.347	0.951	0.868	0.497	1			
var28	0.913	0.442	0.219	0.140	0.688	0.781	0.585	0.999	0.785	0.537	0.827	0.728	0.421	0.331	0.760	0.786	0.661	0.988	0.706	0.371	0.323	0.248	0.632	1		
var29	0.888	0.197	0.098	0.063	0.718	0.957	0.322	0.877	0.614	0.546	0.644	0.868	0.188	0.148	0.578	0.899	0.887	0.835	0.603	0.747	0.687	0.452	0.910	0.894	1	
var30	0.674	-0.117	-0.098	-0.089	0.564	0.956	-0.025	0.600	0.303	0.394	0.320	0.868	-0.116	-0.109	0.262	0.865	0.903	0.532	0.347	0.951	0.868	0.497	1.000	0.632	0.910	1

- While *var 6* (*Exportation of meta-data for extended uses)* is only weak against *vars 13 & 20*, *var 7* (*Use scenario simulation, using active agents)* is weak against all other variables except *vars 9, 13, 20-22, 24 & 25, 27-30*. The poor relationship between *var 6* and *vars 13 and 20* is understandable; the former is about extending design data for different conceptual uses, the latter is about moderating model data for definitive estimates and tender analysis. Moreover, use of scenario simulation *(var 7)* is only relative to value engineering *(var 9)*, object-based tender analysis *(var 20)*, integration of on-site and offsite components of work models *(var 22)* and facilities management functions in *vars 27-30*.
- Apart from *var 9* (which correlates with all variables but *var 24*), all variables from *var 8-12* correlate strongly with each other and most other variables. The variables correlate with all other variables except *vars 13, 20, 24, 25, 27 & 30*. In the case of *var 9*, the goal of value engineering is not to elicit how a project's financial data are embedded into a project model parametrically. They are rather a robust procedure to strengthen the relationship between form, cost, function and components' value. *Vars 8, 10-12* relates to VR simulation of projects. At the moment, there is limited capability to automatically export data from such models *(var 13)* or moderate them for automatic estimating *(var 20)*. VR simulations also do not represent or support parametric representation of financial data *(var 24)*. Until they are converted to or upgraded to as-built models, they cannot be the basis for asset tracking *(var 25)*. For the same reasons as in *vars 24* and *25*, VR simulation models cannot perform facilities management functions *(vars 27-30)*; rather as a platform for clients to use simulation techniques to preview project situations before project implementations.
- *Var 13* (*Auto-quantification of BIM product data)* does not correlate with most variables except *vars 20-22, 24, 25 and 27-30*. In essence, the methodology underpinning model data moderation and data export arising from same (*var 13*) is to support estimators' explicit approach to a tender (*var 20)*. It also supports accountability for possible variations arising from the integration of clients' and contractor's construction process models *(var 21)*, and a model integrating off-site and on-site components of work. It is also relevant to parametric representation of financial data *(var 24)* and the basis for asset tracking *(var 25)*. With this link, this variable integrates with facilities management operations *(vars 27-30)*.

- *Var 14* (*Model moderation or reconstruction in the context of project economics)* is exactly the opposite of *var 13*. It correlates with all other variables except *vars 20, 21, 24, 25 and 27-30*. When project models are re-constructed by estimators in ways that best represent project economics (e.g. cashflow) (*var 14*), consideration will exclude provisions for the integration of clients' process models into contractors' work-process model (*var 21*) because these did not exist at the time of the study. Moreover, rather than reflecting the same tender presentation variable *(var 20)*, data from this activity are conserved for in-house applications. Like *vars 20* and *21*, the realities of executing a project are promoted by how the project financial data are engineered and represented to aid cashflow *(var 24)*. The same thing applies to estimating operations during facilities management; the data, after construction has been completed, are documented as actual project data rather than the cost data used for estimating before construction. Although the operations in *vars 13* and *14* are alike; the former is open to all parties in a project, while the latter is targeted at in-house applications.
- *Var 15 (Process hyper-modelling*) shows a weak correlation against all other variables except *vars 1, 2, 4-6, 8, 11, 12, 14, 19, 23 & 26. Process models (var 15)* are short clips showing how a project will be constructed. Therefore, a process model would have:
    - addressed most requirements laid out by the project team *(var 1)*,
    - decoupled design models and restructured to suit construction and estimating methods *(var 2)*,
    - resolved design issues *(var 4)*
    - shown how the project is resourced *(var 5)*. *Var 5* depends on how data have been exported from the original and reconstructed product model *(var 6)* to simulate different construction approaches *(var 8)*,
    - shown a baseline plan of how cost and resource will be controlled during project execution *(var 11)*
    - indicated how the resultant (decoupled) model was reconstructed for estimating and tendering *(var 12)*
    - pointed out the relationship between in-house approaches to model-based estimating *(var 15)* and process model aimed for presentation during tender *(var 14)*. In other words, when a party proposes a construction process model,

the dynamics of project economics have been appropriated into the model, including risk analysis and benchmarking.

- *Var 19 (Formation of virtual representations of the construction process*) correlates strongly against all other variables except *vars 7, 13, 20, 24, 25, 27 and 30*. When construction models are formulated, rather than using scenario simulation (*var 7*), the emphasis is on construction. Presently there are limited platforms where data from process models can be exported for automatic estimating (*var 13*). Instead of a single process approach in which final tender data are analysed (*var 20*), *var 19* proposes different approaches where the proposer is neither contractually bound during project execution nor is such model a conclusive representation of how the project will be done. As a result, parametric representation of project financial data *(var 24)* in the project model may not rely on such proposals. It is also not logical to integrate such models into asset models and estimating functions during facilities management *(var 27 & 30)*.
- *Var 20 (Tender analysis based on visual, quantitative and qualitative data on contractors)* correlates strongly with all other variables except *vars 2, 4, 5 6, 8, 10-12, 14, 15, 19 & 23*. The relationships between *var 20* and other variables have been explained above (up to *var 19*). With respect to *var 23 (Object-based communication (and analysis) of project finance matters)*, actual project costs are neither predictable nor conclusive until after construction. Thus, rather than relating to tender objects, estimates are constantly updated, and of course are more reliable, when they are related to actual construction (*var 23*).
- *Var 21* correlates strongly with all other variables except *vars 2, 5 & 8*. When contractors' and clients' process models are integrated, an individual party's previous manipulation of the original product model *(var 2)* is no longer the primary reference; it is rather the integrated model. This also applies to the original provisions for resources planning *(var 5)* and multiple approaches to individual party's simulation of the construction process *(var 8)*.
- Similarly, *var 22 (Organization of platforms for the integration of on-site and offsite systems)* correlates strongly with all other variables except *vars 5, 24 & 25*. The relationship between *vars 22 and 5* is explained above. When onsite and offsite procurement models are integrated *(var 22)*, the basis for financial reporting *(var 24)* is the integration of clients' and contractors' models *(var 21)*. The same thing applies

to *var 25 (Integration of project models into asset inventories' models* – design and construction).

- *Var 23 (Object-based communication (and analysis) of project finance matters)* correlates weakly with all other variables except *vars 13, 20, 26, 28 & 29*. While the relationships between *var 23 and vars 13 and 20* have been explained previously, its relationships with *vars 26, 28 & 29* are straightforward. When the actual construction cost data are embedded into model objects *(var 23)*, they provide reliable data for asset inventories *(var 26)*. They can also serve as the basis for updating lifecycle cost data *(var 29)* and for analysing the relationship between space management and project (construction) value *(var 30)*.
- Similarly, *var 24 (Parametric documentation of project's financial data)* is weak against all other variables except *vars 1, 6, 7, 20, 21, 26, 28 & 29*. While relationships between *var 24* and *vars 1 – 21* were explained previously, its relationship with *vars 26, 28* and *30* are similar to that of *var 23*.
- *Var 25 (Integration of project models into asset inventories' models* – design and construction) has been explained previously as strong against *vars 2, 4, 5, 8, 9, 10, 12, 14, 15, 19 & 21*. Meanwhile, its strong relationship with *var 28* is also straightforward; data from asset inventories (*var 25*) are most reliable for tax depreciation (*var 28*).
- *Var 26* (*Establishment of basis for asset tracking)* is strong correlated with all other variables except *vars 7, 9, 13, 20 & 22*. These relationships have been explained previously.
- Moreover, as explained earlier, *vars 27 & 30* are both strongly correlated with *vars 2, 4, 5, 8, 10-12, 14, 15, 19 & 22*.
- Similarly, the situation of *vars 28 & 29* have been explained through other variables previously.

Following this correlation analysis (Table 6.27), Cronbach's Alpha Reliability estimates of the variables were determined in Table 6.28 to establish how the activities are likely to generate workable outcomes when used in a process model for estimating BIM projects. Unlike the 3D CAD regime where more than 50% of the articulated activities add no value to estimating outcomes, most of the activities listed under the BIM regime provide significant contributors, regardless of participants' initial ratings. Only 4 activities, viz. 1 in Stage 1 (*var*

3) and 3 in Stage 3 (*vars 16 – 18*), are discounted due to poor correlations. These exclusions can be justified because:

- *Visualization of design components (var 3)*: although this item was ranked highest by participants, this variable was discounted due to multi-co-linearity. For example, *decoupling of model components (var 2)* is impossible unless the model has been visualized.
- *Evaluated Risk Analysis (ERA) (var 16)*: the situation here is also similar to that of visualization. The ERA is part of *var 15 Process hyper-modelling, including resourcing and costing by ERA, prevalent market conditions and customized operational process benchmarks'.*
- *Conversion of estimates to tender (var 17)* is also relative to *var 10*: *4D/5D modelling* – i.e. in forming 5D models, price data must be incorporated for tender considerations.
- Tender documentation (var 18): this variable is also relative to *vars 15* and *21 – Process hyper-modelling, including resourcing and costing by ERA, prevalent market conditions and customized operational process benchmarks'* and *Moderation/ integration of work-process models.*

Table 6.28: *Cronbach Alpha Reliability estimates of activities in BIM estimating*

Estimating Activities	**Item-Test Correlation**	**Item-Rest Correlation**	**Average Inter-Item Covariance**	**Alpha**
Interaction with the client and the project team **(var 1)**	0.99	0.99	0.44	0.94
Model decoupling and reorganization to reflect estimators' elected construction approach **(var 2)**	0.66	0.63	0.44	0.95
Design analysis **(var 4)**	0.60	0.59	0.45	0.95
Resource planning and modelling **(var 5)**	0.56	0.52	0.43	0.95
Exportation of meta-data for extended uses **(var 6)**	0.97	0.97	0.46	0.95
Use scenario simulation, using active agents **(var 7)**	0.67	0.64	0.43	0.95
Construction scenario simulation **(var 8)**	0.73	0.69	0.42	0.95
Model-based value engineering **(var 9)**	0.86	0.84	0.43	0.94
4D/5D hyper-modelling **(var 10)**	0.91	0.89	0.39	0.94
Cost controlling and scheduling **(var 11)**	0.89	0.88	0.44	0.95
Finalising project models for estimating and tendering **(var 12)**	0.91	0.90	0.42	0.94

Auto-quantification of BIM product data, including 'manual handling' of allied descriptive parameters **(var 13)**	0.49	0.45	0.45	0.95
Model moderation or reconstruction in the context of project economics **(var 14)**	0.66	0.63	0.44	0.95
Process hyper-modelling, including resourcing and costing by ERA, prevalent market conditions and customized operational process benchmarks' **(var 15)**	0.64	0.60	0.43	0.95
Formation of virtual representations of the construction process, and possible alternatives **(var 19)**	0.89	0.88	0.43	0.94
Tender analysis based on visual, quantitative and qualitative data on contractors and bid proposals **(var 20)**	0.55	0.54	0.46	0.95
Moderation/integration of work-process models **(var 21)**	0.87	0.87	0.44	0.95
Organization of platforms for the integration of on-site and offsite systems **(var 22)**	0.87	0.86	0.44	0.95
Object-based communication (and analysis) of project finance matters **(var 23)**	0.93	0.92	0.44	0.95
Parametric documentation of project's financial data **(var 24)**	0.51	0.50	0.46	0.95
Integration of project models into asset inventories' models – design and construction **(var 25)**	0.62	0.57	0.42	0.95
Establishment of basis for asset tracking **(var 26)**	0.72	0.67	0.41	0.95
Management intelligence for future procurements, including estimating for maintenance, replacement, conversion, alteration and rehabilitation works **(var 27)**	0.67	0.64	0.44	0.95
Periodic tax depreciation procedures **(var 28)**	0.85	0.80	0.37	0.95
Consistency in updating cost data in lifecycle product models **(var 29)**	0.85	0.83	0.41	0.94
Value analysis of space usage and cost modelling – to draw lessons for future projects **(var 30)**	0.67	0.61	0.41	0.95
Test scale			**0.43**	**0.95**

In summary, the main findings from Tables 6.27 and 6.28 are that:

- Many studies have misinterpreted the application of BIM to estimating to mean costs can merely be applied to exported product data to automatically prepare estimates (Samphaongoen, 2010, Hardin, 2009, McCuen, 2009). This study demonstrates that

more activities (and roles) are involved in BIM estimating than in any regime that has been reported previously.

- With these extended roles, the estimators' reward (e.g. professional scale of fees) should be reviewed to reflect the shift.
- At present, with 3D CAD, estimators conduct many activities perhaps carried over from manual procedures which do not contribute a significant value to estimating outcomes. Several of the discounted variables in 3D CAD are rated very high in importance e.g. *var 3* which was rated highest, and *vars4 and 23* which are rated among the top 10.
- Estimating with 3D CAD is different from BIM; only 15 activities lead to or add value to the processes of articulating workable outcomes in 3D CAD, while 26 activities generate the estimate outcome in BIM.
- Out of the 11 activities that differentiate estimating in 3D CAD from BIM, 7 *(vars 7, 14, 15, 19, 21, 22 & 24)* are caused by new opportunities for digital innovations incentivised by BIM potentialities.
- The other 4, i.e. the balance of 7 activities taken from 11, are possible with 3D CAD; specifically, *vars 9, 11, 23 & 27*.

Meanwhile, all the undiscounted variables (also referred to as centroid variables) in both 3D CAD and BIM estimating apply differently to each of the practice domains. To understand this discrepancy, discriminant analyses (DA) were conducted to identity how centroid variables separate or apply to each of the practice domains. As all the variables are considered 'good' with optimum Cronbach Alpha Reliability estimate values, the DA helps to understand the overview of how distributed the variables are in each practice domain (see Section 6.6).

6.6 DISCRIMINATION OF VARIABLES IN ESTIMATING PROCESS MODELS ACROSS THE PRACTICE DOMAINS

There are two possible perspectives on how to advance the outcomes of the comparative analyses described in Section 6.5. The first is to progress the analysis via the original exploratory data and/or the outcomes of Cronbach Alpha procedure and discriminate the centroid variables across the four practice domains. The other way is to explore the technical implementation of the outcomes of the Cronbach Alpha procedure by way of computational

analysis. This first perspective is reported in the section. It focuses on using the DA method to discriminate the centroid data before and after reliability tests. The perspective is reported in Chapter 7 through System Architecture EXPRESS-G modelling method and IDEF0 format for representing process models.

The Discriminant Analysis

Background

Discriminant Analysis (DA) is a multivariate statistical technique that develops predictive or descriptive models based on group discrimination obtained from observed (and standardized) variables. It can also be used to ascertain how each variable is classified into the contributory groups. According to Myers and Well (2003), there are at least four common objectives of DA:

1. Through correct classifications, to identify important discriminating variables.
2. To explore the between-group differences, especially those that are significantly associated statistically
3. To discriminate how variables apply within groups while the conditions for objective *2* above applies.
4. To classify new observations into pre-existing groups.

The approach

The descriptive analyses reported in Section 6.4 and 6.5 shows that the variables were rated as statistically close across the four practice domains. DA procedure is used to discriminate the variables and detect which are the best discriminators across board. A similar procedure was used by Ng and Skitmore's (1999) study on prequalification where selection criteria were rated closely by participants from six domains viz private clients, public clients, cost engineers quantity surveyors, project managers, architects and engineers. The authors used canonical discriminant analysis to articulate the statistical association of the variables across the domains so that the resultant model could generate appropriate outcomes across the application domain..

Prior to the reliability test reported in Section 6.5, the variance of most distributions is around 1; the data in this study also passed the normality test. The first step was to test whether normality conditions still applied after the reliability test procedure. This was done to determine whether parametric or non-parametric DA approaches would yield the appropriate results. To establish this, Q-Q residual plotting was used. If the diagonal line in the Q-Q is

exactly 45^0 in any situation, parametric DA approaches apply; otherwise, non-parametric DA approaches apply. As per Figures 6.6a-e and 6.7a-e (see Appendix 3a: Residual values and Q-Q plots), the diagonal line in the residual plot is not exactly 45^0. The simplest direct interpretation of this is that, after the discounting done to the variables during the reliability test, the outcome has lost its normality attributes. Thus, rather than using simple descriptors of normal dispersions like kutorsis and skewness, descriptors of non-parametric function analysis such as kernel (*k*) values are used to explore the discrimination.

To identify the implications of the discrimination before and after reliability test, data in both conditions were discriminated. Generally, the key indicators of strength of discrimination are Eigen, Pillai's Trace test and Wilk's Lambda values (Casella and Berger, 2001, Myers and Well, 2003); the results are shown below. However, it is important to note that, where data do not conform to normality conditions, the discriminant power of function(s) cannot be explained with Wilk's Lambda value alone because the value may be incoherent in multiple analyses or insignificant altogether. To overcome this, Pillai's Trace test and Wilk's Lambda values are interpreted together.

The results - Key Predictive Indicators (KPIs)

Degree of Discrimination

As stated earlier, Wilk's Lambda and Pillai's Trace test values measure the efficacy of a discriminant function. There is a significant difference between the two indicators: Wilks' Lambda measures how much variance in the dependent variable is explained by the independent variable. The closer the Wilk's Lambda value is to 0, the more discriminated the function. Nevertheless, Pillai's trace is a more robust multivariate measure, especially when small samples are used. Based on discriminant variables, it elicits the variance in the dependent variable which is accounted for by the greatest separation of the independent variables. Thus, the higher the Pillai's Trace value, the more the discrimination (Casella and Berger, 2001, Myers and Well, 2003).

Tables 6.29a and 6.29b show the outcomes of discrimination when pre-reliability test data and post-reliability data were used respectively. The analyses show that it took a four-function procedure to fully discriminate pre-reliability test data, while post-reliability test data fully discriminated just one function.

Table 6.29a: *Eigen values of discriminant functions for 3D CAD (per-reliability test)*

Function	Eigen value	% of Variance	Cumulative %	Canonical Correlation
1*	1.9925	77.1414	77.1414	0.8160
2	0.3976	15.3930	92.5345	0.5334
3	0.1824	7.0628	99.5972	0.3928
4	0.0104	0.4028	100.0000	0.1015

*Wilk's Lambda value is 0.200; Pillai's Trace value is 1.1149 @ p<0.0001

Table 6.29b: *Eigen values of discriminant functions for 3D CAD (post-reliability test data)*

	Eigen value	% Variance	Cumulative %	Canonical Correlation
Function 1*	1.3607	100.0000	100.0000	0.7592

*Wilk's Lambda value is 0.42; Pillai's Trace value is 0.5764 @ p<0.0001

As shown in the Table 6.29a, for all the pre-reliability test variables, the Eigen value for Function 1 explains 77% of the variances in participants' descriptions of activities leading to workable outcomes while estimating with 3D CAD. The Wilk's Lambda and Pillai's Trace values of this function is 0.200 and 1.115 respectively at p<0.0001. There are several interpretations of these indicators (i.e. Wilki Lambda's, Pillai's Trace and p-values):

i. At an Eigen value of above 1 and a percentage variance of 77.14%, the variables' discrimination is sufficiently significant at Function 1.
ii. The implication of (*i*) above is clear; although the views expressed in the ratings are relatively close, this statistical indicator shows significant variation in how estimators implement these variables in the different practice domains. In other words, because normality conditions hold (for pre-reliability test variables), the greater the separation, the more the fragmentation (and potential controversies on views regarding the purpose a workable estimate should serve). As BIM is a platform for integration, the variability between 3D CAD estimation regimes (across the practice domains) and the outcomes in BIM regimes could be used to measure the impact of integration on improving workability of estimates. The accuracy of the separation is explored later in this section.
iii. At a p-value of <0.0001 for both indicators, there is a one in 10,000 chance that a relative level of significance will be achieved if the procedure is repeated.

Moreover, Table 6.29b shows 100% variance in the first function, the Eigen value and the canonical correlation is smaller but also significant in the post-reliability test data. Meanwhile, both Wilk's Lambda value and the more reliable Pillai's Trace value show that the significance of the association has declined (at 0.42 and 0.5764 respectively). This can also be interpreted as followed:

1. The discounted variables have a significant impact on the percentage variance. Different practice domains (Section 3.2) have had significantly different views on the criticality of the variables. Thus, they have triggered more discrimination across the practice domains (because both Wilk's Lambda and Pillai's Trace values are lower).
2. Notwithstanding (1) above, the 100% variance means all the variables in the post-reliability test were accounted for in the discrimination. However, the discrimination is weaker than it was before the reliability test. As such, if the variables in the discriminant function are adopted for a process model across the practice domains, there is a high propensity for a reduction in conflicting views on what an appropriate estimating outcome should be.
3. The same *p* value applies to both scenarios in pre-reliability and post-hoc data.

The implication of the three interpretations above is that estimators have different views of the impact of post-reliability test activities on their estimating outcomes. However, the discrimination of views across the practice domains is both technically and statistically significant, but much less than when ad-hoc data were used for the analysis. Thus, whether from a parametric or non-parametric perspective, the activities in post-reliability tests analyses are more likely to promote integration than in the pre-reliability test situation. The accuracy of the discrimination is further explored later in this section.

Estimating activities in BIM regimes were discriminated as in 3D CAD. As shown in Tables 6.30a and 6.30b, for pre-reliability test and post-reliability test data respectively, the former was discriminated in a four-procedure *function* while the latter was discriminated fully in just one *function*.

Table 6.30a: *Eigen values of discriminant functions for BIM (prior to reliability test)*

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1*	5.3739	95.7764	95.7764	0.9182
2	0.1805	3.2164	98.9928	0.3910
3	0.0406	0.7239	99.7167	0.1976
4	0.0159	0.2833	100.0000	0.1250

*Wiki Lambda value is 0.125, Pillai's Trace value is 1.0507 @ p<0.0001

Table 6.30b: *Eigen values of discriminant functions for BIM (post-reliability test)*

	Eigen value	% Variance	Cumulative %	Canonical Correlation
Function 1*	0.4216	100.0000	100.0000	0.5446

*Wilk's Lambda value is 0.42; Pillai's Trace value is 0.5764 @ p<0.0001

In the four- function procedure, Function 1 was the most significantly discriminated at an Eigen value of 5.3739, variance of 95.77% and a canonical correlation of 0.9182. This analysis shows that, prior to discounting some variables due to multi-co-linearity and weak association, about 96% of the variables accounts for the significant discrimination across the practice domains., This finding seems complicated because at this stage of BIM implementation, collaboration and integration should have impacted on the discrimination more significantly. This may be explained by the following reasons:-

- At the moment, there is no definitive framework on the most appropriate approach for estimators to collaborate. In the 3D CAD scenario, the same mechanism is missing.
- Because of the uncertainty, there have been different business interpretations of how to deploy BIM. Increasing the trajectory of innovation practices in each of the practice domain increases the discrimination.
- The accuracy of the discrimination is another reason. This is explored later in this section.

After the reliability test (Table 6.30b), all the standardized variables were found to have contributed to the discrimination. However, the discrimination is weaker than before the reliability test; estimators' views of the variables are firmer across the different practice domains.

Based on the DA procedure, it is statistically crucial to conclude that there is a significant variance in estimators' views of how best to achieve estimating outcomes with the identified variables (stages and activities). Moreover, the outcomes they achieve are also significantly

incongruent; as such, the impact of the platforms (i.e. 3D CAD and BIM) upon which estimates are calculated in each domain can be explored as individual streams. A way to do this is by exploring the classification matrix of the discriminant function (as described and in the next section).

Classification Matrix (CM)

CM measures the accuracy of the discrimination across the contributory domains – i.e. MModel, DModel, FModel and NModel practices. In the canonical plots (Figures 6.8a, 6.8b, 6.9a and 6.9b for pre and post-reliability analysis for 3D CAD and BIM respectively in Appendix 3b: Canonical Plots), domain plots around the reference centroids are shown. For pre-reliability analysis scenario, Canonical Function 1 is plotted against Canonical Function 2. The outcome shows that the discriminations are significantly incongruent i.e. all the contributory domains discriminate substantially, and in the same direction. All the discriminated domains are on the positive side in 3D CAD analysis but on the negative side in BIM. These scenarios can be interpreted in two ways:

- Being on the positive or negative side of the plot does not mean the line of thinking is 'positive' or 'negative'. Thus, the discrimination in participants' views on the variables is as though the value streams (or impact of the design application platform i.e. 3D CAD or BIM) across all the practice domains are in the same direction. For example, this could mean in the direction of process improvement, enhanced accuracy, objectivity in judgement, quicker steps to reliable outcomes, openness to innovation and speculation for more popularity of BIM and so on.
- It also indicates that the two paradigms are significantly different; activities in 3D CAD may favour conventional procedures, whilst those in BIM are not; the latter favour of collaboration and integration.

As there is only one canonical function in post-reliability analysis, the discrimination in 3D CAD and BIM domains are relative to the interpretations above (see Figures 6.8b and 6.9b in Appendix 3b). To explore what these value streams are, particularly on each of the variables, a valid procedure is to examine and compare the discriminant function coefficients and accuracy of classification of each of the practice domains (see below).

Discriminant Analysis functions and coefficients

DA coefficients elicit the magnitude of discrimination across group variables; in the case of the practice domains; the larger the magnitude of the standardized coefficients, the greater the discrimination of the domain. Previously, the scoring factors leading to Cronbach' Alpha Reliability estimate for estimating stages (see Table 6.19) show that MModel, NModel and DModel are the most discriminated groups in 3D CAD. As shown in Table 6.31, a relative outcome is retained when the same data is subjected to discriminant analysis. Meanwhile, when the post-reliability test data were subjected to DA, the outcome regarding group discrimination is different: The FModel practice is the least discriminated, while DModel and NModel are the most discriminated. Moreover, all practice domains are in one direction (positive), except for the NModel practice firms (see asterisk in Table 6.31).

Table 6.31: *Discriminant Function Scoring Coefficient*

Business models	**3D CAD**		**BIM**	
	Pre-reliability	*Post-reliability*	*Pre-reliability*	*Post-reliability*
MModel	1.125	0.223	0.248	0.768
DModel	0.641	0.799	1.547	0.676
FModel	0.208	0.194	0.832	0.655
NModel	1.157	0.761	-3.501*	0.224

In BIM, the data from the pre-reliability analysis shows the NModel discriminates most significantly (-3.50), followed by the DModel (+1.55) and FModel (+0.83). In both CAD and BIM scenarios, the overriding mindset of NModel has focused on facilitating the project goal in the long run; thus it favours integrative behaviours even when practice platforms are fragmented. More importantly, whether in CAD or BIM, collaborative and integrative behaviours have been proven to act as an incentive for enhanced project performance e.g. through trust and objective risk sharing among project parties (see (Campbell and Harris, 2005)). Thus, regardless of the approach taken in deploying estimating activities, a mindset in favour of integration and objective risk sharing is more likely to propel more outstanding outcomes than when such are absent, misapplied or under-utilized.

There are a few conclusions to be drawn from this:-

i. Consultant estimators (i.e. practitioners from the function structure model) seem to have held very strong views about the discounted activities. It appears that the professional service they render to clients is incomplete without those activities.

While other stakeholders seem to have prioritized only the items which are being scientifically established to add value to estimating outcomes, FModel practitioners appear to think differently (as per Figure 6.8a); this seems to make them biased towards clients' (MModel) position.

ii. The point elicited above partly explains some of the sceptical views on services rendered by independent estimators (e.g. professional quantity surveyors). Some have argued that unless estimators are used as independent value-audits, their engagement cannot be justified for pre-contract responsibility, especially when their estimates at this point are neither contractually binding nor free from complications. Of relevance to this is the recent report by the UK's Construction Industry Council (2011) that shows a significant decline in the number of quantity surveyors engaged on residential projects, compared to other profession. Prior to this, a similar discovery has been reported by Hardie et al. (2005) regarding quantity surveyors' commitment to adopting change and innovation in the industry.

iii. The two points above justify the recommendations of the UK's Monopoly and Mergers Commission's 1977 report on "*Surveyors services: a report on the supply of surveyors' services with reference to scale fees*". The Commission ruled that the professional scale of fees charged by independent estimators was anti-competitive and operating against the public interest.

What has a decline in the use of quantity surveyors and the abolition of professional scales of fees got to do with estimating in 3D CAD and BIM? Arguably, these views underpin the need for a re-think in estimating practice on integrative platforms. First, rather than jeopardize the chances of estimators, as more findings from this study shows more activities are involved in BIM estimation than 3D CAD's. Thus, there are more opportunities in integrative platforms than those seemed lost in a fragmented platform. This claim is supported further by the additional findings set out below. Secondly, estimating practice needs some re-engineering in BIM. At the moment, it is unclear how professional services in BIM are valued; the conventional scale of fee approach has been jeopardized by the UK's Monopoly and Mergers Commission's report (1977). Although such a report does not cover issues in Australia, however, the issue of the intellectual property of digital services is critical in Australia.

As per the analysis in Table 6.31, the NModel (+0.224) discriminates less than other models when data from post-reliability analysis were used. The most discriminated groups are

MModel (+0.768), DModel (+0.676) and FModels (+0.655). Meanwhile, all the models discriminate in the same direction. There are few points to draw out from here:

- With or without BIM, clients' and contractors' mindset on contract implementation has remained relatively (unchanged) in the same direction; it is still short-termed, protective and driven by fragmented obligations. In contrast, one of the critical potentialities of BIM is the propensity for longevity in contract relationships, as well as defragmentation across trade boundaries.
- The point above explains the complication which was identified earlier under Table 6.30a; this complication arises from a weak market drive for integration. BIM is 'real', but the impact of its deliverable is neither fully understood by clients, nor yet fully understood and driven definitively in appropriate industry frameworks (legal instruments, policies frameworks and industry knowledge).
- As NModel and FModel are in the same direction, both domains seem to take the greatest advantage of BIM deliverables at the moment.
- Conventionally, estimating procedures are biased to clients' (MModel) in terms of the right to initiate and define value streams (e.g. as per Fine B (1974) model and the use of SMM). This bias is the single most important cause of disutility in that contracting: requirements are often ambiguous (Shehu and Akintoye, 2009) and risks are unevenly distributed between contract parties (Olawale and Sun, 2010, Sweasey and Skitmore, 2007). To most clients, BIM's deliverables are interpreted as the potential for improved cost performance, but misapplied as lowering construction costs and added-cost value to clients. While contractors design their estimating procedures to comply with clients' needs, there are more options for contractors to operate project-based estimates in ways that promote objective risk evaluation (which clients can see through process models). Such procedures also add value by serving as platforms for workers' training, intra and inter-party communication, and as the basis for negotiating cost parameters with clients. In a real sense, clients (operators of MModels) are not under any of contractor's burdens; rather they are literarily indemnified by their consultants (the operators of FModel whose opinions are closest to the centroid).

In conclusion, the discrimination between the practice domains indicated above has been obtained only for post-reliability test scenarios in the form of regression equations for both

3D CAD and parametric BIM paradigms. Depending on the perceived priorities of the party applying the models, there are strong indications in the analyses presented in this section to suggest that the variables are statistically significant in delivering workable estimating outcomes. The accuracy of the discriminant functions is discussed after the model equations below:

$$DF_{(Ov,\ 3D\ CAD)} = -32.1366 + 0.2865x_1 + 0.2682x_7 + 0.2682x_8 + 0.2284x_9 + 0.2566x_{10} + 0.1960x_{12} + 0.2841x_{14} + 0.2566x_{15} + 0.2777x_{16} + 0.2682x_{17} + 0.2284x_{18} + 0.2729x_{19} + 0.2841x_{25} + 0.2284x_{30} + 0.2841x_{31}$$ **Equation 6.1**

$$DF_{(Mm,\ 3D\ CAD)} = -33.4430 + 0.1363x_1 + 0.2027x_7 + 0.2027x_8 + 0.2482x_9 + 0.2643x_{10} + 0.2027x_{12} + 0.2551x_{14} + 0.2551x_{15} + 0.2551x_{16} + 0.2608x_{17} + 0.2284x_{18} + 0.2608x_{19} + 0.2027x_{25} + 0.2027x_{30} + 0.0133x_{31}.$$ **Equation 6.2**

$$DF_{(Dm,\ 3D\ CAD)} = -15.5941 + 0.6515x_1 + 0.9697x_7 + 0.9954x_8 + 0.0447x_9 + 0.0447x_{10} + 0.0447x_{12} + 0.9990x_{14} + 0.4103x_{15} + 0.7518x_{16} + 0.8866x_{17} + 0.8866x_{18} + 0.9990x_{19} + 0.9990x_{25} + 0.8866x_{30} + 0.8866x_{31}.$$ **Equation 6.3**

$$DF_{(Fm,\ 3D\ CAD)} = -33.8502 + 0.2579x_1 + 0.1231x_7 + 0.2447x_8 + 0.2579x_9 + 0.2447x_{10} + 0.2379x_{12} + 0.2579x_{14} + 0.2579x_{15} + 0.0111x_{16} + 0.2158x_{17} + 0.2158x_{18} + 0.2447x_{19} + 0.2158x_{25} + 0.2158x_{30} + 0.2158x_{31}.$$ **Equation 6.4**

$$DF_{(Nm,\ 3D\ CAD)} = -39.0386 + 0.2325x_1 + 0.3114x_7 + 0.3114x_8 + 0.3114x_9 + 0.3114x_{10} + 0.3649x_{12} + 0.3649x_{14} + 0.3649x_{15} + 0.3649x_{16} + 0.2325x_{17} + 0.3649x_{18} + 0.1142x_{19} + 0.1142x_{25} + 0.3649x_{30} + 0.3649x_{31}.$$ **Equation 6.5**

Nomenclature

DF = discriminant function; *Mm = Matrix model;* *Dm = Divisional model;*
Fm = Functional model; *Nm = Networked model* *ov = Overall*
X_n = varn, where n is the corresponding variable number under 3D CAD regime as shown below.

Var 1 = *Formation and interaction between the project team;* **var 7 =** *Site visit/investigation; including geo-technical investigation*; **var 8 =** *Feasibility appraisal: assessing factors that contribute to the economic life of the project;* **var 9 =** *Preparation of feasibility budget (in line with cost limits);* **var 10 =** *Involvement in the production of schematic designs (based on cost plans)*; **var 12 =** *Conceptual estimation (parametric methods);* **var 14 =** *Collation of provisional estimates for specialist components and services;* **var 15 =** *Cost analysis*

based on detailed design – to ensure that project is within budget; **var 16 =** *Project documentation for public planning purposes;* **var 17 =** *Clients' final cost checking prior to going to tender;* **var 18 =** *Tender documentation in readiness for 'call to tender';* **var 19 =** *Clients' call for tender, including prequalification;* **var 25 =** *Tender analysis, contractor selection and contract documentation;* **var 30 =** *Post occupancy evaluation and project documentation in respect to cost (including database updating);* **var 31 =** *Facilities management, including tax depreciation and lifecycle costing*

$$DF_{(Ov,\ Para'\ BIM)} = -12.3735 + 0.2262x_1 + 0.2311x_2 + 0.2383x_4 + 0.2262x_5 + 0.2204x_6 + 0.2394x_7 + 0.2404x_8 + 0.2394x_9 + 0.1839x_{10} + 0.2394x_{11} + 0.2404x_{12} + 0.2404x_{13} + 0.2366x_{14} + 0.2413x_{15} + 0.2410x_{19} + 0.2205x_{20} + 0.2394x_{21} + 0.2324x_{22} + 0.2410x_{23} + 0.2205x_{24} + 0.2204x_{25} + 0.2071x_{26} + 0.2410x_{27} + 0.1839x_{28} + 0.2311x_{29} + 0.2204x_{30}$$

Equation 6.6

$$DF_{(Mm,\ Para'\ BIM)} = -8.5960 + 0.2099x_1 + 0.3214x_2 + 0.1458x_4 + 0.3607x_5 + 0.1458x_6 + 0.1458x_7 + 0.5166x_8 + 0.2455x_9 + 0.7093x_{10} + 0.2455x_{11} + 0.4004x_{12} + 0.1458x_{13} + 0.2828x_{14} + 0.4004x_{15} + 0.3214x_{19} + 0.0723x_{20} + 0.1766x_{21} + 0.1766x_{22} + 0.2828x_{23} + 0.0723x_{24} + 0.2828x_{25} + 0.5166x_{26} + 0.1458x_{27} + 0.7093x_{28} + 0.3607x_{29} + 0.2828x_{30}$$

Equation 6.7

$$DF_{(Dm,\ Para'\ BIM)} = -10.2806 + 0.2213x_1 + 0.1104x_2 + 0.1104x_4 + 0.1104x_5 + 0.1902x_6 + 0.2805x_7 + 0.1443x_8 + 0.2471x_9 + 0.2805x_{10} + 0.1902x_{11} + 0.2213x_{12} + 0.2805x_{13} + 0.1104x_{14} + 0.1104x_{15} + 0.1902x_{19} + 0.1902x_{20} + 0.2471x_{21} + 0.2011x_{22} + 0.2213x_{23} + 0.1902x_{24} + 0.2668x_{25} + 0.2805x_{26} + 0.2805x_{27} + 0.2121x_{28} + 0.2668x_{29} + 0.2121x_{30}$$

Equation 6.8

$$DF_{(Fm,\ Para'\ BIM)} = -12.7770 + 0.2467x_1 + 0.2467x_2 + 0.2467x_4 + 0.2022x_5 + 0.2464x_6 + 0.2467x_7 + 0.2467x_8 + 0.2239x_9 + 0.2022x_{10} + 0.2366x_{11} + 0.2467x_{12} + 0.2467x_{13} + 0.2467x_{14} + 0.2366x_{15} + 0.2467x_{19} + 0.2239x_{20} + 0.2366x_{21} + 0.2239x_{22} + 0.2366x_{23} + 0.2467x_{24} + 0.0792x_{25} + 0.0521x_{26} + 0.2366x_{27} + 0.2239x_{28} + 0.2366x_{29} + 0.1588x_{30}$$

Equation 6.9

$$DF_{(Nm,\ Para'\ BIM)} = -18.2642 + 0.3926x_1 + 0.3961x_2 + 0.4068x_4 + 0.3997x_5 + 0.2439x_6 + 0.4068x_7 + 0.3961x_8 + 0.4068x_9 + 0.2439x_{10} + 0.4068x_{11} + 0.4032x_{12} + 0.2439x_{13} + 0.4068x_{14} + 0.4068x_{15} + 0.4068x_{19} + 0.3926x_{20} + 0.4068x_{21} +$$

$$0.4032x_{22} + 0.2439x_{23} + 0.3891x_{24} + 0.4068x_{25} + 0.3926x_{26} + 0.4032x_{27} + 0.4068x_{28} + 0.3961x_{29} + 0.4068x_{30}$$ **Equation 6.10**

Nomenclature

DF = discriminant function; *Mm = Matrix model;* *Dm = Divisional model;*
Fm = Functional model; *Nm = Networked model* *ov = Overall*
X_n = varn, where n is the corresponding variable number under 3D CAD regime as shown below.

Var 1 = *Interaction with the client and the project team*; **var 2 =** *Model decoupling and reorganization to reflect estimators' elected construction approach;* **var 4 =** *Design analysis;* **var 5 =** *Resource planning and modelling;* **var 6 =** *Exportation of meta-data for extended uses;* **var 7 =** *Use scenario simulation, using active agents*; **var 8 =** *Construction scenario simulation;* **var 9 =** *Model-based value engineering;* **var 10 =** *4D/5D hyper-modelling;* **var 11 =** *Cost controlling and scheduling;* **var 12 =** *Finalising project models for estimating and tendering*; **var 13 =** *Auto-quantification of BIM product data, including 'manual handling' of allied descriptive parameters*; **var 14 =** *Model moderation or reconstruction in the context of project economics;* **var 15 =** *Process hyper-modelling, including resourcing and costing by ERA, prevalent market conditions and customized operational process benchmarks';* **var 19 =** *Formation of virtual representation of the construction process, and possible alternatives;* **var 20 =** *Tender analysis based on visual, quantitative and qualitative data on contractors and bid proposals;* **var 21 =** *Moderation/integration of work-process models;* **var 22 =** *Organization of platforms for the integration of on-site and offsite systems;* **var 23 =** *Object-based communication (and analysis) of project finance matters***; var 24 =** *Parametric documentation of project's financial data***; var 25 =** *Integration of project models into asset inventories' models* – design and construction*;* **var 26 =** *Establishment of basis for asset tracking;* **var 27 =** *Management intelligence for future procurements, including estimating for maintenance, replacement, conversion, alteration and rehabilitation works;* **var 28 =** *Periodic tax depreciation procedures;* **var 29 =** *Consistency in updating cost data in lifecycle product models;* **var 30 =** *Value analysis of space usage and cost modelling – to draw lessons for future projects*

Accuracy of Classification

There are different ways of measuring accuracy discrimination; when both parametric and non-parametric conditions apply. If the normality conditions apply, the accuracy of each of the models can be examined through their respective degree correct classifications within each group. For example, before reliability tests, in the overall model for BIM, 5 (16.67%) of the variables were misclassified (*vars 1, 6, 14, 15 & 19*). For 3D CAD, only 1 (3.23%) variable (*var1*) was misclassified. A wrong classification means the variables did not discriminate i.e. all the practice domains applied the variables the same way. Further steps could be taken to explore the possibility of discrimination in the variables across the practice domains by generating additional discriminant functions. One approach is to seek a second

discrimination through logarithmic function. In this case, the likelihood of discrimination in these variables after a second logarithmic function is 13.52% and 3.69% for BIM and 3D CAD, respectively. These figures are not significant, thus considering a second function to elicit the discrimination is not necessary.

As pointed out earlier, after the reliability estimate procedure, the discriminant analyses have only yielded reliable outcomes with non-parametric tools. In this mode, the most reliable option is to apply kernel *(k)* values and measure the accuracy of the groups through cross validation. When processed through the SAS system, an error in each group is automatically generated (see Table 6.32).

Table 6.32: *Accuracy of classification*

Errors	MModel	DModel	FModel	NModel	Overall
3D CAD	0.1587	0.1821	0.1580	0.0899	0.0693
Parametric BIM	0.2306	0.1666	0.1905	0.0352	0.0924

In 3D CAD regime, the discrimination is approximately 85% accurate for the MModel and 82% for DModel, 85% for FModel, and about 91% accurate for NModel. Overall, this analysis shows that the discriminant function along the centroid is 93% accurate. In BIM regime, the discriminant function for estimating with the post reliability test variables is 79% accurate for MModel, 83% accurate in DModel, 81% accurate in FModel and 96% accurate in NModel and 91% accurate if the centroid regression model is used. In both circumstances, the models work more with estimating processes in NModel, than in any other form of business. Although all the other groups are better off when they apply the centroid regression model, this finding shows that the accuracy of estimating procedures (using the elicited 'reliable' variables) increases as the industry moves from client-favoured fragmented styles to BIM's collaborative platform. For example, as shown in Table 6.31, accuracy levels decrease in MModel and FModel, while there are significant improvements in accuracy levels of DModel and NModel when estimating practices in 3D CAD are compared to BIM's. These findings are discussed in Chapter 7.

6.6 SUMMARY OF STATISTICAL ANALYSIS

In this chapter, data have been explored from 17 experienced industry practitioners, whose domains of practice range from MModel (client organizations), DModel (contracting organizations), FModel (consulting organizations) and NModels (integrated project

development (IPD) experts). Before the views of these experts are explored, estimating procedures using 5 BIM-compliant software applications were investigated with a view to articulate activities leading to workable estimates in BIM.

In exploratory studies, this study discovered two regimes of BIM implementation; some organizations have transited from 2D CAD to 3D CAD, while some have advanced into BIM estimating. The goal of this research therefore is to articulate the activities leading to workable estimates in both paradigms across the four practice domains identified above. Following the exploratory analysis, 31 activities were identified from research participants' discussions as leading to estimating outcomes in 3D CAD and 30 activities in BIM. The importance of each of the activities, as emphasised in participants discussions, was rated in all the practice domains from 1 to 5; with 1 being 'not relevant' and 5 being 'highly important and inevitable'. Further to the exploratory analysis, a normality test was conducted on the data prior to reliability tests; this demonstrated that normality conditions hold and that parametric tools would lead to valid outcomes.

Furthermore, analysis by scoring factor shows the relationship between the stages in both paradigms across the practice domains. As shown in Table 6.19, the MModel, DModel and NModel have the highest scoring factors in 3D CAD, while the FModel, MModel and DModels are the highest rated in parametric BIM. This finding is also consistent with the findings in analysis of variance and multiple comparison tests.

Following this, the Cronbach Alpha procedure identified the activities that have not contributed to the strength of the bond between the activities. The analysis in Table 2.26 shows that less than 50% of the activities identified under the 3D CAD regime add value to the estimating outcome, and these explain 96% of variables needed to generate reliable estimates. The finding in BIM is different, only four of the 30 activities were discounted, and the outstanding variables explain 95% of possible variables needed to generate reliable estimates.

These findings are significant; estimating in both 3D CAD and BIM require more activities than some claims in the literature. Moreover, while 3D CAD is relative to conventional procedures (this confirms (Dean and McClendon, 2007), BIM triggers quite a wide range for opportunities for estimators (also confirms Tse (2009)). The analysis also shows that the retained activities in both paradigms are strongly correlated.

Further to these, the variables were subjected to discriminant analysis to explore how they are deployed in different practice domains. The analysis shows that normality conditions no longer hold when non-value adding activities have been discounted. Thus, only a non-

parametric approach to discriminant analysis led to significant outcomes after reliability tests. To further justify the importance of this discrimination, both data scenarios (i.e. prior and post-reliability tests) were compared (Tables 6.29 and 6.30). While equations 1 to 10 were used to express the result of post-hoc discriminant functions, the degree of association of the activities across the practice domains was shown in Figures 6.8 and 6.9.

The analysis in Table 6.32 shows the degree of accuracy of the predictive model i.e. in the 3D CAD regime, 85% discrimination accuracy in the MModel, 82% in DModel, 85% in FModel, and 91% in NModel, and 93% along the centroid. In the parametric BIM regime, the discrimination was 79% accurate in MModel, 83% in DModel, 81% in FModel and 96% accurate in NModels, and 91% accurate along the centroid. In both circumstances, the models align more to estimating procedures that NModel are used to than in any other form of business. The computational configuration of the process models are presented in Chapter 7.

7 TOWARDS AN IMPLEMENTATION OF THE PROCESS MODELS

7.0 TOWARDS AN IMPLEMENTATION OF THE PROCESS MODELS

7.1 INTRODUCTION

In Chapter 6, the estimating stages and activities (or variables) in using 3D CAD and BIM have been explored from the themes identified from research participants' discussions. These variables were analysed to identify whether the correlations between them are consistently coherent. This has involved using exploratory and descriptive statistics to test for normality and reliability. In this chapter, in the researcher's own view, the implementation of the centroid process models which were developed in Chapter 6 is discussed in three ways:

- The construction of a system architecture through which the stages and activities in the process models work together to deliver satisfactory estimating outcomes
- The development of EXPRESS-G models for the estimating activities using 3D CAD and BIM to demonstrate the progression of events leading to workable outcomes when the established models are implemented.
- The development of IDEF0 models to indicate how the developed models can be implemented for software development.

7.2 System architecture for the process models

Statistical analyses in Chapter 6 have shown that all the five stages identified in the exploratory procedures are relevant to developing workable estimating outcomes. To implement the process models represented through the statistical analyses, each of the stages can be used on isolated or integrated platforms during estimating. As discussed in Sections 7.2.1 and 7.2.2 estimating stages are generally based on database systems.

Organizational business systems in the form of fragmented and integrated databases (e.g. Enterprise Resource Planning (ERP) systems) are popular for construction project implementation, and for running the day-to-day operations of construction businesses. For example, in the work of Buijs (2010), ERP systems, frequently driven on ORACLE and SAP, are frequently described for many resourcing purposes, from financial management to human resource management and supply chain management. The main goal of this section is to describe how the process models developed in Chapter 6 can be configured for implementation in a way that is similar to ERP systems so that estimating practices are able to implement the process model they consider most suitable.

7.2.1 System Architecture for 3D CAD estimating

Based on the findings of the statistical analyses presented in Chapter 6, the process models were configured as shown in Figure 7.1 and 7.2 for 3D CAD and BIM estimating processes

respectively. In Figure 7.1, the first task is team formation and creation of a framework interaction when 3D CAD is used to prepare construction drawings. However, in BIM estimating, more activities are required in the first stage (see 'Activities' in Figure 7.2). In addition to their involvement in constructing project teams, this study has pointed out that estimators analyse designs and, plan resources and outline construction methods. Estimators also re-construct design models into formats that best represent their presentation approaches. Through this, they structure how data will be exported from the design models (for descriptions of work items and quantities) and project databases (for methods, risks and costs). The peculiarities of the activities in both paradigms are discussed separately below.

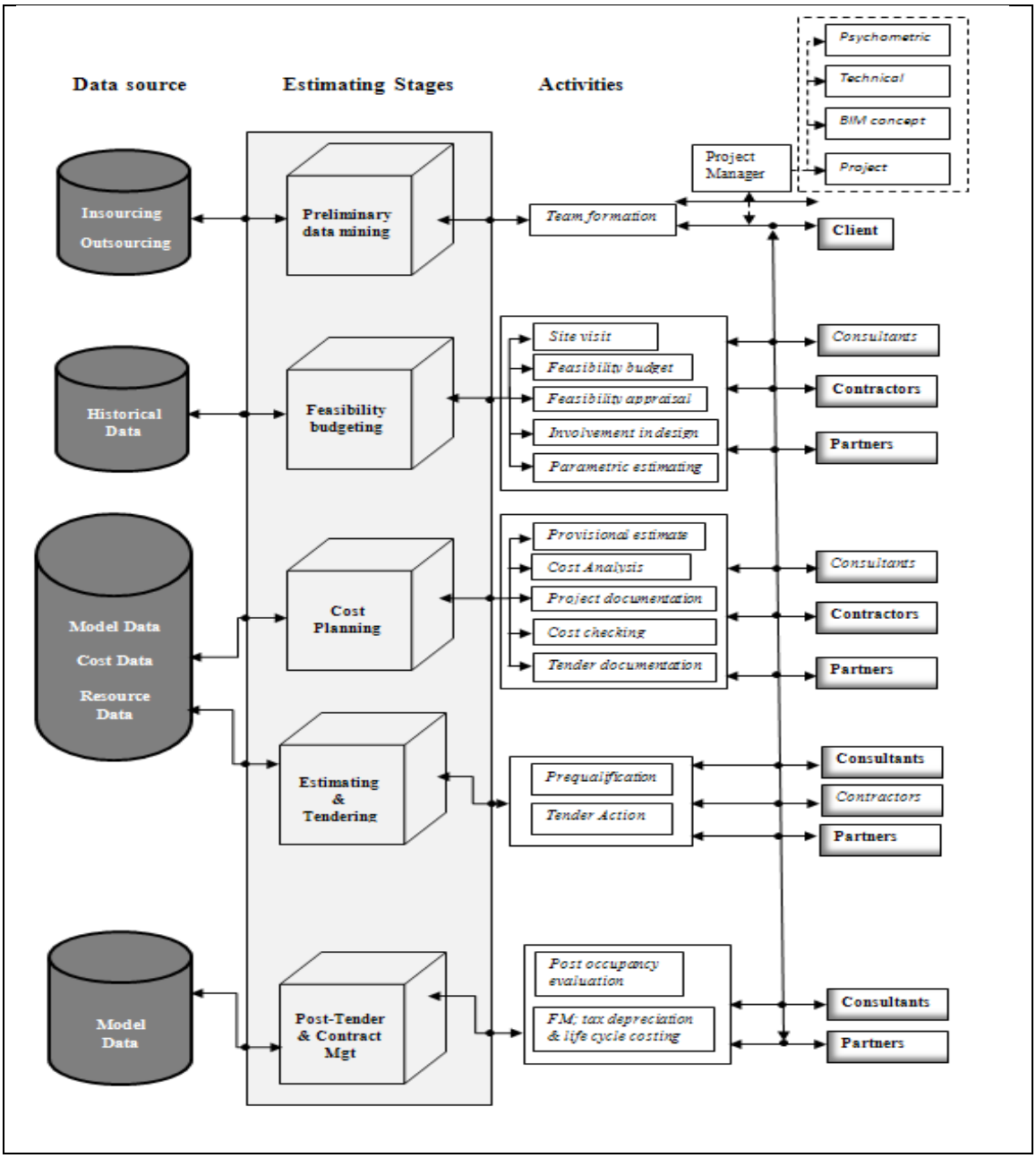


Figure 7.1: System architecture for estimating with 3D CAD

- *Stage 1: Preliminary data mining – Team formation for 3D CAD estimating.* Several authors note that estimators are involved in project team formation (Ashworth and Hogg, 2007). This is to guide clients in conceptualizing the cost implications of preliminary choices at the very early stages of a project. This includes accommodating clients' requirements within budgets, providing guidelines on procurement routes and advice about the cost implications of the risks inherent in their decisions. All four practice domains (e.g. MModel) involve and incorporate estimators in team formation differently. In matrix model organisations, psychometric modelling may be involved to determine appropriate team constructs (i.e. attributes of those to be included in a team, whether to in-source or outsource team members or to use project management approaches). It may also be necessary to establish whether clients need to create specialized project environments where project teams require additional training or orientation during project implementation (including instruction on how to collaborate, styles of communication and new applications). A more detailed discussion on psychometric modelling is provided in (Steyer et al., 1992).

  In divisional model organisations, the involvement of estimators in constituting project teams may range from partner selection to creating methodologies for resourcing projects. This context of team constitution is different from matrix model organisations: MModel estimators may be involved in selecting design teams whilst DModel estimators may only be invited by clients to contribute to specific aspects of decision-making at this stage. Additionally, DModel estimators may be involved in selecting their teams for estimating and tendering e.g. first, to select their project team; and second, to source data from their potential subcontractors and suppliers. Team selection could take the form of intra-organization strategizing (as estimators interact within their organization) and inter-organizational learning (which includes negotiation skills and semi-formal business practices) (Taylor and Unsal, 2009). These examples of team formation are also relevant to estimators in functional-unit practices and networked model organizations.

  Each of the practice domains apply the cost database systems for preliminary data mining differently. There are two goals in such application: (1) to conceptualize immediate outcomes in estimating (e.g. create budgets); (2) to underpin future steps in controlling and managing costs. The nature of the variables that facilitate outcomes at this stage therefore includes qualitative data (e.g. on behavioural constructs) and quantitative (e.g. cost implications of past decisions).

- *Stage 2: Feasibility budgeting in 3D CAD estimating.* As shown in Figure 7.1, feasibility budgeting in 3D CAD estimating involves site visits, feasibility budgets and appraisal during designing (to provide cost advice) and parametric estimating. All these activities have similar attributes across the four practice domains. Logically, they also correlate with the Stage 1 activity of team formation and interaction. For example, through site visits, estimators are able to relate a project's conceptual budget to other components of a feasibility study e.g. environmental costs and social cost implications. Site visits also help to strengthen how they apply base costs that other members of the estimating team would have defined as well as guide other team members in making other project-related decisions. Therefore the nature of variables in the databases required for this includes qualitative data such as descriptors of work items (e.g. components, resource requirements) and quantitative data (e.g. costs, durations and resource data).
- *Stage 3: Cost planning in 3D CAD estimating.* There are 5 activities in this stage: provisional estimate for each project element (to conform within budget), cost analysis, project documentation (for DA), cost checking, and tender documentation. Similar to the activities in Stage 2, estimators in the various practice domains have the same approach to these activities, and the nature of the variables in the databases for this stage is largely quantitative.
- *Stage 4: Estimating and Tendering*. There are two main activities in this Stage: prequalification and tender action. At this stage, depending on the practice domain, estimators are expected to set criteria for prequalification and contractor selection and prepare documentation for the same. Tender action also involves analysing tender prices, based on price data and non-price data (Palaneeswaran and Kumaraswamy, 2001). Either by requesting information or by demonstrating capabilities to undertake a project, estimators, regardless of practice domain, observe the same procedure while implementing prequalification. In particular, clients' estimators prequalify candidate contractors; contractors also apply their own prequalification standards to select partners, subcontractors and suppliers. The same situation applies to tendering: estimators are involved in estimating and preparing tenders and comparing these across bidders. Client's estimators compare competitors' bids; contractors estimators compare sub-contractors' bids. Like Stage 1: Preliminary data mining, the nature of variables in the databases used for this stage is both qualitative (e.g. contractors'

attributes, project components) and quantitative (tenders prices, estimates and prequalification scores).

- *Stage 5*: *Post tender activities and contract management.* Analysis in Chapter 6 shows that, in Australia, and when using 2D CAD and 3D CAD applications, estimators are mostly involved by clients in pre-construction activities. This is also evidenced in the work of Chan et al. (2012) who illustrates target-cost contracting as an approach that project owners use to rely only on contractors' cost projections before construction. During construction, the values of work have to be ascertained from time to time. However, these roles could be included in the responsibilities of construction managers and project managers who are accountable for managing projects.

  According to the findings described in Chapter 6, the main activities performed by estimators after construction are post-occupancy evaluation (value audits) and facilities management related activities such as tax depreciation and lifecycle costing. The nature of the variables required to develop databases for these operations is qualitative (project descriptors such as project elements, texture, colour etc.) and qualitative data (quantity of work done, costs and prices, duration and resources).

7.2.2 System Architecture for BIM estimating

As shown in Figure 7.2, there are five stages in BIM estimating. The system architecture for the stages and activities is discussed below:

- *Stage 1: Project conceptualization and design analysis*. Estimating with BIM at this stage involves five activities: team formation, decoupling of conceptual project models, design analysis, resource planning and exporting metadata unto estimating and planning platforms. These activities require robust database support to deliver satisfactory outcomes. For example, in constituting project teams in BIM, clients need to outline the frameworks for enhancing project delivery through BIM deliverables e.g. parametricism, object-based communication, automation and process integration. This may require some initiation or training on collaboration and how to use project-specific technologies. All these are at a cost to clients, and must be estimated and engineered along project value streams. Thus, this activity requires qualitative data (e.g. for team collaboration attributes, communication frameworks) as well as quantitative data (e.g. cost data on professional fees and BIM implementation costs).

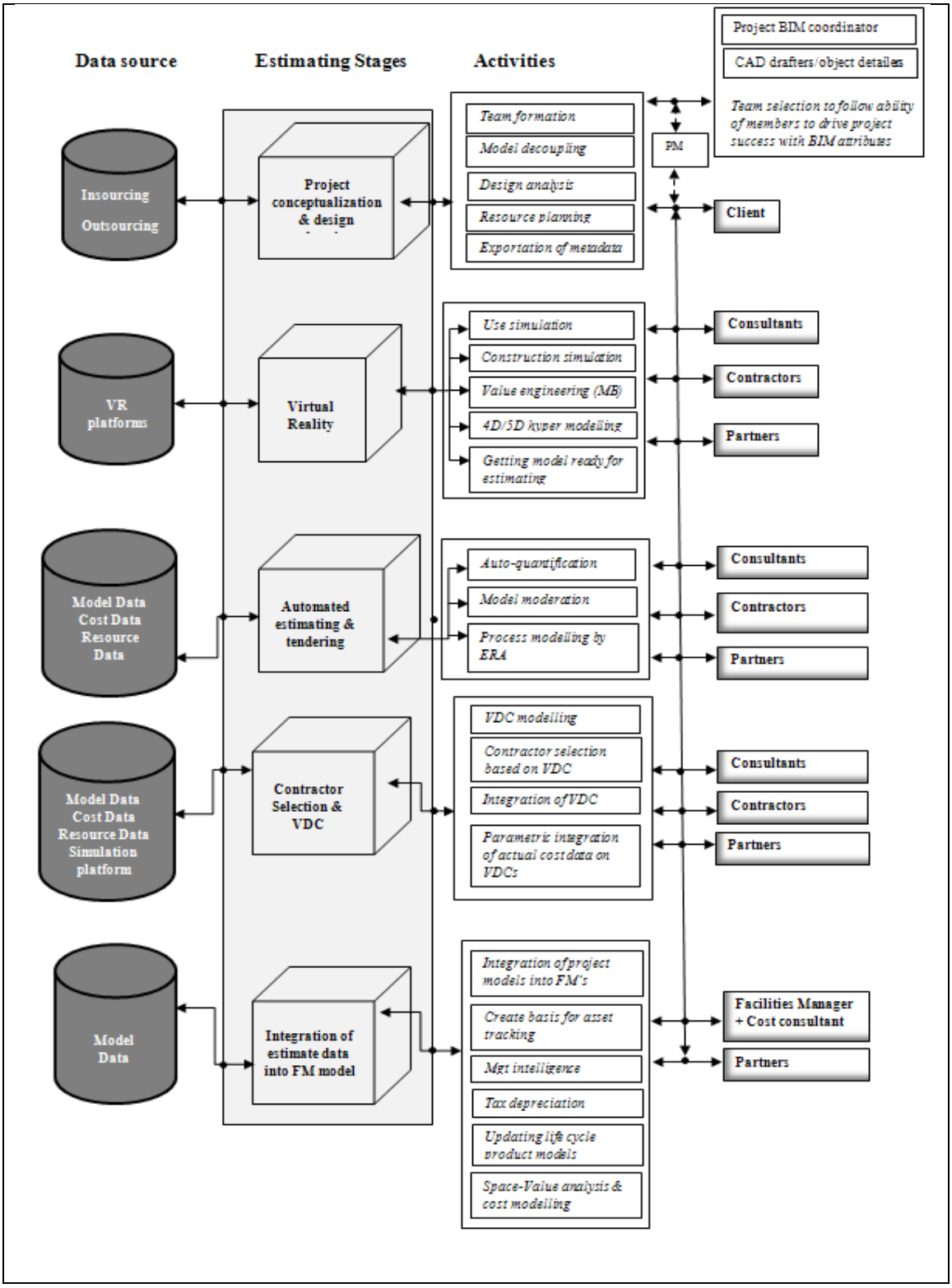


Figure 7.2: System architecture for estimating with BIM

Design analysis depends on streamlined technical requirements that enhance project feasibility and project economics. This activity is serviced by qualitative data such as checklists of information that facilitate the economic goals of a project. This also applies to the manner in which estimators break down BIM models for their estimates

(e.g. based on checklists for location-based decoupling of models, SMMs, trades, project elements, section and cashflow forecasts). It is the data from model de-coupling that will be used for resource planning, and this depends on quantitative (resource data and durations) and qualitative data (construction methods and risks descriptors).

- *Stage 2: 3D visualization and VR*. There are five activities in this stage viz. use simulation, construction simulation, value engineering, 4D/5D hyper modelling, and preparation of project models for estimating. How a facility will be used may be simulated using a conceptual project model (Yan, 2008) and simulations of construction activities can be based on the same model (Abdelkarim, 2010). Both of these raise questions about the value that each project component adds to project goals (Sabol, 2008). It is along the line (values contributed by project elements) that estimates are structured in relation to function and cashflow. When data from BIM models are related to timelines and conceptual costs, 4D and 5D models may be developed from 3D CAD systems.

  Invariably therefore, stages 1 and 2 have different outcomes: the former creates an enriched form of conventional estimating process whilst the latter gives rise to visual process models that clients and other stakeholders can create and view to aid their decision making. How these activities relate to each other is discussed in Section 7.3.2. Meanwhile, like Stage 1, all the activities in Stage 2 are supported by parametric databases.

- *Stage 3: Automated estimating and tendering*. There are three activities in this stage viz. auto-quantification, model moderation and process modelling by evaluated risk analysis (ERA). From BIM models, quantity data can be exported in different ways:
  - Based on a project model, without any form of moderation (e.g. by using translators or CSV data exports).
  - The grammar of the data modelling underlying BIM models can be trained to perform specific functions. This training leads to filtering model data in such a way that only the data required by estimators will the reported as the grammar has been translated.
  - Similarly, models can be moderated to reflect a particular reporting structure and construction approach. Data may also be export.

- Based on construction simulation (Stage 2), and different simulations of risk scenarios, model data may be exported from simulation platforms for estimating.

Automated estimates are developed when each of above-mentioned procedures are deployed with coded costs and resource databases. That is, the quantity data are coded to recognize coded cost and resource data from the databases supporting the estimating processes. In a similar manner, estimates may be coded to produce tender prices.

- *Stage 4: Contractor selection and VDC models:* based on the detailed designs used in estimating and tendering, comprehensive construction simulations can be developed by any of the potential parties to a proposed contract (e.g. VDC model from the perspective of client / project teams and VDC from the perspective of constructors). Both perspectives of VDC models relate to time, costs and tender so that tender analysis could be based on them. For example, by viewing contractors' VDC in line with their tender, clients are able to make judgments about the company that is most suitable to handle their projects. Thus, contractors can prepare different VDC models for tender (short and abstract) and for construction (for performance management). After tender, VDC from both perspectives can be integrated, and become the basis through which contract performance is measured (Kunz and Fischer, 2012).
- *Stage 5: Integration of estimate data into FM models.* There are six activities in this stage. First, as-built models become the baseline for FM models. Second, on the FM model, model data need to be secured. This involves mapping out assets to be tracked so that their cost indices can be monitored. Third, it is necessary to extend BIM models to different FM platforms to meet the performance goals of a project (Ballesty et al., 2007, Luciani, 2007, Olatunji and Sher, 2010b). The activities that follow are estimating periodic tax depreciations for constructed facilities, updating lifecycle cost model for projects and the continuous space-value analysis of projects. These last activities are likely to change in accordance with the various stages of a facility's life. Thus, they need to be monitored periodically.

With these system configurations, activities in BIM estimating relate to each other in particular ways that make process integration workable. Based on previous studies (such as (Underwood and Alshawi, 1997, Schenck and Wilson, 1994), these relationships can be

expressed in the form of EXPRESS-G models. As discussed in Section 7.3 this is the way that has been chosen to implement the process models represented in Section 6.5.

7.3 EXPRESS-G MODELS FOR THE PROCESS MODELS

According to ISO 10303-11, EXPRESS-G is a standard graphical notation for information models. It is a useful companion to the EXPRESS language for displaying entity and type definitions, relationships and cardinality. According to Underwood and Alshawi (1997), the EXPRESS-G modelling technique was developed by Schenck and Wilson (1994), and has been used for process modelling studies involving estimating (e.g. Underwood and Alshawi's (1997) work on the integration of pre-construction estimating and interim valuations). The main contribution of this study to existing knowledge on the application of EXPRESS-G is to extend Underwood and Alshawi's (1997) work to include activities in the very early stages of project development and those that contribute to facilities operation including construction estimating and valuation. The activities to be added are based on the findings of the statistical procedures reported in Section 6.6.

The EXPRESS-G models presented in this study are to be used by estimators and estimating organizations intending to implement BIM estimating systems in their businesses. Most importantly, they could be used to develop estimating applications based on the findings in Chapter 6 , especially the process models. The EXPRESS-G model uses specialized notations to represent activities in a sequence. There are rules in applying these, viz:

- *Entities:* Process models are made of variables (activities) called entities, and these relate with each other in a defined way. For the structured process models reported in this study, estimating activities, represented with rectangular boxes, are the entities.
- *Relationships between and within entities:* Each entity has two levels of relationships: relationship with another entity, and relationships with attributes (i.e. steps and objectives) within each activity' attributes. Relationships between entities are shown as line connectors; the start of the relationship is represented with a small circle – see Figures 7.3 and 7.5 for entity-level frameworks for estimating procedures in 3D CAD and BIM estimating respectively.
- *Variables and descriptive attributes:* Apart from entity level relationships, there are relationships within the attributes that describe each entity. For example, team formation is an activity, but there are several steps and objectives in it. While entity-

level relationships reflect the activities, secondary EXPRESS-G models are used to represent the descriptors of each activity- see Figures 7.4 and 7.6 for the secondary EXPRESS-G models for 3D CAD and BIM estimating respectively.

- *Multi-level relationships:* An entity may have more than one associated relationship. These relationships are determined by defined project requirements and can be adjusted by the different practice domains as they require.

7.3.1 EXPRESS-G models for 3D CAD estimating

The primary entities in EXPRESS-G models for 3D CAD estimating are indicated in Figure 7.3. Verbs have been used to specify how implementers apply to the databases explained in Section 7.2. Clearly, the model components relate differently to each other. For example, Figure 7.3 suggests that after team formation, estimators' involvement in the early stages of design can commence at the same time as site investigation. Moreover, it also suggests that feasibility budgeting, an integral part of feasibility study, can commence after site investigation and estimators' involvement in the early stages of design. Where a client requires estimators to provide comprehensive feasibility reports, feasibility budgets can commence once feasibility study has started; otherwise, preparation of feasibility budgets can commence immediately after site investigation.

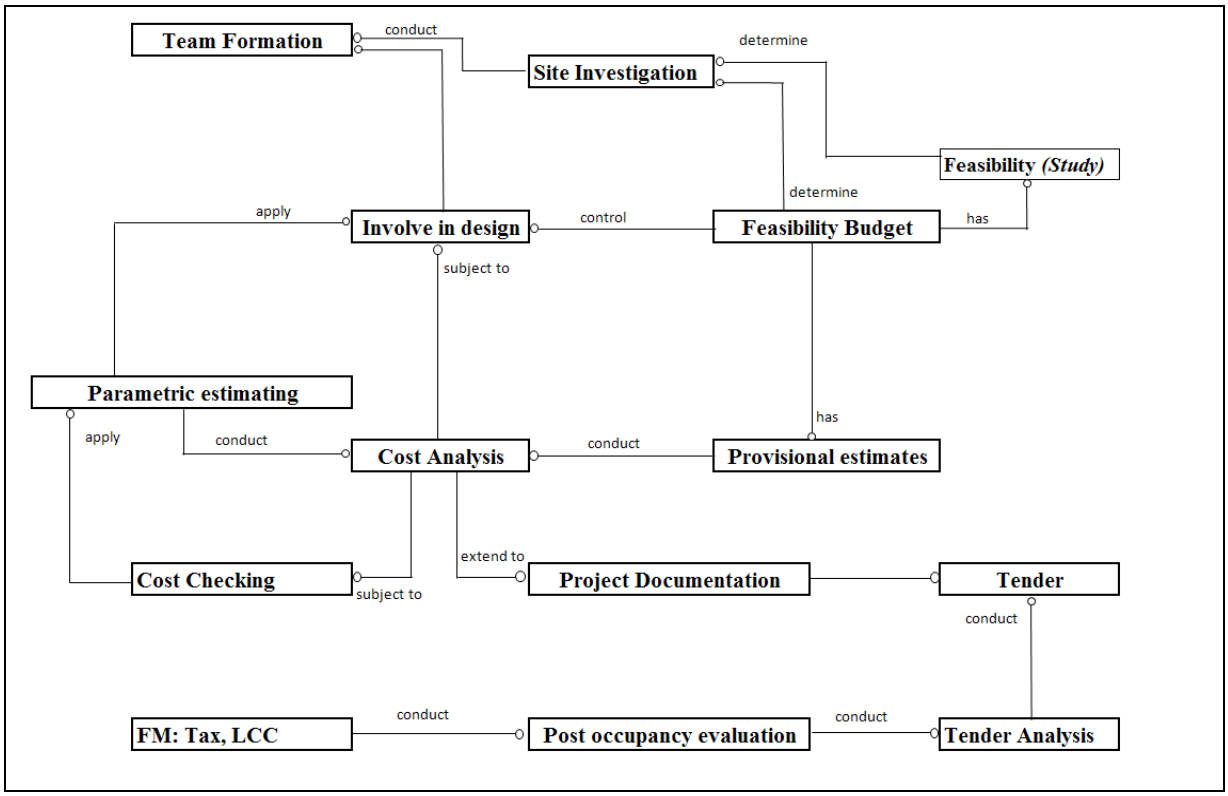


Figure 7.3: Primary entities of EXPRESS-G model for 3D CAD estimating

Figure 7.3 also shows that estimators require parametric estimating to provide cost guides during design. Provisional estimates are required to develop feasibility budgets. Cost analysis is central to provisional estimates and parametric estimating: estimators' involvement during design is to ensure that project budgets are not exceeded. Thus, estimators have to analyse design proposals and project budgets in line with provisional estimates before they apply their parametric cost data. This parametric costs data must be checked continuously as design processes advance. It is after this that designs are made ready for project documentation (DA), following which calls for tender and tender analyses take place. Analysis of data on 3D CAD estimating (Section 6.4) shows that clients may not involve independent estimators during construction unless disputes arise. They may also rely on estimates from contractors from the beginning of the project to the end. Thus, clients may only request cost re-evaluations at the end of a contract. Tax depreciations on constructed facilities also commences once construction has been completed.

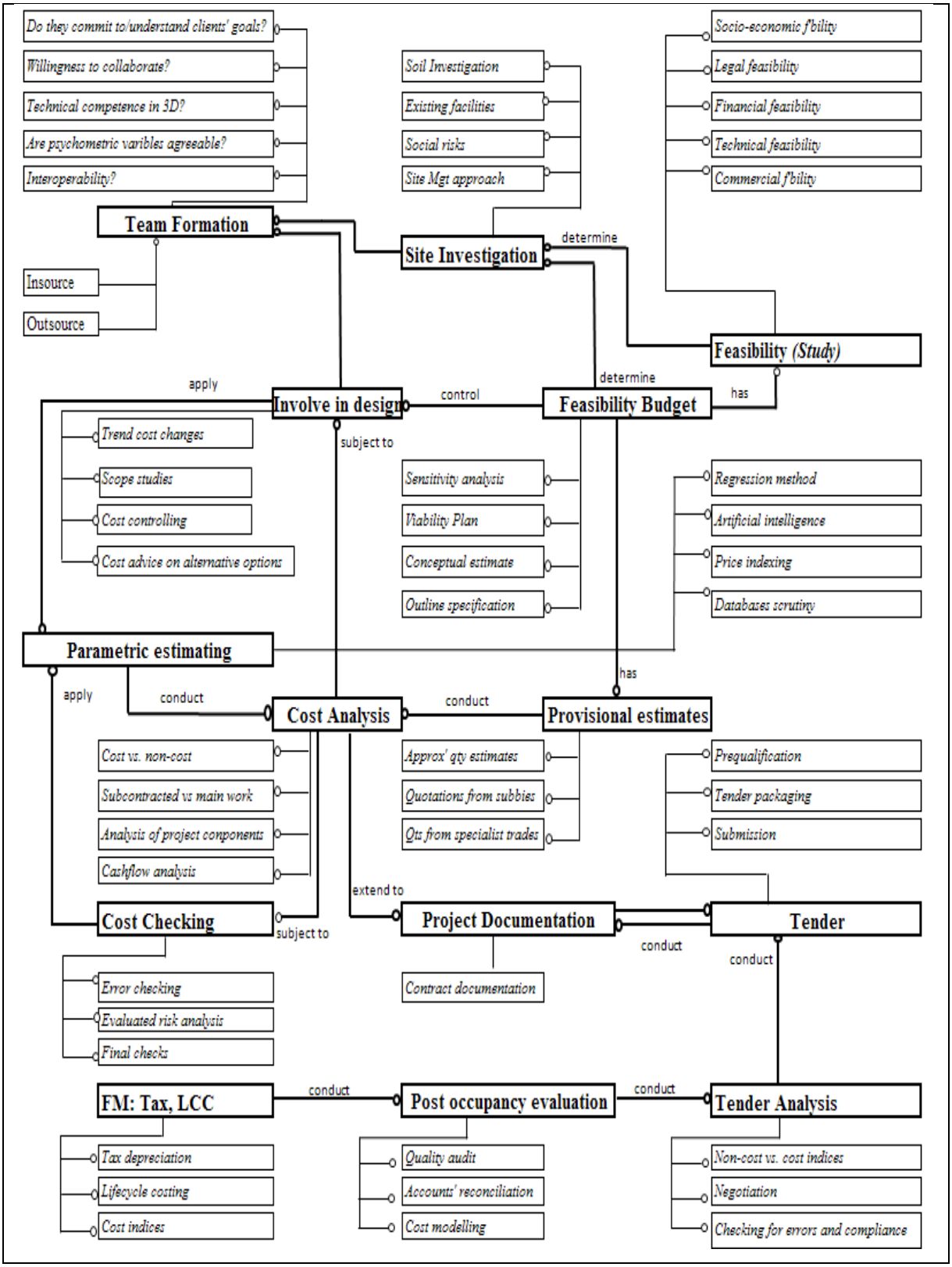


Figure 7.4: Indicative secondary entities for EXPRESS-G model for 3D CAD estimating

Figure 7.4 shows that each activity has attributes. It is the prerogative of estimators in each of the practice domains to define what these attributes are. For example, the attributes of team formation include understanding clients' goals, collaboration, familiarity with 3D,

psychometrics and interoperability. Site investigation is comprises soil investigation, state of existing facilities, evaluation of a project's social risks within its proposed location and site management approach. Feasibility budget also involves sensitivity analyses of conceptual budgets related to risks and the development of financial plans for projects indicating their viability. A feasibility budget also includes a conceptual estimate of a project as well as an outline specification of what the estimate is targeted to achieve. According to the International Cost Engineering Council (ICEC) (2002), estimators involvement during the early stages of design is based on the services they provide during project initiation. These include cost trending, scope studies, cost controlling and cost advice and alternative options.

Sample-attributes of other activities are shown in Figure 7.4. It is important to note the relationships within the attributes of each activity and between the activities. Figure 7.4 implies that although the estimating activities are networked, there are limited inter-activity relationships between the attributes. In the case of BIM estimating, the situation is different: there are more activities than in 3D CAD estimating and the attributes of an activity relate within and across other activities. The EXPRESS-G for BIM estimating is discussed in Section 7.3.2.

7.3.2 EXPRESS-G for BIM estimating

In BIM, the activities (also known as entities in EXPRESS-G modelling) leading to project estimates are different from 3D CAD (as illustrated in the analyses in Sections 6.2 – 6.6). The relationships between the primary entities are represented in Figure 7.5 which shows BIM estimating starting with clients and teams' interactions, followed by conceptual project models being presented by designers. When such a conceptual project model is analysed, estimators draft resource and execution plans in the form of milestones. Moreover, the metadata arising from the design analyses form the basis for auto-quantification and a simulation of how the proposed facility will be used. The design analysis model may also be used for value engineering i.e. analysing the contribution of each project element to the project goal, and comparing alternative options. Meanwhile, simulation of construction process options is based on how the resource and execution plans have been drafted; this and use simulation can be presented with virtual design construction (VDC) models.

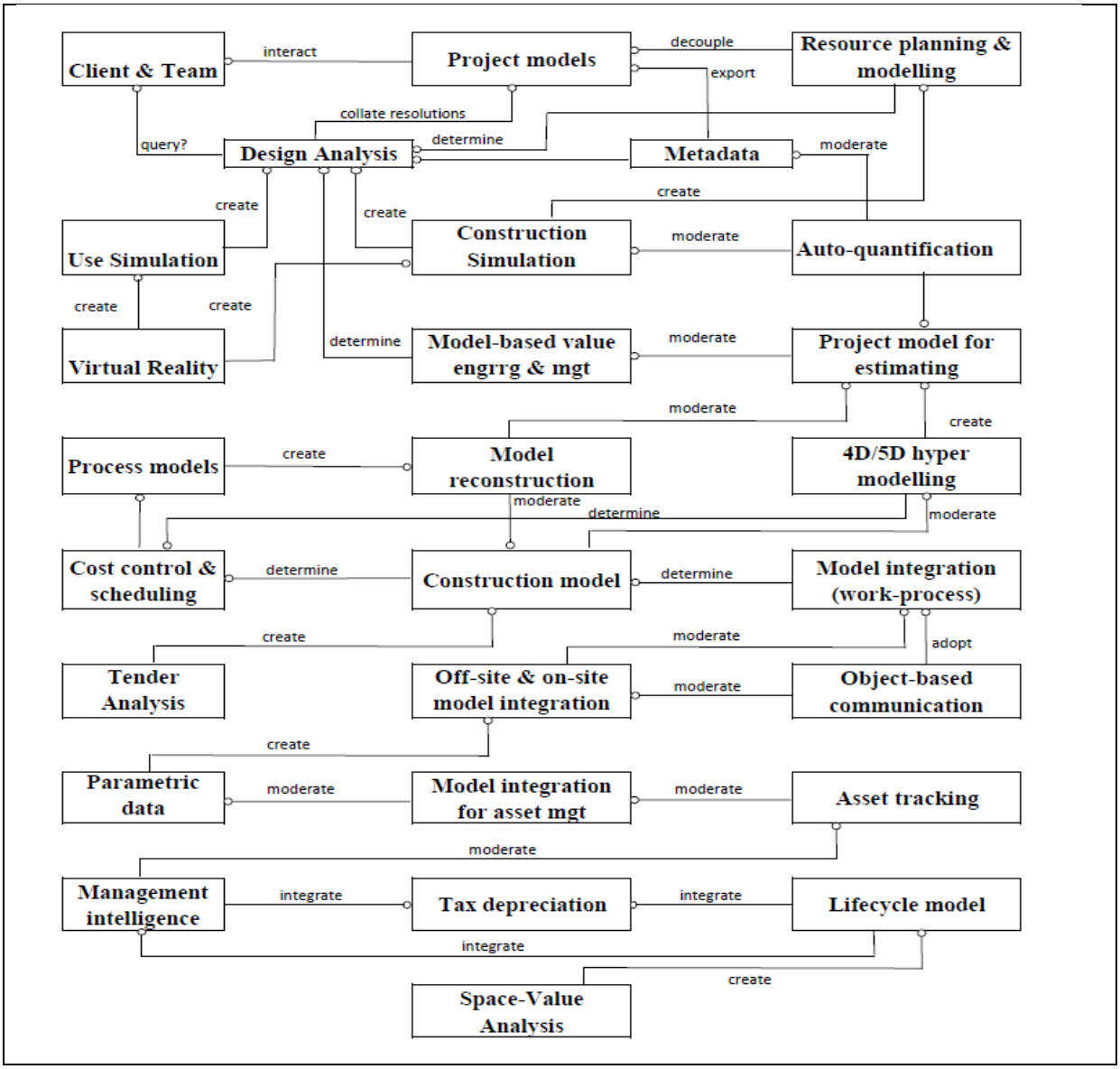


Figure 7.5: Primary entities of EXPRESS-G model for BIM estimating

As suggested in Figure 7.5, developing project models for estimating relies on the outcomes of value engineering and auto-quantification that have occurred in the course of the design. Such a project model can then be reconstructed to form indicative construction process models by each potential contract party – contractors will extract parts of this for tender; and contractor's and client's approaches to the construction process can be integrated into a single process model after tender. Meanwhile, when time and costs are integrated into the process models, 4D/5D hyper-models may be generated; and these may be used for cost control and scheduling. The same model (4D/5D hyper-models) may also be used to form construction models which contractors and/or clients will update continuously as work progresses. At the same time, the construction process model, which both clients and contractors have agreed, to will be updated and analysed to compare 'as-budgeted' to 'as-constructed' parameters. Where

different models apply to off-site and on-site construction, both models may be integrated into the 'as-constructed' model. The parametric cost data for a project is based on actual costs that are entered into the integrated construction model. After construction, all 'as-constructed' models may be integrated for asset management, and used for asset tracking and other facilities management operations, including tax depreciations, lifecycle cost modelling and space-value analysis.

Each of the aforementioned activities may be described by attributes that are specific to the business perspectives of each practice domain. Some indicative secondary descriptors for the activities in BIM estimating are presented in Figure 7.6 (see Appendix 4 – EXPRESS-G model for BIM estimating) and broken down to parts *a* – *e* to enhance presentation. Figure 7.6a shows the indicative secondary descriptors of the first five activities in BIM estimating in full. As this figure shows, the descriptors of team formation in BIM include evaluation of the cost component of the team formation e.g. calculating the cost value of the intellectual property that is exchanged during BIM implementation. Also included is the cost of formulating the frameworks for BIM implementation; including training and creating policy guidelines specific to the project scenario at hand. These descriptors relate to those of the preliminary estimation of conceptual project models; which includes estimator's conceptualizations of project goals (by comparing direct project costs to secondary cost variables e.g. social costs, environmental costs and so forth). They also include establishing value streams for a project and determining the extent of present and future expenditure required to match the targeted value streams. These descriptors relate to other activities' attributes: conceptual resource planning, design analysis, proposed use simulation and value-space analysis. For example, understanding clients' intentions through conceptual project models helps estimators explore relationships between function, value and cost (Yaman and Tas, 2007). Similarly, understanding project goals from conceptual project models also enables estimators to ask questions about omissions and clashes in a model as well as carry out other functions during design analysis.

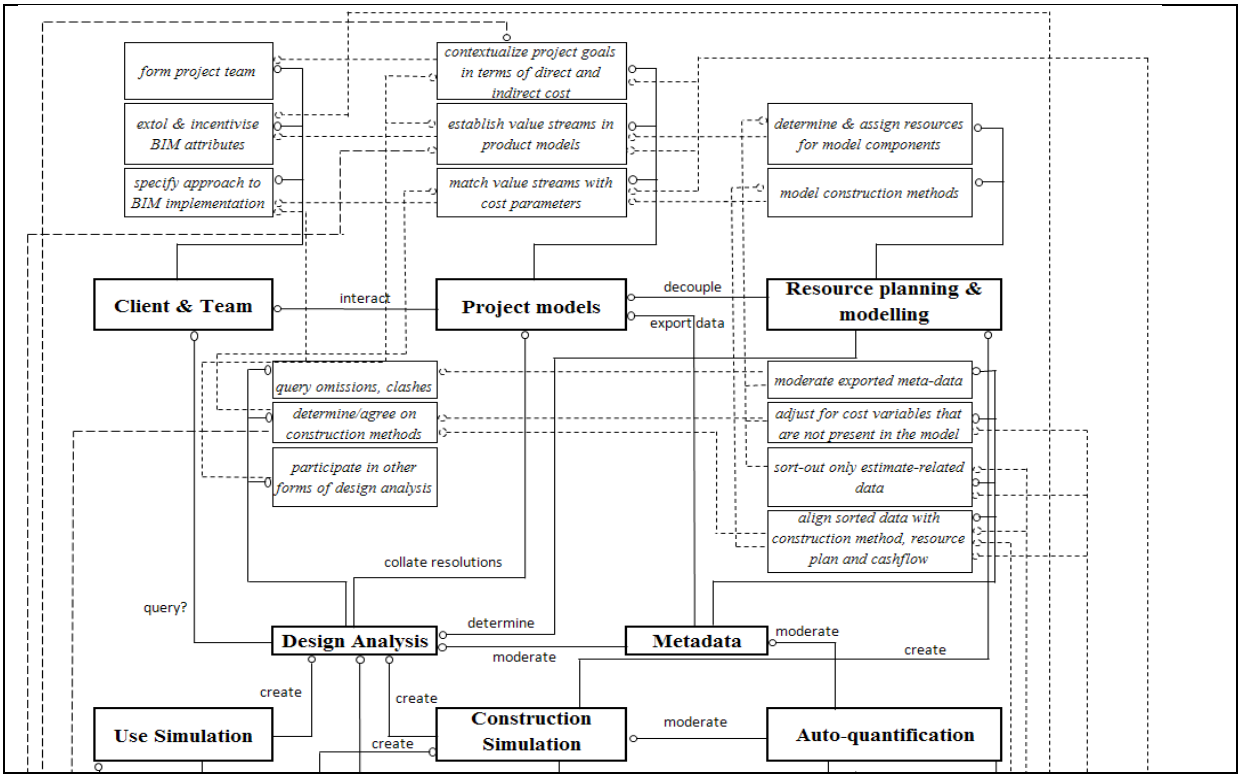


Figure 7.6a: Indicative descriptors of the first five activities in BIM estimating

Only two indicative secondary attributes (resource planning and modelling) are included in Figure 7.6a. Both descriptors respond to establishing value streams in conceptual project models and how the models are moderated to create metadata for quantity measurement and construction simulation. For example, for design models to be reconstructed appropriately into specific construction approaches, this reconstruction, and how model components are resourced, should relate to project value streams, without compromising cost limits (Fontinini and Picchi, 2004). Moreover, when designs are analysed, an estimator's goal is to ensure that estimates and the construction methods they represent agree with client's goals. These activities are not stand-alone activities; they correspond directly to the ways in which metadata from models are structured for estimating. Where some cost-related variables are not represented, are provisionally represented or are misrepresented in the conceptual models, consideration need to be made by allowing floats in the resources and in how the project cashflow has been planned.

In Figure 7.6b, the attributes of another five activities in BIM estimating are presented. This figure shows the relationships between the secondary descriptors of use simulation, construction simulation, auto-quantification, 3D visualization and virtual reality, model-based

value engineering and restructured process model for estimating. The descriptors of use simulation include identifying the factors influencing clients' satisfaction, cost parameters in simulation agents and the relationships between function, cost and value. As explained earlier in this section, these variables apply to how value streams have been mapped-out in the conceptual models. They also apply to how auto-quantification has been structured from model metadata, and take into consideration the potential contract conditions and cashflow mechanisms that underlie the proposed construction processes being estimated.

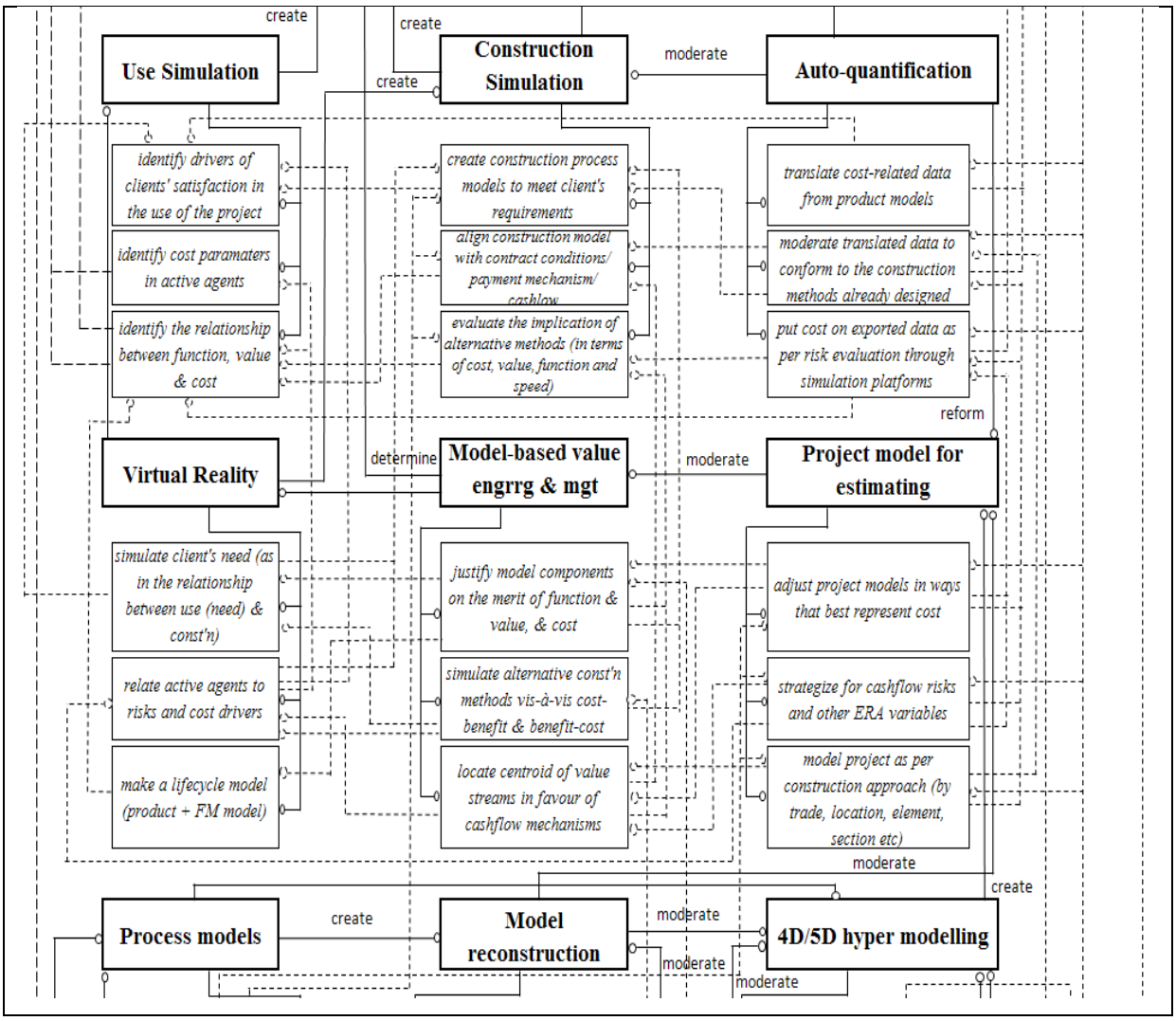


Figure 7.6b: Indicative descriptors of another six activities in BIM estimating

As shown in Figure 7.6b, construction simulation also relates to use simulation through understanding of project goals and the relationships between function value and cost. This is important because alternative construction methods can be evaluated on the basis of project goals of function, cost and speed. The construction simulation descriptors also relate to those of other activities; including virtual reality, value management and how project models may

have been restructured for estimating. For example, when VDC models are created for a project, these could entail creating lifecycle models where both use and construction scenarios are represented. The activities represented in VDC help estimators to visualise construction-associated risks and how they are likely to impact on project cashflow.

Figure 7.6c shows descriptors of another set of six activities in BIM estimating. These include attributes of process models (short simulation clips showing construction approaches, together with their tender), VDCs showing more detailed construction methods (both client and contractors could have separate versions of this) and 4D/5D models showing the relationships between the design models, construction duration and costs. Three other activities are shown in Figure 7.6c: the descriptors of cost control and scheduling, (actual) construction models and integrated models on which progress are measured against 'as-planned'.

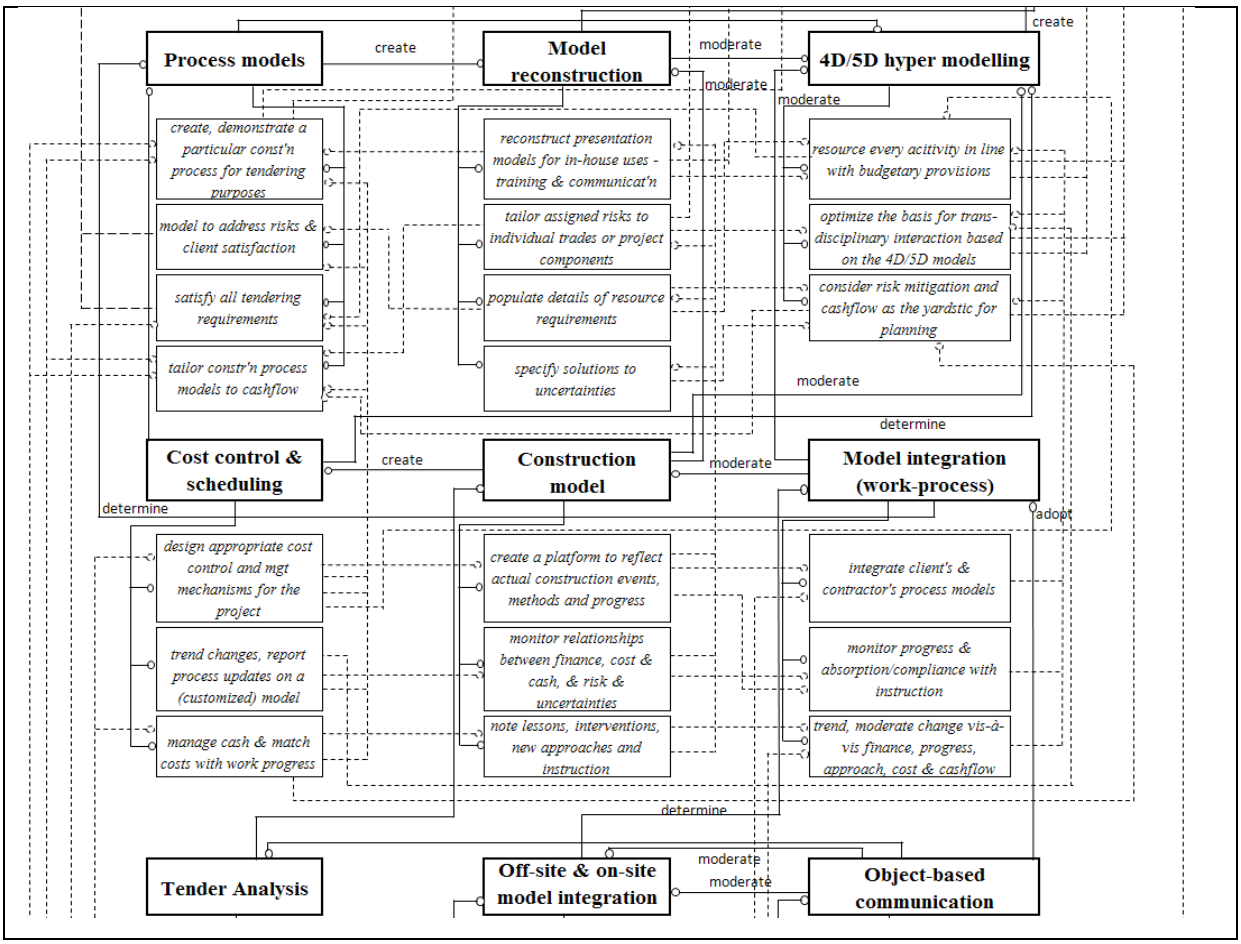


Figure 7.6c: Indicate descriptors of the middle set of six activities in BIM estimating

Figure 7.6c suggests that meeting client's requirement is vital to constructing process models for tendering purposes. These models relate to client's goals in how the potential use, and

construction, of a facility has been simulated, based on the conceptual project models discussed earlier. Meanwhile, these short simulation clips of indicative construction processes are a part of model redevelopment which individual parties in project implementation would have prepared prior to tender. These models are used for in-house communication and training, and to simulate possible solutions against potential risks and uncertainties. Resources, and the associated costs and duration of construction relate to the model reconstruction that takes into account clients' goals and construction risks. Information from 4D/5D models helps estimators to control and manage production costs, and monitor changes when they occur.

Meanwhile the process models prepared by each project party needs to be integrated as a basis for project execution. This is to demonstrate that stakeholders' views are thoroughly integrated before construction work commences. Actual progress can then be measured against that originally planned and changes in cashflow assessed. Each party may choose to keep in-house construction models, or only update when necessary.

In Figure 7.6d, indicative descriptors of the top six of the last 10 activities in BIM estimating are shown. This starts with tender analysis, an activity which describes how process models from candidate contractors, together with their tender, are reviewed and adjudged to meet clients' goals for projects. The descriptors in this activity therefore relate to how project goals and value streams have been understood in previous activities. Each party's in-house construction models and the integrated model upon which work progress is assessed take into consideration how off-site and on-site models have been integrated. Clients are usually interested in monitoring this while judging whether contractors are actually conforming to contractual instructions. This is on the same basis that communications are based between client and contractors, and between contractors and fabricators.

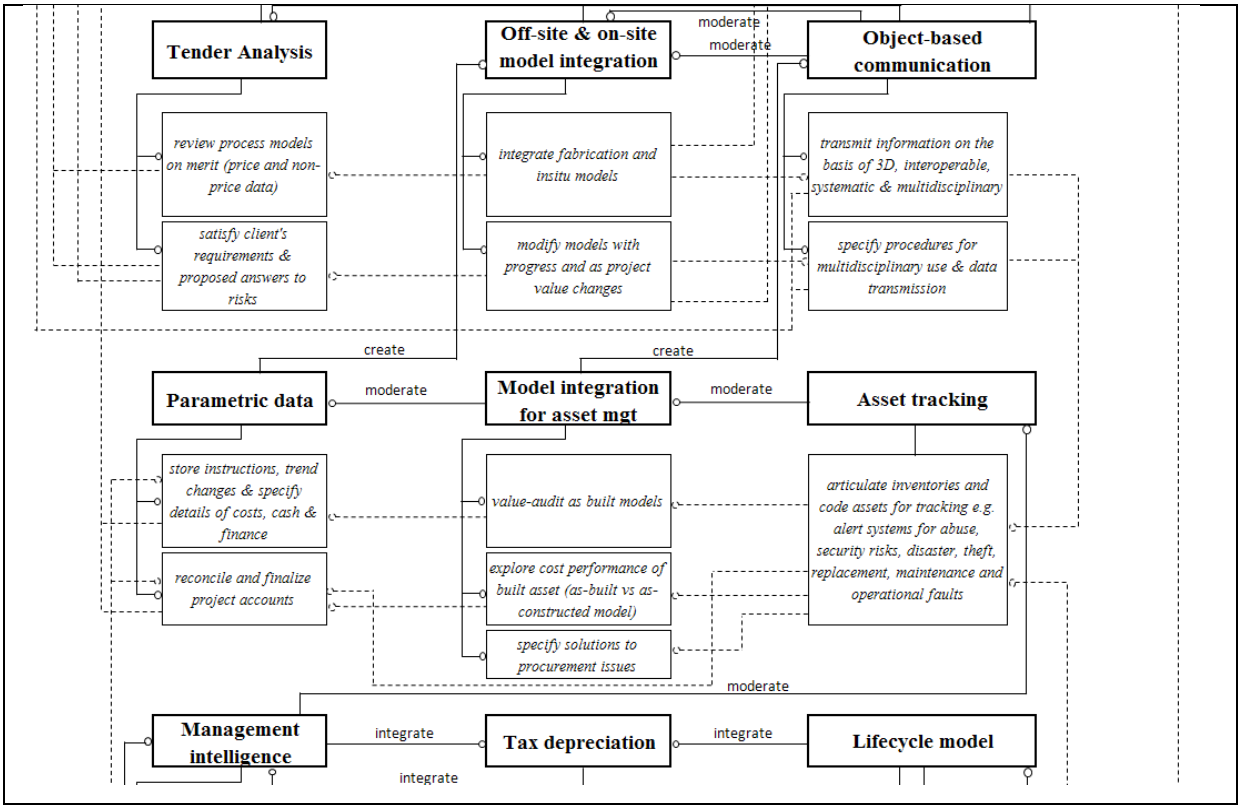


Figure 7.6d: Indicative descriptors of the top six of the last 10 activities in BIM

Cost (and financial) data from the main integrated model containing every aspect of the work as planned, as communicated and as executed constitute the cost database for a project. This is crucial for reconciling project accounts and for future planning. Moreover, it is also expedient to establish how cost data are embedded into the integrated model for asset tracking and management purposes. This includes the as-built values of every component of the constructed facility and how these may be tracked in the future, including corrective and protective interventions.

The remaining descriptors of BIM estimating activities are shown in Figure 7.6e. This includes estimating roles in facilities management procedures, which include tracking and managing post-construction procurements and relating these to project history (thus providing history of clients' project goals (Ballesty et al., 2007). Tax depreciation updates and lifecycle cost models of the facility are based on this. For benchmarking and future investments decisions, the relationships between constructed space and earned value of a project can be analysed across the different stages of the project. This includes matching clients' requirements with observed value streams, costs and finance.

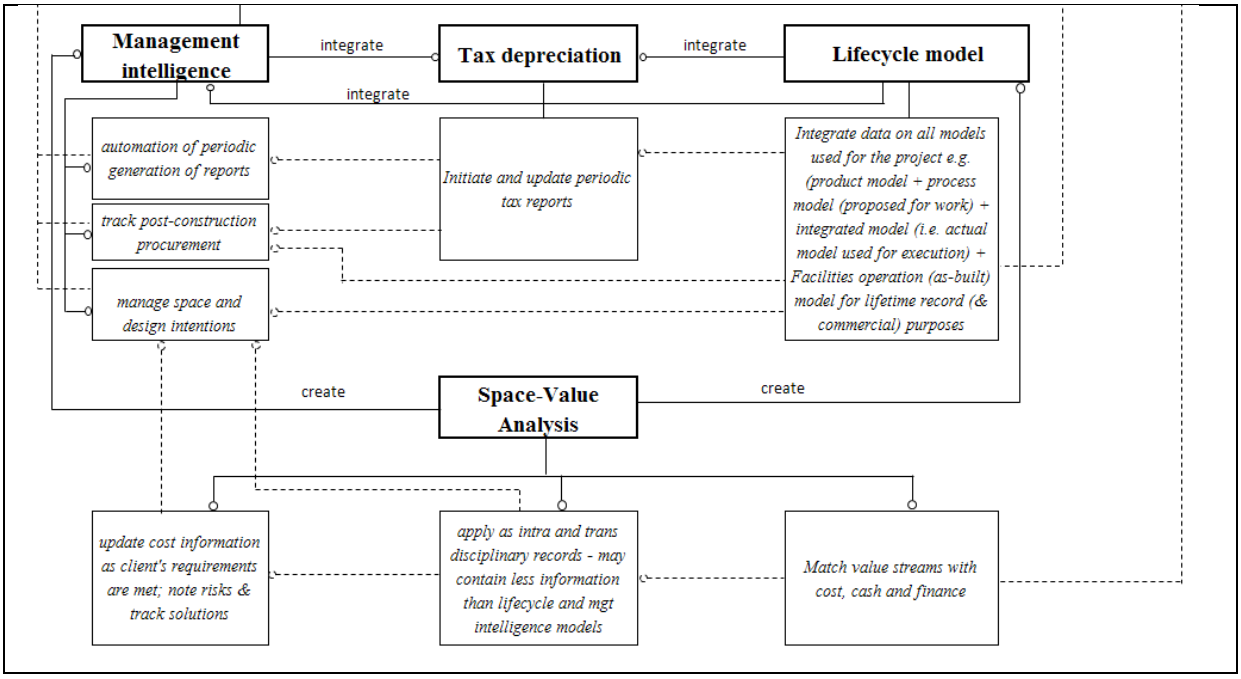


Figure 7.6e: Indicative descriptors of the last four activities in BIM estimating

An indicative understanding of the attributes of 3D CAD and BIM estimating has been presented in this section in the form of secondary EXPRESS-G models. The attributes included in these modules can be populated and applied in different estimating practices based on specific project needs. However, the variables in both domains (i.e. 3D CAD and BIM) can be advanced for application development. The primary basis for this is discussed in integrated definition format in Section 7.4.

7.4 INTEGRATION DEFINITION FORMAT (IDEF0) MODELS

This section investigates how the findings in Sections 6.3 – 6.5 apply in enterprise modelling and application development in the light of the process models developed for BIM and 3D CAD estimating. Studies on enterprise modelling have conceptualized information systems in businesses as a representation of organization behaviour (Vergidis et al., 2008, Kassem et al., 2011). As argued in Chapters 2 and 3, the relationships between information systems and construction business behaviour, and estimating practice are commercially sensitive and critical.

Different estimating practices exhibit different business behaviours. As indicated in Section 6.1, all of the estimating organizations in this study deployed different applications. Many were customized and some were commercial. This subsection proposes two Integration Definition (IDEF0) format models, one for 3D CAD and the other for BIM estimating activities. These models are preliminary: they propose foundational advice on how the

process models developed in this study can be implemented as applications. They can also be used for hands-on-job training, for curriculum development for BIM estimating and as a springboard for future studies. Meanwhile, it is vital for users of the models to research further forms of these IDEF0 formats as may suit their implementation strategies.

IDEF0 models are not new to construction estimating and BIM. In Underwood and Alshawi's (1997) work, they were used to model information systems for a particular pattern of organizational behaviour dealing with pre-construction and construction estimating. Although the design platform used in Underwood and Alshawi's work is unknown, arguments by Aranda-Mena et al (2009) on the commercial application of BIM suggest that Underwood and Alshawi's procedures work well with 3D CAD and BIM, and can be extended to estimating activities throughout a project's development lifecycle. Kassem et al (2011) further explained how business processes are represented in IDEF0 models with a particular focus on information management options in BIM and 3D CAD. Thus this additional evidence adds weight to the merit of this approach.

The overriding aim of IDEF0 models is to define the possible outcomes arising from each estimating stage and to identify the environments under which these outcomes are likely to generate satisfactory outcomes for estimators. To simplify the interpretation of IDEF0 models, the common four directions of flow in IDEF0 models are explained below:

- Horizontal **inward** arrows pointing into a node/entity (from the left) signifying input. The variables represented as entities are the same as those in the centroid models for 3D CAD and BIM estimating.

- Horizontal **outward** arrow pointing out of a node/entity (to the right) showing outputs generated from the inputs. This is shown as outcomes of inputs when they have been acted upon by system controls within the entity.

- Vertical **downward** arrow pointing into a node/entity from the top showing control measures though which outcomes are generated. These entities are sourced from literature to strengthen the technical applications of the findings of this study.

- Vertical **upward** arrow pointing into a node/entity from the bottom showing mechanisms through which outcomes are generated. They are sourced from literature and industry interactions.

7.4.1 Integration Definition Format (IDEF0) for 3D CAD estimating

Figure 7.7 shows that the first estimating activity in the 3D paradigm, *v1*, team formation and interaction, is preceded by f_0 , project's goals and targets. The relationship between *v1* and f_0 is such that workable outcomes will only arise from *v1* if *v1* and f_0 are moderated by f_1 (defined client's requirements) and f_2 (thorough risks analysis). Several studies have supported the notion that constrution estimates are not generated by superficial arithmetic operations, but by in-depth analysis of clients' needs and the risks involved in achieving them (Harris et al., 2006, Kometa et al., 1994, Sinclair et al., 2002). This implies the expediency of control measures in IDEF0 models to reinforce system outcomes from one stage to another.

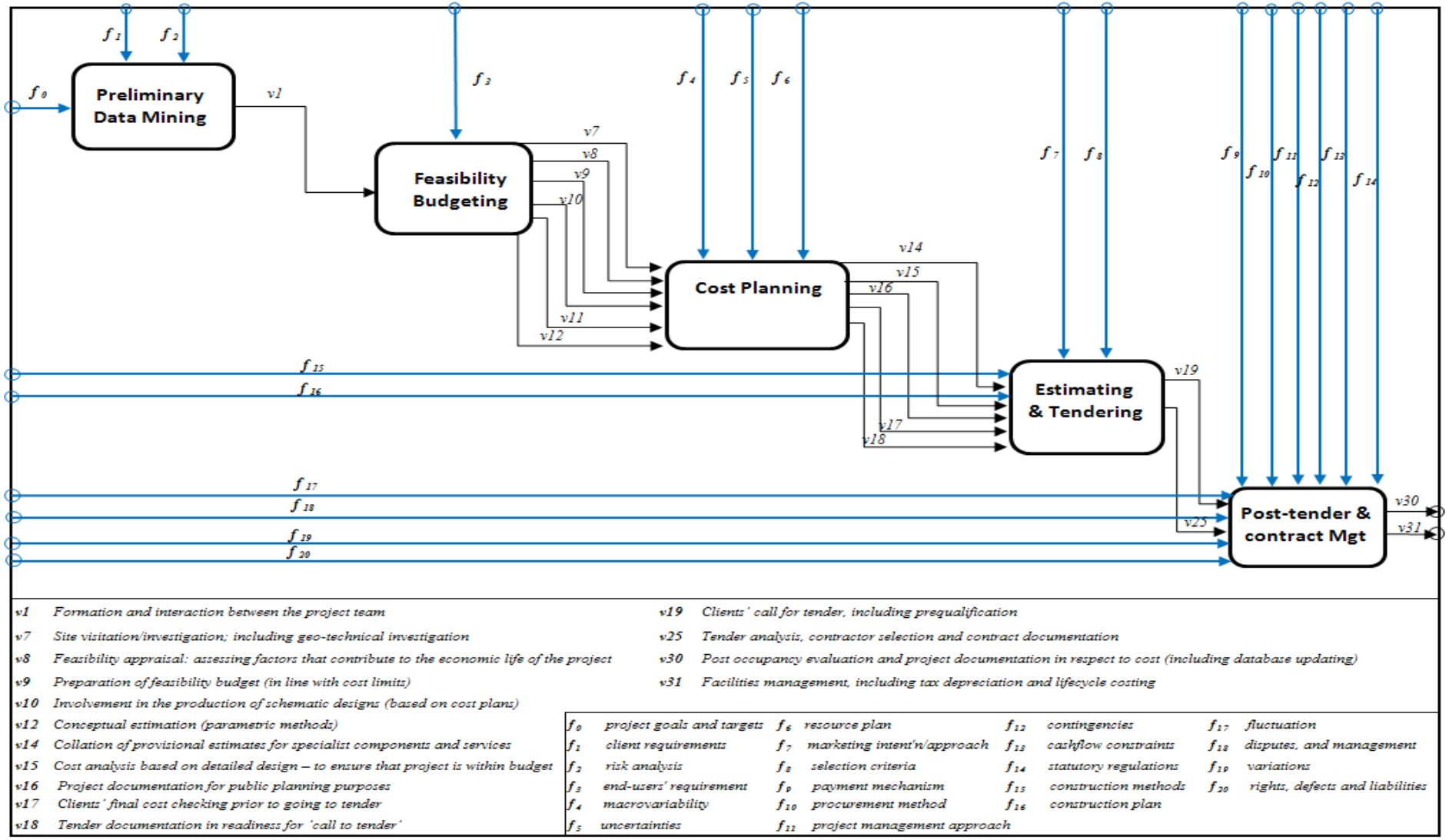


Figure 7.7: IDEF0 (A0) model descriptors of 3D CAD estimating

The second activity, *v2* (site investigation), when undertaken in line with end-users' requirements, strengthens the basis for generating workable estimates (Info Tech, 2009). This is because estimators are able to evaluate site constraints and opportunities within the proposed project location while estimating. Site investigation also stengthens the outcomes of *v7 – 12* (i.e. from feasibility appraisal and budget to conceptual estimation), upon which cost planning operations are based. These activities are controlled by client's requirements (Acharya et al., 2006b, Kamara et al., 2002, Koppinen et al., 2008). The outcomes of cost planning operations are also further reinforced when they are considered in line with macro-economic variability (f_4) (Baloi and Price, 2003), uncertainities (f_5) (Olawale and Sun, 2010)) and constraints in resource plans (f_5) (Shehu and Akintoye, 2010). The resultant *v14-18* leads to robust outcomes for the final stages of pre-construction estimating and tendering.

When contractors' marketing approaches during bidding (f_7) (see (Dorée, 2004, Green, 1989, Skitmore and Smyth, 2009)) are considered in these variables (v14-18), and clients' non-cost selection criteria for contractors (f_8), the outcomes are suitable for post-tender estimates (Anagnostopoulos and Vavatsikos, 2006, Churchill, 1979, Drew and Skitmore, 1993, Skitmore and Smyth, 2009, Walker and Ruekert, 1987). Moreover, the outcomes of *v14-18* are also reinforced with a thorough review of possible construction methods (f_{15}) and the design of a definitive construction plan (f_{16}) (Yizhe and Youjie, 1992). The resultant outcome of this strengthens the basis on how prequalification variables are designed (*v19*) and how tenders are analyzed (*v25*) (Brook, 2008, Green, 1989). The outcomes arising from 3D CAD estimating up to this point are sufficiently robust in their impact on value-audit/post occupancy assessment of the built asset (*v30*) and tax depreciation (*v31*). The importance of many controlling factors on *v19* and *v25* are documented in literature. For example, Christodoulou (2008) observes that construction estimates can only be reliable when considerations for payment mechanisms (f_9) are rationally included into estimates. Wong et al (2004) also documented the impact of procurement methods (f_{10}) on estimates. Other factors to consider are project management approaches (f_{11}) (Levy, 2006), contingencies (f_{12}) (Baccarini, 2005), cashflow contraints (f_{13}) (Green, 1989) and statutory regulations (of clients/governemnt (f_{14}) (Winch, 2001, 2006).

Moreover, there are other factors that could be considered to make estimates workable. These include fluctuations in pricing regimes (f_{17}) (Olatunji, 2010c), disputes and their management (f_{18}) (Younis et al., 2008), variations (f_{19}) (Underwood and Alshawi, 1997) and contract parties rights, defects in works and liabilities (f_{20}) (Ng et al., 2004b). These factors are

different from project to project and from place to place. Hence, process control measures for implementing the nominated 3D CAD estimating models can be built around project-based measures.

The situation in BIM estimating is substantially different from 3D CAD's. Using the same controlling and moderation mechanisms, IDEF0 models for BIM estimating is discussed below in Section 7.4.2.

7.4.2 Integration Definition Format (IDEF0) for BIM estimating

The difference between 3D CAD estimating and BIM's has been established through statistical analyses and the implementation of research findings (from Sections 6.2 – 7.3). The IDEF0 model for BIM estimating is presented Figure 7.8. Although the initial input in both regimes starts with f_0 (creation of project goals and targets), BIM estimating requires fewer control factors than 3D CAD, and can accommodate a more robust value mechanism through visualization, simulation, multi-disciplinary collaboration, integration and parametricism. For example, fundamentally, the essence of deploying BIM is to optimize value in accordance with client's requirements (f_1). In 3D CAD, as acknowledged in several studies (including. (Gu et al., 2008, Shen et al., 2010b)), the framework for collaboration is weak. Thus, as clients' requirements are driven between individual disciplines, 3D CAD estimating is susceptible to process dysfunctions arising from fragmentation. However, with collaborative interaction between clients and project team members, it is reasonable to assume that the first estimating stage in BIM, project conceptualization, has addressed additional steps to be taken by estimators to capture client's requirements independently.

Furthermore, BIM estimating creates a novel approach to risk analysis (f_2): project development can be simulated and visualized through virtual representations both to predict construction processes and to model actual construction events. Following risk analysis during project conceptualization, collaboration reinforces all estimating activities in the first stage of BIM estimating: collaborative interaction between the project team and client (*v1*), model decoupling to define cost parameters (*v2*), design analysis (*v4*), resource modelling (*v5*) and deployment of metadata from a wide range of applications (*v6*).

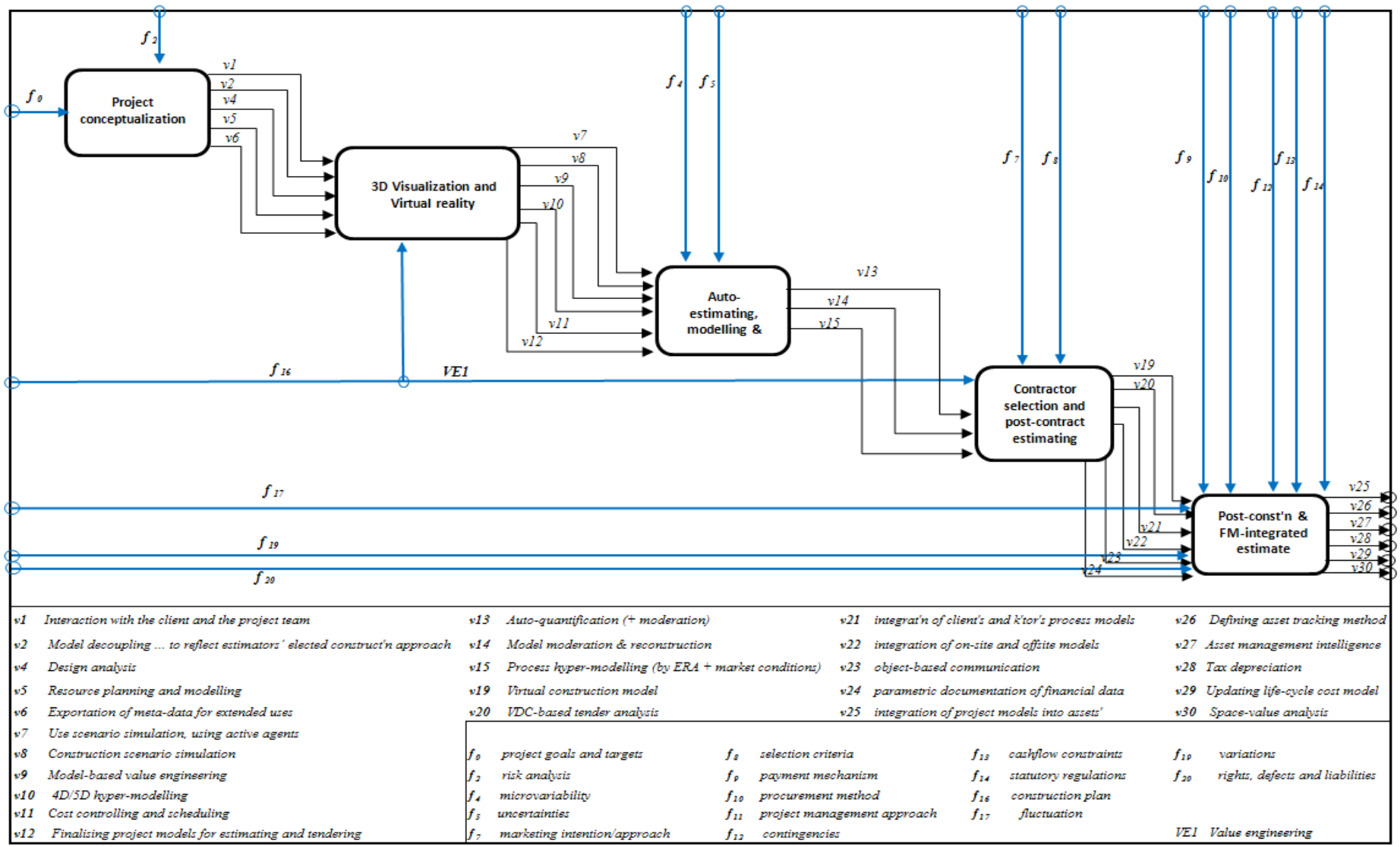


Figure 7.8: IDEF0 model for BIM estimating

A control measure is suggested while the Stage activities advance to Stage 2 (3D visualization and VR). It is often necessary to define a specific spectrum of value engineering approaches when VR activities (*v7-12*) are conducted to enhance estimating. Such specificity is required to define whether soft or hard value engineering will be appropriate for the estimating activities at this stage (Bártolo, 2000, Barton, 2000, Fontinini and Picchi, 2004). With this, value streams are explored through different options in use simulations (*v7*), construction methods' simulation (*v8*), object-based value engineering (*v9*), 4D and 5D hyper modelling (*v10*), cost controlling and scheduling (*v11*), and how project models are finalized for conclusive estimating and tendering (v*12*).

During Stage 3 (Automated estimating and tendering), the outcomes of virtual reality are critical to decision making. It is essential to considering macro-variability (f_4) and uncertainties (f_5) at this stage while utilising auto-quantification data (*v13*), data from model decomposition and reconstruction (*v14*) and when developing process hyper-models (*v15*) (Baloi and Price, 2003). When these activities are supplemented with detailed construction plans (f_{16}), objective decisions can be taken on how selection criteria are set for contractors and how construction costs are controlled and managed. The resultant *v25 – v30* are sufficiently reliable for estimating operations during facilities management when variations (f_{17}), fluctuations (f_{18}) and statutory rights and liabilities (f_{19}) are integrated into *v19 – v24*, and controlled by payment mechanisms (f_9), cost-related considerations in procurement methods (f_{10}), project management approaches (f_{12}), payment mechanisms (f_{13}) and statutory regulations (f_{14}). The relevance of the controlling factors (from $f_{16} – f_{20}$) in BIM estimating is as discussed under 3D CAD estimating in Section 7.4.1.

7.5 SUMMARY: IMPLEMENTATION OF PROCESS MODELS FOR 3D-CAD AND BIM ESTIMATING

Process models have been developed through statistical procedures as reported in Chapter 6. These models apply to estimating outcomes in the various practice domains differently. In this chapter, applications of the process models to business management constructs are presented from three perspectives. First, key characteristics for system architectures are presented for developing applications for the process models. The nature of the variables in the different databases that are required for 3D CAD and BIM estimating were identified.

Furthermore, EXPRESS-G models were used to align estimating activities in 3D CAD and BIM centroid models. The EXPRESS-G approach used in this study illustrated the relationships between the activities in the process models in terms of the primary and secondary descriptors. The illustrations simplified the implementation of the process models for application development, business development, training, teaching and research, and for developing structures for valuing estimating services in 3D CAD and BIM estimating. Figures 7.3 and 7.4 were used to show that 3D CAD estimating processes are largely fragmented, whilst Figures 7.5 and 7.6 were used to show that there are strong integrated relationships within and across the descriptors of each activity in BIM estimating. These relationships provide guides when developing applications for estimating with both 3D CAD and BIM.

The process models were also presented in primary IDEF0 formats. Figures 7.7 and 7.8 were used to show the control factors under which outcomes of estimating activities can be strengthened in 3D CAD and BIM respectively. Illustrations in the figures suggest that BIM estimating has fewer control mechanisms and more estimating activities than 3D CAD estimating. In all, this chapter has explained how the findings from the statistical procedures in Chapter 6 can be implemented and advanced for application development. Other findings of the research, in relation to the research questions, aim and objectives are discussed in Chapter 8.

8 CONCLUSIONS

8.0 CONCLUSIONS

8.1 INTRODUCTION

This study has achieved the objectives stated in Section 1.4, and further discussed in Section 8.2. The purpose of this chapter is to explain how the research objectives have achieved the study aim, and how the study aim has addressed the questions the study has sought to answer. Through an in-depth review of literature, the study established that:

- Information Technology (IT) has had critical impact not just on estimating practices but on business cultures and professional service delivery in the construction industry. With or without IT, there are different business perspectives of estimating goals, processes and outcomes. This study used four constructs of organizational modelling to categorise construction estimating into four practice domains viz Model (MModel) to represent client organizations, Divisional model (DModel) to represent contracting organizations, Functional-unit model (FModel) to represent consulting practices and Networked model (NModel) to represent specialized project delivery platforms (SPDPs).
- Integrity of design data is critical to achieving estimating goals. Thus, this study reviewed key functional characteristics of different IT-based design platforms to identify critical enablers of satisfaction in estimating outcomes. In particular, this study has established the impact of BIM on the accuracy of design data as well as the impact of BIM deliverables on estimating processes.

There are four additional sections in this chapter:

- Section 8.2 presents a summary of the outcomes of this study, and aligns the research objectives with the study aim. It then describes how the study aim has answered the research questions.
- Section 8.3 outlines the benefits of the research findings.
- Section 8.4 discusses the recommendations of the research, and
- Section 8.5 specifies areas for further studies.

8.2 STUDY ACHIEVEMENTS

The four objectives of this study have been stated in Section 1.4:

The target of Objective 1 was to explore the activities required to develop workable estimates in different practice domains, using 3D CAD and BIM in form of process models. This objective was achieved by using multiple research methods to explore how estimating is conducted by estimators in different practice domains. To address this objective, the researcher interacted with estimating software developers whose products are 3D CAD and BIM compliant. Five software developers were interviewed from four software development companies. Moreover, four interactive sessions were observed where the software developers made presentations before 77 subject-experts on the impact of BIM on their business processes. Following this, representatives from two organizations from each of the four business models (identified in Section 8.1) were interviewed and their organizations' perspectives on estimating procedures and outcomes were explored. 17 highly experienced participants took part in the focus group discussions and interviews and were able to describe the activities leading to 3D CAD and BIM estimating outcomes in their organizations. Data from these sessions were subsequently coded and used to articulate estimating stages and activities (Sections 6.3 and 6.4). Ultimately, five stages were identified in both 3D CAD and BIM. 31 activities were identified in 3D CAD estimating and 30 activities in BIM estimating.

The focus of Objective 2 was to investigate the degree of association and reliability of the estimating activities identified for Objective 1 as the parameters for developing process models for the different estimating practice domains. This was achieved by quantising participants' emphases on these activities. These emphases indicated participants' opinions of the importance of these activities. This made it possible to rate each of the estimating activities and stages in 3D CAD and BIM for each discussion session and practice domain. With these ratings, statistical procedures were used to measure the degrees of association between the activities and to ascertain whether these associations were sufficiently reliable to create representative (centroid) process models for both 3D CAD and BIM estimating. ANOVA measures of central dispersion, as well as Fisher-Hayter (F-H) multiple comparisons were able to highlight significant internal consistency in the activities of both 3D CAD and BIM estimating. When these consistencies were tested for reliability using Cronbach's Alpha

reliability estimate procedures, analyses showed that more than 50% of the activities in 3D CAD estimating exhibited weak correlation (i.e. did not add value to estimating outcomes) and thus cannot be included in the process models for 3D CAD estimating. However, using the same procedure, 26 out of 30 activities in BIM estimating were statistically significant and were thus included in the BIM estimating process models.

Objective 3 sought to analyse the discrimination of each practice domain according to the outcomes of Objective 2 i.e. to determine whether there are clear separation or distinctions in how the centroid model apply to each of the practice domains. Discriminant analysis (DA) was conducted on the centroid models established for Objective 2 to compare DA outcomes when ad-hoc (data before reliability tests) and post-hoc data (data after reliability test) were analysed. In BIM, ad-hoc data analysis showed that the NModel discriminated most significantly (-3.50), followed by the DModel (+1.55) and FModel (+0.83). When post-hoc data were analysed, NModel (+0.224) discriminated less than other practice domains: the most discriminated groups were MModel (+0.768), DModel (+0.676) and FModel (+0.655). Discriminant functions were developed for the centroids and for applications in the four practice domains.

These discriminations were measured using Wilk's Lambda and Pillia's Trace values through which the Eigen values and percentage variances of the discriminant functions were compared across the four practice domains. For ad-hoc data, discrimination was significant in Function 1. The Eigen value for the Function 1 (1.9925) explains 77% of the variances in participants' descriptions of activities leading to workable 3D CAD estimating outcomes. The Wilk's Lambda and Pillai's Trace values of this function is 0.200 and 1.115 respectively at $p<0.0001$. Similarly, for post-hoc data, there was 100% variance across variables and the practice domains in Function 1. Both Wilk's Lambda value Pillai's Trace values showed significance in variables' association (at 0.42 and 0.5764 respectively). In BIM estimating, the Function 1 generated from ad-hoc data was significantly discriminated at an Eigen value of 5.3739, variance of 95.77% and a canonical correlation of 0.9182. The Wilk's Lambda and Pillai's Trace values for this function (0.125 and 1.0507 respectively) were also significant at $p<0.0001$. For post-hoc data of BIM estimating process models, there was 100% variance across variables and the practice domains in Function 1. Both Wilk's Lambda value Pillai's Trace values show significance in variables' association (at 0.42 and 0.5764 respectively).

Accuracies of the discriminations were measured with a classification matrix. When using post-hoc data, in 3D CAD estimating, the discrimination was approximately 85% accurate for the MModel, 82% for DModel, 85% for FModel, and about 91% accurate for NModel. Overall, analysis showed that the discriminant function along the centroid was 93% accurate. For BIM estimating, the discriminant function for estimating with the post reliability test variables was 79% accurate for MModel, 83% accurate in DModel, 81% in FModel, 96% accurate in NModel and 91% accurate if the centroid regression model was used.

Finally, Objective 4 explored strategies for the technical implementation of Objective 3. In Chapter 7, computational applications of the centroid models were illustrated by describing system architectures for implementing both 3D CAD and BIM estimating process models. The natures of variables in the databases that drive both systems were identified, explored and clarified. EXPRESS-G models were used to illustrate how the activities (and their descriptors) in both 3D CAD and BIM estimating could be configured to derive satisfactory outcomes. While it is the prerogative of construction businesses to develop the descriptors of each activity, and the relationship between one activity and another, the study nominated IDEF0 formats for deploying the findings from the data analyses for application development. In particular, control measures and considerations for strengthening the outcomes of each estimating stage were nominated. The benefits of this, and other outcomes of the research, are listed in Section 8.3.

From the aforementioned sections, it is clear that the aim of the research – to explore the impact of BIM on estimating – has been met. Findings from this study have shown that 3D CAD estimating replicates conventional estimating processes. Analyses show that IT and changes to construction project governance culture (see (Winch, 2001)) are changing clients' priorities in the services they demand from estimators. For instance, the discounting of some activities in 3D CAD estimating during reliability analyses reflects a change in market reaction to the services rendered by independent estimators (FModel) in Australia during pre-construction and the construction phase. Although participants across board have strong views about the estimating activities, analyses show that clients prefer to let contractors take responsibility for estimating. It is only on the basis of this that price negotiations are constructed.

Various studies highlight clients' reluctance to engage independent estimators on their projects as having critical consequences for the estimating discipline (Acharya et al., 2006b, Aibinu and Pasco, 2008, Cartlidge, 2006, Olatunji et al., 2010b). However, the analyses of BIM estimating produced in this study challenge this view: there are more activities (and roles) for estimators in BIM than in 3D CAD. The new estimating roles in BIM include developing methodologies for moderating BIM data and for constructing visual process models through which projects can be analysed and visualized from cost perspectives. These impacts provide answers to the questions posed in Section 1.4: 'how does BIM impact on estimating processes?' and 'what tools are required in the different estimating domains to operate and deliver appropriate outcomes in BIM?' Particularly, the answers to the first question were provided by identifying the estimating activities in 3D CAD and BIM, and by comparing these to expose the benefits of BIM for estimating processes. The latter question was answered by exploring the attributes of existing CAE applications with 3D CAD and BIM capabilities. When these were integrated into participants' views about estimating processes, some approaches to deliver appropriate outcomes while estimating with 3D CAD and BIM were nominated through new system architectures and computational approaches to implementing the research findings for application development.

8.3 BENEFITS OF THE RESEARCH

The findings of this research do have some valuable contributions to industry practice and construction management research. The benefits are summarized below:

- *Potential Research Outcomes:* Findings of this research have pointed out estimating activities and stages leading to workable outcomes in 3D CAD and BIM estimating. It has also shown the bases for process improvements in 3D CAD and BIM estimating. Through Cronbach's reliability test procedures, it has shown that certain estimating activities in both 3D CAD and BIM are unlikely to add value to estimating outcomes. The study also developed process models that are useable across the various practice domains where estimators have had strongly different views on how estimating outcomes are generated. The process models can be used for training, for application development and to advance dedicated research on contemporary estimating processes. Furthermore, the study was able to show the

direction of separation of views per practice domain; this helps to create flexibility in how the research findings can be applied to generate the most optimum outcomes.

- *Methodology:* This study combines method plurality and mixed method research to generate its outcomes. The weaknesses of each of the combined research paradigms were minimized. More importantly, it contributes to existing knowledge on plurality and mixed research methods by the quantisation procedure it illustrates: the study was able to convert qualitative data into numbers, process them and resolve them to a logical conclusion.
- *Applications:* This study applies to the theory and practice of estimating in the construction industry. Through the outcomes of reliability tests and discriminant analysis, it indicates that the inherent views on estimating processes and outcomes by estimators are ontologically stratified and richly nuanced. The process models established in the research may also be flexible for a wide range of applications in the industry: for training, for software development, for advanced research, for process improvement, for curriculum design, as the basis for putting value to estimators' professional services on digital platforms and for benchmarking.
- *Originality and Value:* The popularity of BIM in the construction industry has grown rapidly in the past decade. However, only limited work has been done on its impact on estimating practice. With a view that has not been taken in other studies (the estimating practice is an ontologically stratified discipline), this study has used empirical data to map out estimating processes in line with existing theories on organizational modelling.

8.4 RECOMMENDATIONS

Based on the findings of this study, and the associated arguments raised, the following recommendations are proposed:

- Estimators require both accurate data and robust management of same to develop workable estimates. There is currently limited evidence to suggest that deploying BIM guarantees accurate and workable estimates; whether in terms of the integrity of BIM's model data or how such BIM data are structured. It is therefore recommended that individual practices, or on a collective basis through the platforms of professional

institutions, should create guides describing how to explore and apply BIM model data to meet construction project goals.

- The BIM estimating activities highlighted in this study are not included in most construction estimating curricula. It is recommended that courses be developed applying these activities to promote BIM estimating amongst estimators from different business domains.
- In the past, professional practice in the construction industry has been fragmented. However, the implication of BIM is that, through integration and collaboration, trade boundaries are likely to diminish. Thus, rather than concentrating on quantification skills, it is recommended that estimators should develop skills that enable them to manage model data, estimate with them and explore other roles in BIM.

8.5 AREAS FOR FURTHER RESEARCH

- *Change management:* Construction organizations are under immense pressure to change from conventional processes and adopt BIM. Previous studies on change have not reflected the complexity of change, even though it is widely acknowledged that effective change involves variations to business processes, cultures, roles, tools, and business philosophies (Chapter 4). Whether change domains are treated individually or in combination, as emergent, short term, medium term or long term, it is worth exploring how businesses respond to change differently. In the course of this research, it is evident that further research is worthwhile on the following subjects:
    - How each business domain or entity should develop and deploy workable methodologies for managing organizational change in the context of digital technologies.
    - How best to capture, integrate and consolidate the interactions between change denominators (e.g. process change, cultural change, role change, tool change and change to business philosophies) and change agents (skilling, legal frameworks etc.) to develop robust research and business outcomes on the subject of change and BIM.
- *Software development*: Only limited work is available on developing methodologies for exporting data from VDC models for estimating. Specifically, further studies are required to:

- Define technical and business frameworks for selecting software applications for estimating practices e.g. to address issues around flexibility, coherence on methods of measurement, openness on utilization of data and so on.
- Develop tools that can be used for multi-directional feedback systems to integrate cyber and physical systems in project development.

- *Legal framework:* Recent studies such as Olatunji (2011c), Fairfield (2005) and McAdam (2010) have provided simple commentaries on BIM and its implications for existing legal frameworks. The parameters argued by these authors (e.g. model ownership, intellectual propertization, service valuation, trust and interoperability) have not reached conclusive resolutions. Most importantly, for BIM to deliver on its promises, the construction industry requires consistent appraisals of existing legal frameworks to reflect contemporary potentialities of digital processes.

8.6 LIMITATIONS OF THE RESEARCH

The following limitations are evident on the findings reported in this work:

- The sample population is small. It most likely that the opinions of the participants may neither wholly represent organization they came from nor the overall view of all estimators in the Australian construction industry.
- The process models suggested in this research have default limitations. These have been detailed in Section 5.2.2. Moreover, the process models requires field trials.
- In Chapter 7, approaches to the implementation of the process model have been suggested through IDEF0 and EXPRESS-G models. These frameworks require field trials

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Appendix 1: A Summary of estimating methods

Table 2.2: *A Summary of estimating methods*

Construction Phase	Estimating Techniques	Estimating Model	Basis of Estimating	Project type	Domain of use	Framework	Limitations
Pre-Project and Pre-Construction Phase	Cost limit calculation	$P = f_r(q)$	Product-based	All forms of construction	Client	Deterministic / probabilistic	Variable are few, vague and conceptual. Thus, there are precision problems (Uher and Loosemore, 2004)
	Functional Unit	$P = qr$	Product-based	All forms of construction	Client Contractor	Deterministic	Variables are very few; estimates based on this method are conceptual. Thus, accuracy is a major concern (Collier, 1974)
	Gross floor area	$P = qr$	Product-based	Buildings	Client Contractor	Deterministic	Estimate is based on one variable (GFA). Because each project elicits a unique response to economic variables, it is cumbersome to generate and deploy data appropriately. Hence estimates can merely be superficial (Gerrard, 2000).
	Unit	$P = qr$	Product-based	All forms of construction	Client Contractor	Deterministic	Estimates are based only on a single major item. The costs of non-critical but supplementary items are often estimated imprecisely (Brook, 2008).
	Parametric	$P = f_r(q_1, q_2, q_3 \ldots q_n)$	Product-based	All forms of	Client	Deterministic	Only few defining parameters are considered in parametric models.

		Process-based	construction	Contractor		The cost of undefined items could become critical and jeopardize estimated outcomes (Cheung and Skitmore, 2005).
Graphical	$P = f_r(q)$	Product-based Process-based	Process Plant/ Industrial projects	Client Contractor	Deterministic	This method is mostly based on intuition (Loveland, 2000). The reliability of this method has been questioned by Ondar and Yurkov (1973)
Functional dependency	$P = f_r(q_1, q_2, q_3 \ldots q_n)$	Product-based Process-based	All forms of construction	Client Contractor	Deterministic	This is often based on the functionality of project components. The relationship between value and function can only be subjective in this way (Bártolo, 2000, Barton, 2000).
Approximate Quantities:						
Conventional method	$P = \sum_{i=1}^{N} q_i r_i$	Product-based	All forms of construction	Client Contractor	Deterministic	Few items are used in determining this. Expected accuracy level is minimal and outcomes are mostly discretionary (Sbordone, 2002).
Gleeda Model	$P = \sum_{i=1}^{N} q_i r_i$	Product-based	Buildings	Client Contractor	Deterministic	Same as above. Only significant items are considered. It could be time-consuming and would require a large amount of data of high quality. Yet accuracy is not guaranteed (Chou et al., 2005, Sanders et al., 1992)

Gilmore Model	$P = \sum_{i=1}^{N} q_i r_i$	Product-based	Buildings	Client Contractor	Deterministic	Similar to other forms of preliminary estimates, the model is based on few critical items and can be extended to later stages of project planning. However, there could be wide error margins due to inadequacies in designs (Walton and Stevens, 1997).
Ross 1 Model	$P = \sum_{i=1}^{N} q_i r_i$	Product-based	Buildings	Client Contractor	Deterministic	Skitmore and Patchell (1990) have evaluated the accuracy of these models. Even when only 17 cases were used, their general accuracy did not exceed 50%; much lower in Ross 1 model (25%) and Ross 3 model (30%).
Ross 2 Model	$P + \sum_{i=1}^{N} q_i r_i$	Product-based	Buildings	Client Contractor	Deterministic	
Ross 3 Model	$P + \sum_{i=1}^{N} q_i r_i$	Product-based	Buildings	Client Contractor	Deterministic	
	$P_i = a + bq_1 + e$, $e = N(0, \sigma^2)$					
Cube	$P = qr$	Product-based	All forms of construction	Client Contractor	Deterministic	This is an obsolete method, and has been discontinued due to its numerous problems. Major amongst these is the lack of relationships between the cost of content and the volume of cubic shape (Ashworth, 2004).

Conference	$P = f(P_1, P_2 ... P_n)$	Product-based Process-based	Process Plant/ Industrial projects	Client Contractor	Deterministic	This method is used for prototype cases where historical data is not applicable, and the viewpoint of a conference of experts is of merit. However, the experts are not likely to be the constructors; hence their opinions may be biased, inconclusive and imperfect. Thus, lack of accuracy is a possibility.
Interpolation	$P = qr$	Product-based	Buildings	Client Contractor	Deterministic	This method is used to generate conceptual estimates based on location, as per the proximity of the estimated value of a similar past project in that precinct. However, there is no statistical framework to support the model (Martinez, 2010). Accessing appropriate data could also be cumbersome.
Storey enclosure	$P = qr$	Product-based	Buildings	Client Contractor	Deterministic	This method is largely unused in practice (Ashworth, 2004). However, Cheung (2005) has refined this and concluded that *"subjective judgement is unavoidable"* (pp. 201). Skitmore and Patchell (1990) also reported the general accuracy level of the model as 15 -30%

Elemental Cost Planning	$P = \sum_{i=1}^{N} q_i r_i$	Product-based	Buildings	Client	Deterministic	The goal of this model is to ensure that designs are made within cost limits, and such that the variables of value engineering and lifecycle costing are considered at the design stage. However, this is only superficial as costing a design is not absolutely the same as costing its construction (Ogunlana, 1989).
Elsie Model	$p^2 = \sum_{i=1}^{N} q_i r_i$	Product-based	Office buildings	Client	Deterministic	Many authors (e.g. Weitzman (1976), Clemhout (1981)) have referred to this model as pioneering in terms of setting standards for measurement. The model was popular in the United States after World War II. Its limitations are relative to those of estimates which are based on gross floor area. Therefore, its outcomes can only be superficial.
Regression models	$P = a + \sum_{i=1}^{N} q_i r_i + e$ $e = N(0, \sigma^2)$	Product-based Process-based	All forms of construction	Client Contractor	Deterministic / probabilistic	Often based on regressed variables, these types of estimating models may have limitations in terms of scope of application. Previous studies (Aibinu and Pasco, 2008, Akintoye and Skitmore, 1993) have shown that the outcomes of regression models are not perfect for estimating purposes.

BCIS model	$$P = \sum_{i=1}^{N} q_i\, r_i$$	Product-based	Buildings	Client Contractor	Deterministic	These models are based on robust data from previous similar projects. However, the procedure could be subjected to proximity issues.
Factoring method	$$P = \sum_{i=1}^{N} fact_i \sum_{i=1}^{N} q_i\, r_i$$ a) m = 1 (Lang method) b) m > 1, $fact_1 \neq fact_2$….. (Hand method) c) $fact_i = U(\alpha_i, \beta_i)$ (Chiltern Method)	Product-based	Engineering projects	Client Contractor	Deterministic	This method relies on factoring the cost of a project on an estimated portion such that when other parts are factored, the total cost could be estimated. This approach has been proved to be subjective and misleading (Babalola and Aladegbaiye, 2006).
Comparative	$P_2 = P_1 + \sum_{i=1}^{N} p_{2i} - p_{1i}$	Product-based	All forms of construction	Client Contractor	Deterministic	Comparative estimating models are often targeted at eliciting *comparative values* of alternative options. Ogunsemi and Jagboro (2006) have identified how unrealistic this can be as most determinants of costs and value are hidden until under construction.

Exponent	$P_2 = P_1 \frac{q_2}{q_1} r$	Product-based	Building and Engineering projects	Client Contractor	Deterministic	Developed by Jelen and Black (1983), this method often refers to the similarity between a completed project and a proposed one. The limitation of this approach has been argued by Flanagan and Norman (1993), in which the authors argue that the individual project has its unique distinctive risks which cannot be generalized as others.
Operational estimating model	$P = \sum_{i=1}^{N} q_i \, r_i$	Process-based	All forms of construction	Contractor	Deterministic	Past studies have shown that the model is not suitable for non-deterministic scenarios (Barbosa et al., 2009). According to Kern and Formoso (2006), unless it is reinforced with best practices models of cost management, it might not be an attractive option for clients. Bowman (2006) also suggested that the success of this model depends on the specificity of duration limits, otherwise clients might end up paying for resource idleness, waiting and most of the time for which plant is technically inoperative or when productivity is below par.

Bill of Quantities Pricing						
Traditional model	$P = \sum_{i=1}^{N} q_i\, r_i$	Product-based	All forms of construction	Client Contractor	Deterministic	The efficacy of bills of quantities has been criticized in many studies. Some of these criticisms have concentrated on rigidity (Morledge and Kings, 2006); being product-based instead of being project-based (Sutrisna et al., 2005); obsolescence and complexity of measurement standards (Davis et al., 2009b); possibility of measurement process being irrational and subjective (Singh and Banjoko, 1990), and can be subject to inadequacies such as errors, omissions, conflicts and duplications (Aibinu and Pasco, 2008).
B-Fine model	$P = \sum_{i=1}^{N} q_i\, r_i$	Product-based	Buildings	Client Contractor	Deterministic	
Significant item estimating	$P = \sum_{i=1}^{N} q_i\, r_i$	Product-based	Buildings	Client Contractor	Deterministic	The limitations of this process are similar to estimating methods by factoring.

Friedman's model	$P(x) = 1/n \sum_{i=1}^{\infty} p(i)$	Process-based	All forms of construction	Contractor	Deterministic /probabilistic	Past studies have been very sceptical about this model. Ioannou (1988) describes it as a model that "*does not produce results supported by common sense when applied to symmetrical situations"* (pp. 214).
Tendering: Bid unbalancing models						
Gates' model	$P_{i.} = \frac{1}{1 + \sum_{\substack{j=1 \\ j \neq i}}^{k} \frac{1 - P_{ij}}{P_{ij}}}$	Process-based	All forms of construction	Contractor	probabilistic	This model has existed for some decades before Skitmore et al. (2007b) developed its mathematical proof. There is no evidence in the literature to suggest that Skitmore et al.'s proofs have been tested and validated
Stark's model	$P(b_1, k_1; \ldots; b_n, K_n) = P(b_1,k_1) + \ldots + P(b_n,K_n)$	Process-based	All forms of construction	Contractor	probabilistic	Rothkopf and Harstad (1994) have pointed out that this model has generalization problems. Thus, it is not suitable for contractors who are not willing to take risks.
Ashley and Teicholz's model	$DI_j = \frac{P_j \sum_{n=1}^{N} Q'_{nj} (1+r)^{-n}}{Q_j}$	Process-based	All forms of construction	Contractor	probabilistic	Cattell et al. (2007b) has accused this model of double counting. Park et al. (2005) also added that the model has no tolerance for time lags while discounting cashflow.

Diekmann et al.'s model	$R_o = \mu - k\sigma^2$	Process-based	All forms of construction	Contractor	probabilistic	The model failed to consider lead and lag times in discouting cashflow (Cattell et al., 2007a), Afshar and Amiri (2010) also added that it is impossible for the model to account for all forms of risks and uncertainties.
Afshar and Amiri's model	MaxZ = $\sum_{i=1}\sum_{j=1} d^j\, p_{ij}(X_i - C_i)Q_i$ - $\sum_{j=1}^{t} d^j\, F_j$ = $\sum_{t=1}^{n} A_i Q_i(X_i - C_i) - F_0$	Process-based	All forms of construction	Contractor	probabilistic	According to Cattell et al. (2007a), the approach of accounting for risks and uncertainties proposed in this model is inconclusive. Other forms of uncertainties which are not considered in the model are viable and should not be jettisoned
Cattell et al's model	$PV_j = \sum_{n=1}^{N}\left(\frac{1}{1+r_j}\right)^n \left[\left(\lambda_{nj}\left(Q_j + Q'_j\right)\right)\left[Y_{nj} f P_j - C'_{nj}\right]\right]$	Process-based	All forms of construction	Contractor	probabilistic	The argument on risks in this model is similar to others which are inconclusive on the subject of risks and uncertainties. There is no evidence in the literature to suggest that this model in particular has been validated.
Christodoulou's Model	$H_x = p_x \ln\left(\frac{1}{p_x}\right)$	Process-based	All forms of construction	Contractor	probabilistic	The author relied on a similar previous work by Choi and Russell (2005) to establish a relationship between financial risk, entropy, bid-unbalancing and profitability. However it is as yet unclear how entropy quotients correlate with contractor's chances of fulfilling business

							interests i.e. winning a bid and making a profit
Construction Phase	PERT-COST	$P = \sum_{i=1}^{N} p_i$ $p_i = N(q_i r_i \sigma_i^2)$	Process-based	All forms of construction	Contractor	Probabilistic	Some major problems of PERT have been eloquently argued by Donaldson and Coon (1965). There are critical concerns in this work indicating that PERT is not suitable for the stochastic nature of construction activities; neither is any model that relies on its philosophy for estimating.
	Risk Estimating	$P = \sum_{i=1}^{N} q_i\, r_i$	Process-based	All forms of construction	Contractor	Probabilistic	There are gaps in the literature on universally acceptable methodologies for quantifying and predicting risks (Edwards and Bowen, 1993, Flanagan and Norman, 1993, Potts, 2003)
	Norms (Schedule)	$P = \sum_{i=1}^{N} q_i\, r_i$	Process-based	All forms of construction	Contractor	Deterministic	The problems of this model are similar to those of the PERT-COST model above.
	Lu Qian model	$P = \sum_{i=1}^{N} q_i\, r_i$	Product-based Process-based	All forms of construction	Client Contractor	Deterministic	Little is known about this model. The author of the model even doubted its practicality (see pp. 150 of Lu and Smith (1997))

Creative Problem Solving (CPS) model	$P = \sum_{i=1}^{N} t_i r_i + \sum_{i=1}^{N} n_i$ $t_i = F(\mu_i, \sigma_i^2)$	Product-based Process-based	All forms of construction	Client Contractor	Probabilistic	The problems of this model are similar to those of conference model. Skitmore and Patchell (1990) have estimated its general accuracy level as 6.5%
Price Index methods						
Laspeyres' model	$\frac{\sum_j p_{tj} \times q_{oj}}{\sum_j p_{oj} \times q_{oj}}$	Product-based	All forms of construction	Client Contractor	Probabilistic	Previous studies (Mak et al., 2000) have indicated that the construction industry is less likely to be less dependent on non-stochastic tools.
Paasche's model	$\frac{\sum_j p_{tj} \times q_{tj}}{\sum_j p_{oj} \times q_{tj}}$	Product-based	All forms of construction	Client Contractor	Probabilistic	
Fisher's model	$\sqrt{\frac{\sum_j p_{tj} \times q_{oj}}{\sum_j p_{oj} \times q_{oj}} \times \frac{\sum_j p_{tj} \times q_{tj}}{\sum_j p_{oj} \times q_{tj}}}$	Product-based	All forms of construction	Client Contractor	Probabilistic	
Quality audit models	$P = \sum_{i=1}^{N} q_i r_i$	Product-based	All forms of construction	Client Contractor	Probabilistic	This is difficult to predict as the quality depends on utility and value, most of the variables of which are partially intangible (Abdelsalam and Gad, 2009).

Post-occupancy Phase	Life cycle regression models	$P = f(P_1, P_2 \ldots P_n)$	Product-based	All forms of construction	Client Contractor	Probabilistic	Previous studies (Flanagan et al., 1987, Woodward, 1997, Wübbenhorst, 1986) have attempted this without much definitive luck. LCC models are still susceptible to black-box paradox problems.

Legend: *r* stands for rates, *q* stands for quantities, *fr* stands for *function* of *rates*, *P* stands for Price.

Appendix 2: Research Ethics and Methodology documentation

Content:

- Ethics approval notice
- Information statements for organizations
- Information statements for individuals
- Consent form for organizations
- Consent form for individuals
- Interview questions

HUMAN RESEARCH ETHICS COMMITTEE

Notification of Expedited Approval

To Chief Investigator or Project Supervisor:	**Mr William Sher**
Cc Co-investigators / Research Students:	**Mr Oluwole Olatunji** **Dr Ning Gu**
Re Protocol:	**Exploring the impacts of Building Information Modelling (BIM) on estimating practice for construction projects**
Date:	**02-Sep-2009**
Reference No:	**H-2009-0275**
Date of Initial Approval:	**01-Sep-2009**

Thank you for your **Response to Conditional Approval** submission to the Human Research Ethics Committee (HREC) seeking approval in relation to the above protocol.

Your submission was considered under **Expedited** review by the Chair/Deputy Chair.

I am pleased to advise that the decision on your submission is **Approved** effective **01-Sep-2009**.

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research, 2007, and the requirements within this University relating to human research.

Approval will remain valid subject to the submission, and satisfactory assessment, of annual progress reports. *If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.*

The full Committee will be asked to ratify this decision at its next scheduled meeting. A formal *Certificate of Approval* will be available upon request. Your approval number is **H-2009-0275**.

If the research requires the use of an Information Statement, ensure this number is inserted at the relevant point in the Complaints paragraph prior to distribution to potential participants
You may then proceed with the research.

Conditions of Approval

This approval has been granted subject to you complying with the requirements for *Monitoring of Progress*, *Reporting of Adverse Events*, and *Variations to the Approved Protocol* as detailed below.

PLEASE NOTE:
In the case where the HREC has "noted" the approval of an External HREC, progress reports and

reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, or a Renewal of approval, you will apply to the External HREC for approval in the first instance and then Register that approval with the University's HREC.

- ***Monitoring of Progress***

Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. A progress report is required on an annual basis. Continuation of your HREC approval for this project is conditional upon receipt, and satisfactory assessment, of annual progress reports. You will be advised when a report is due.

- ***Reporting of Adverse Events***

1. It is the responsibility of the person **first named on this Approval Advice** to report adverse events.
2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
3. Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Approval Advice to the (HREC) by way of the Adverse Event Report form within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
4. Serious adverse events are defined as:
    - Causing death, life threatening or serious disability.
    - Causing or prolonging hospitalisation.
    - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
    - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
    - Any other event which might affect the continued ethical acceptability of the project.
5. Reports of adverse events must include:
    - Participant's study identification number;
    - date of birth;
    - date of entry into the study;
    - treatment arm (if applicable);
    - date of event;
    - details of event;
    - the investigator's opinion as to whether the event is related to the research procedures; and
    - action taken in response to the event.
6. Adverse events which do not fall within the definition of serious or unexpected, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.

- ***Variations to approved protocol***

If you wish to change, or deviate from, the approved protocol, you will need to submit an *Application for Variation to Approved Human Research*. Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. **Variations must be approved by the (HREC) before they are implemented** except when Registering an approval of a variation from

an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

Linkage of ethics approval to a new Grant

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.

Best wishes for a successful project.

Associate Professor Alison Ferguson

Chair, Human Research Ethics Committee

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FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

1st September, 2009

Dear Sir/Madam,

Information Statements (for Organizations) the Research Project: Exploring the impacts of Building Information Modelling (BIM) on estimating practice

You are invited to take part in the research project identified above which is being conducted by a team led by Mr Willy Sher from the University of Newcastle. The study is part of a PhD investigation being undertaken by Oluwole Olatunji. As a major stakeholder in construction business in Australia, your organization has been selected and invited to participate in interviews on the impact of Building Information Modelling (BIM) on estimating practice. In the first phase, we will be exploring the challenges inherent in conventional estimating processes. In the second phase, we will develop workable process models to incorporate BIM with estimating, and will be seeking your input to validate our proposals. Our request is that you **nominate** some of your employees to assist us in the interviews. Details of the interviews are described below.

Why is the research being conducted?

Construction software applications have developed at a remarkable pace in recent years. Several industry reports have noted the limitations of CAD and described how the industry has been struggling to overcome these challenges. BIM has the potential to address the limitations of CAD, and there are indications that a revolution in construction practices triggered by BIM has begun. Estimators and other construction professionals need to understand BIM concepts and how these affect estimating practices. Therefore, this research aims to investigate the impact of BIM on estimating practice. On completion, information will be shared on how to adopt best practices in the face of market competition in an industry subject to constant changes.

Who can participate in the research?

We wish to interview estimators as well as other stakeholders involved in managing BIM processes. These include executive officers and decision makers in estimating practices, estimators in public, consulting and contracting organizations, procurement officers, private developers, construction managers, project planners, developers and vendors of estimating applications, BIM researchers, project managers, CAD users, developers and vendors of software applications for estimating CAD and or BIM designs, promoters of BIM adoption and deployment, BIM researchers and consultants, team members on BIM projects and others who are responsible for estimating practice in Australia.

What choice do you have?

Your organization's participation in this research is entirely voluntary. Only if you give your informed consent will your organization be included. Whether or not you decide to participate, your decision will not disadvantage you in any way. If your organization decides to participate, you may withdraw your organization at any time without giving a reason. Further, you may also withdraw your organization's data either partially or entirely at anytime.

What will you be asked to do?

If you agree to participate we are seeking your assistance in identifying members of your workforce to be interviewed on two occasions. These individuals will be interviewed by a member of the research team on a one-to-one basis and asked questions about estimating practice. During the first interview, participants will be asked about the challenges of conventional estimating processes. In the second, participants will be asked to validate new process models for preparing estimates based on BIM projects. The interviews will take place at a time and location that is convenient to your staff. The interviews will be audio recorded and they will be able to review the recordings and the resulting transcripts to edit or erase their contribution if they so wish.

How much time will it take?
Each interview will last for approximately forty-five minutes.

What are the risks and benefits of participating?
There are no known risks associated with your participation. The participants will be asked to talk openly and freely about issues which affect their everyday professional practice. The insights you provide will not only shed light on estimating practice in Australia, but may also lead to more effective and productive industry practice.

How will your privacy be protected?
We assure you that the participants' privacy, confidentiality and anonymity will be maintained. If they wish to, they may de-identify (remove all traceable details like names, location, clients etc) **before** providing any data. Any data they do provide will, in any case, be de-identified by Mr Olatunji. Although direct quotes from participants may be used, they will not be identified in any report arising from the project. Only the research team will have access to the data which will be stored in a locked cabinet in the School of Architecture and Built Environment, University of Newcastle, and destroyed after five years.

How will the information collected be used?
The de-identified data from all participants will be collated and analyzed to identify relationships between design methods and the probity of estimates. From this, process models for estimating BIM projects will be developed and validated. The results of the project will be presented in Mr Olatunji's thesis, journal articles and conference proceedings. The University of Newcastle owns the intellectual property of this research.

What do you need to do to participate?
Please be sure you understand this document before your organization consents to participate. If there is anything you do not understand, or you have questions please contact the researchers. If your organization would like to participate, please complete the attached consent form and return it to the researchers. We will then contact you and provide you with documentation to give to those members of staff you identify to be interviewed.

Further Information
If you would like further information about the project please contact Willy Sher. Thank

you for considering this invitation.

Yours faithfully

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FACULTY OF ENGINEERING
AND BUILT ENVIRONMENT

THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA

1st September, 2009

Dear Sir/Madam,

Information Statements (for Individuals) the Research Project:
Exploring the impacts of Building Information Modelling (BIM) on estimating practice

You are invited to take part in this research project identified above. You have been nominated by your employer as a valuable contributor to estimating practice and / or a supporter of the adoption and deployment Building Information Modelling (BIM). The research is being conducted by a team led by Mr Willy Sher from the University of Newcastle, as part of a PhD investigation being undertaken by Oluwole Olatunji. As a major stakeholder in construction business in Australia, your organization has been selected and invited to participate in interviews about the impact of Building Information Modelling (BIM) on estimating practice. We would like to interview you on two occasions. In the first, we wish to explore the challenges inherent in conventional estimating processes. We will then collate the responses of all those whom we interview and develop process models to incorporate BIM with estimating. We will then seek your input during a second interview to obtain your views on these process models.

Why is the research being conducted?

Construction software applications have developed at a remarkable pace in recent years. Several industry reports have noted the limitations of CAD and described how the industry has been struggling to overcome these challenges. BIM has the potential to address the limitations of CAD, and there are indications that a revolution in construction practices triggered by BIM has begun. Estimators and other construction professionals need to understand BIM concepts and how these affect estimating practices. Therefore, this research aims to investigate the impact of BIM on estimating practice. On completion, information will be shared on how to adopt best practices in the face of market competition in an industry subject to constant changes.

Who can participate in the research?

We wish to interview estimators as well as other stakeholders involved in managing BIM processes. These include executive officers and decision makers in estimating practices, estimators in public, consulting and contracting organizations, procurement officers, private developers, construction managers, project planners, developers and vendors of estimating applications, BIM researchers, project managers, CAD users, developers and vendors of software applications for estimating CAD and or BIM designs, promoters of BIM adoption and deployment, BIM researchers and consultants, team members on BIM projects and others who are responsible for estimating practice in Australia.

What choice do you have?

Your participation in this research is entirely voluntary. Only if you give your informed consent will you be included. Whether or not you decide to participate, your decision will not disadvantage you in any way. If you decide to participate, you may withdraw at any time without giving a reason. Further, you may also withdraw your data either partially or entirely at anytime.

What will you be asked to do?

You will be interviewed by a member of the research team on a one-to-one basis and asked questions about estimating practice. During the first interview, you will be questioned about the challenges of conventional estimating processes. In the second interview you will be asked to validate new process models for preparing estimates based on BIM projects. The interviews will take place at a time and location that is convenient to you. The interviews will be audio recorded and you will be able to review the recording and the resulting transcripts to edit or erase your contribution if you so wish.

How much time will it take?
Each interview will last for approximately forty-five minutes.

What are the risks and benefits of participating?
There are no known risks associated with your participation. You will be asked to talk openly and freely about issues which affect your everyday professional practice. The insights you provide will not only shed light on estimating practice in Australia, but may also lead to more effective and productive industry practice.

How will your privacy be protected?
As a participant you are assured that your privacy, confidentiality and anonymity will be maintained. If you wish to, you may de-identify (remove all traceable details like names, location, clients etc) **before** providing any data. Any data you do provide will, in any case, be de-identified by Mr Olatunji.

Although direct quotes from participants may be used, you will not be identified in any report arising from the project. Only the research team will have access to the data which will be stored in a locked cabinet in the School of Architecture and Built Environment, University of Newcastle, and destroyed after five years.

How will the information collected be used?
The de-identified data from all participants will be collated and analyzed to identify relationships between design methods and the probity of estimates. From this, process models for estimating BIM projects will be developed and validated. The results of the project will be presented in Mr Olatunji's thesis, journal articles and conference proceedings. The University of Newcastle owns the intellectual property of this research.

What do you need to do to participate?
Please be sure you understand this document before you consent to participate. If there is anything you do not understand, or you have questions please contact the researchers. If you would like to participate, please complete the attached consent form and return it to the researchers. We will then contact you to arrange a convenient time to interview you.

Further Information
If you would like further information about the project please contact Willy Sher. Thank

you for considering this invitation.

Yours faithfully

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1st September, 2009

Consent Form (for Individuals) for the Research Project:
Exploring the impacts of Building Information Modelling (BIM) on estimating practice
Sher, Willy David; Gu, Ning; Olatunji, Oluwole Alfred

I agree to participate in the above research project and give my consent freely.

I understand that the project will be conducted as described in the Information Statement, a copy of which I have retained.

I understand I can withdraw from the project at any time and do not have to give any reason for withdrawing.

I consent to participate in an interview and have it recorded.

I understand that my personal information will remain confidential to the researchers.

I have had the opportunity to have questions answered to my satisfaction.

Print Name:_____

Signature:_____ **Date:** _____

Please feel free to contact any of the under-listed for clarification, if any

The Research Team

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PhD RESEARCH ON THE IMPACTS OF BUILDING INFORMATION MODELLING (BIM) ON ESTIMATING PRACTICE

Interview (Semi-structured) questions

The questions provided below will form the basis of the interview. Depending on the responses of each interviewee, the researcher may ask complementary questions to clarify relevant points.

Phase 1

This phase of the interview is aimed at exploring the limitations of conventional design systems in relation to estimating conventions. The questions will be in three parts. Part 1 seeks data about the interviewee's organizations in relation to estimating practice. Part 2 explores the challenges estimators face while estimating manual, CAD and BIM designs. Part 3 identifies the various steps when preparing estimates based on BIM data. These steps will be used to develop process models for estimating BIM projects to be validated in phase 2.

Part 1: Brief about the organization:

5. What is the nature of your firm's business?
6. When was your organization founded?
7. What is the current technical staff strength of your firm?
8. On the average, how many projects has your firm completed annually over the past five years?
9. Please categorize the projects by type:
10. What type of estimating does your organization engage in?
7. Please discuss your experience with the following types of design methods:
   (a) Hand-drawn designs
   (b) CAD designs
   (c) BIM projects
8. Please explain your estimation processes

Part 2: About estimating processes and the nature of projects

9. Do the design methods listed in Q8, Part 1 provide adequate information to enable you to estimate construction costs accurately? Please discuss…
10. How do the following options affect estimating accuracies in each method provided in Q9 Pt 1?
    - *Typographical errors*
    - *Arithmetic errors*
    - *Misapplication of SMM rules*
    - *Confusing descriptions*
    - *Storage problems*
    - *Conflict of interest*
    - *Others*
11. How do you alleviate these problems?
12. How do you use your estimating applications to perform the following functions?
    - *Extract data from all kinds of drawing formats e.g. dwg, pdf, jpeg*
    - *Automate input primary data (like descriptions, quantities, units, items and rates)*
    - *Compatible with integrated databases, but update quantities manually*
    - *Dedicated applications supplied by clients or other consultants*
    - *Digitize hardcopies of estimates already prepared*
    - *Others*
13. Using specific de-identified cases, please provide data on the cost performance of the

following design tools

Part 3: Process models

14. How do BIM designs compare with CAD drawings?
15. Please provide details on how the following estimating processes are conducted in BIM projects:
    - *Decompose building models into estimating components*
    - *Auto-capture data from object models*
    - *Distil descriptions of work items from meta data*
    - *Auto-match items with cost databases*
    - *Generate reports*
    - *Integrate project planning tools*
    - *Analyze reports*
    - *Produce final reports*
    - *Other tasks*
16. Please share a specific challenge you had with BIM estimating.

Appendix 3: Graphical representations in Data Analysis

Appendix 3a – Residual values and Q-Q plots

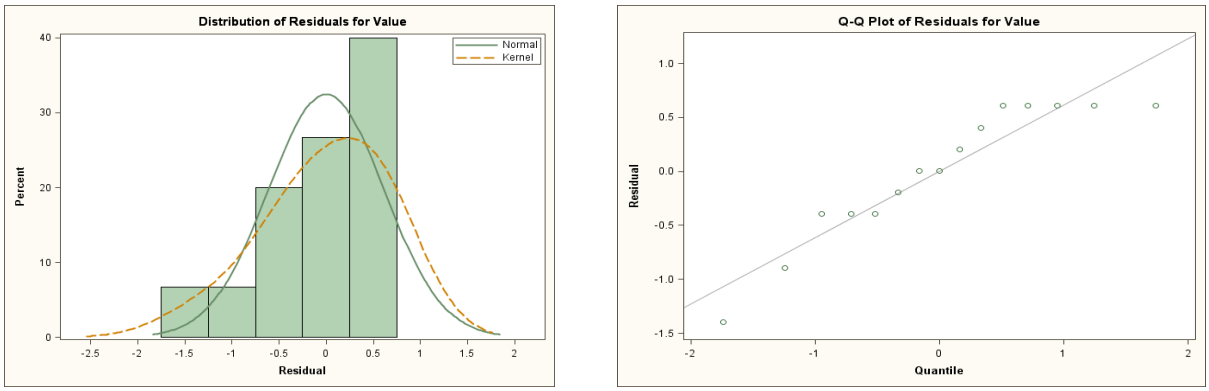


Figure 6.6a: Matrix model practice domain (3D CAD)

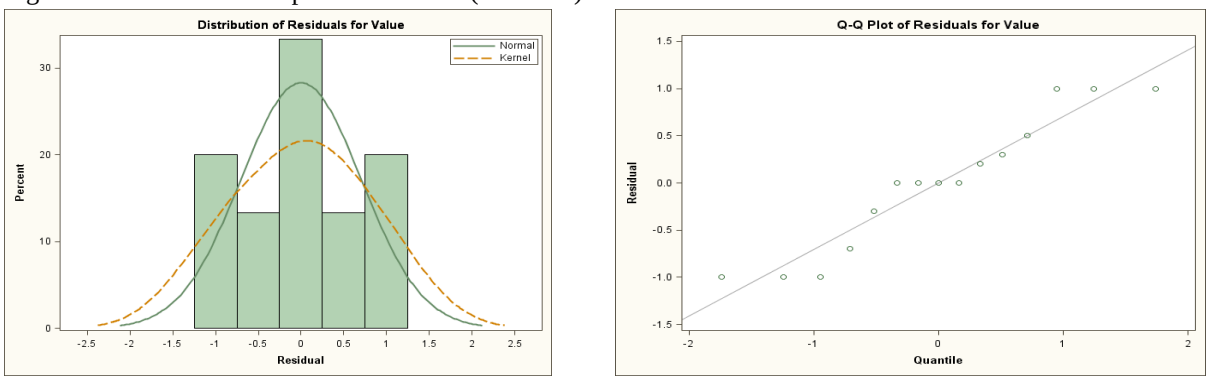


Figure 6.6b: Divisional Model practice domain (3D CAD)

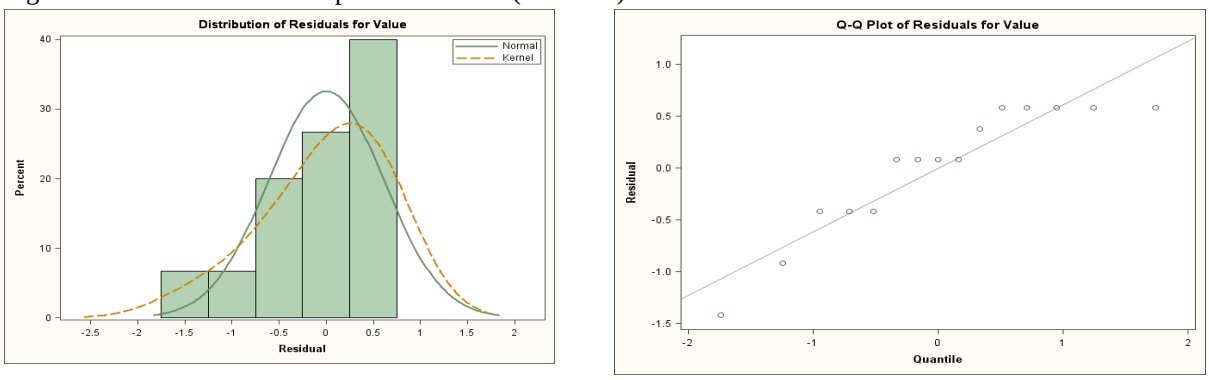


Figure 6.6c: Functional model practice domain (3D CAD)

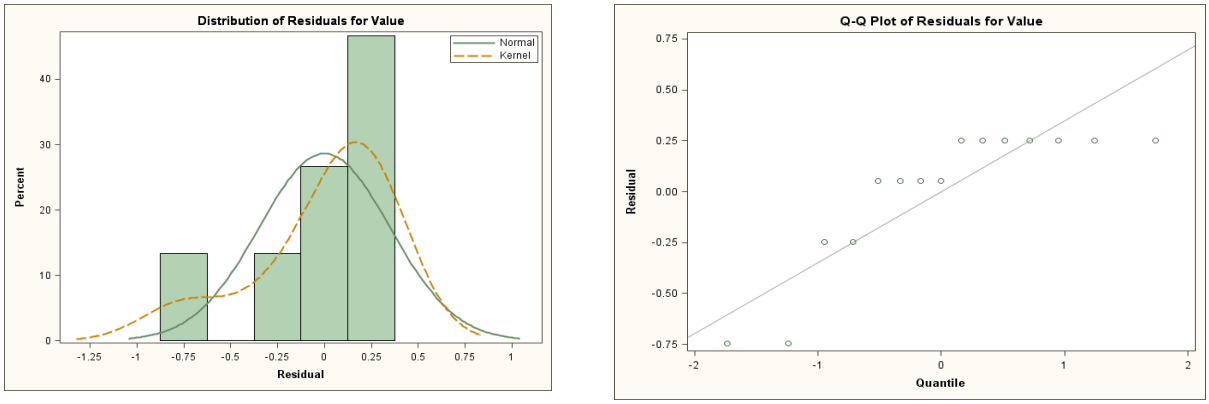
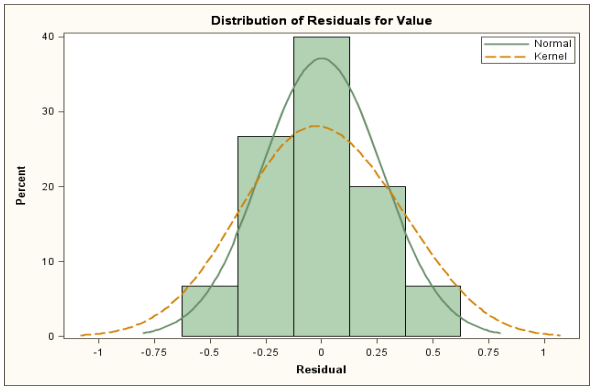


Figure 6.6d: Networked model practice domain (3D CAD)



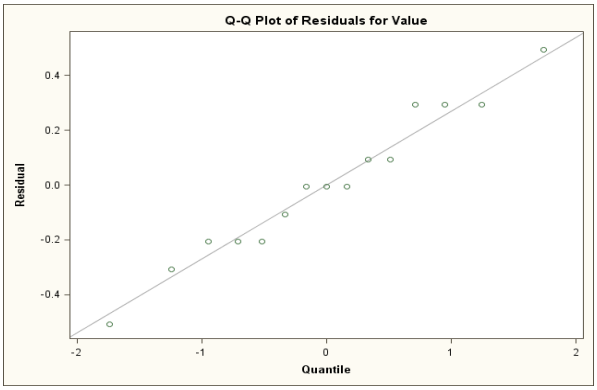
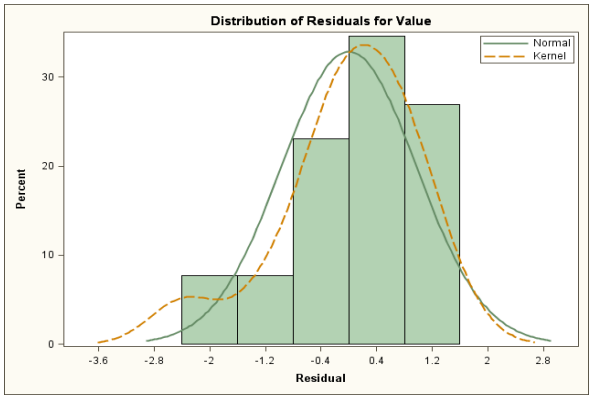


Figure 6.6e: Centroid model (3D CAD)



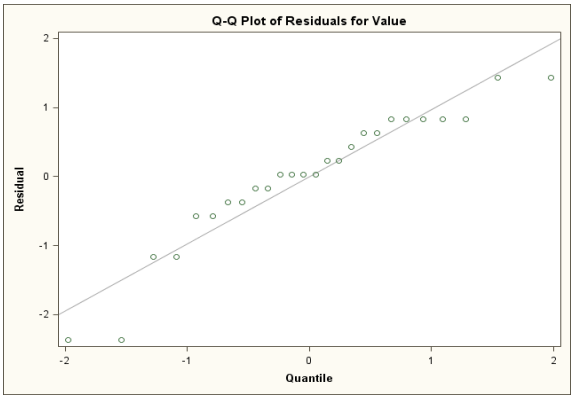
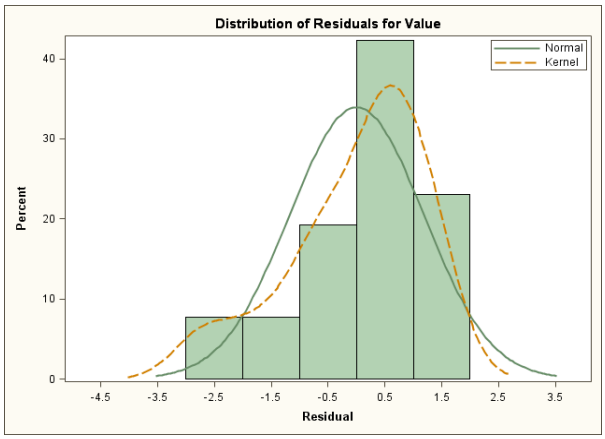


Figure 6.7a: Matrix model practice domain (BIM)



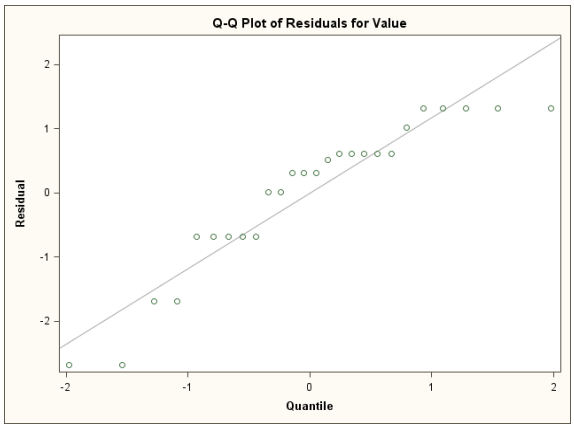
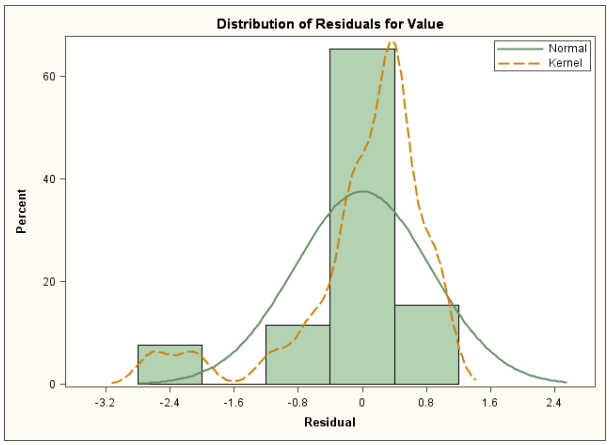


Figure 6.7b: Divisional model practice domain (BIM)



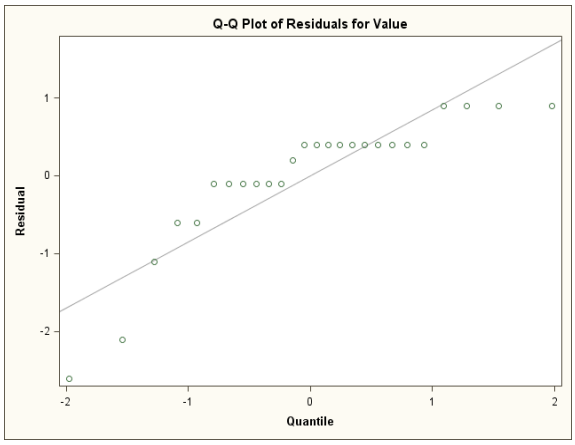


Figure 6.7c: Functional-unit model practice domain (BIM)

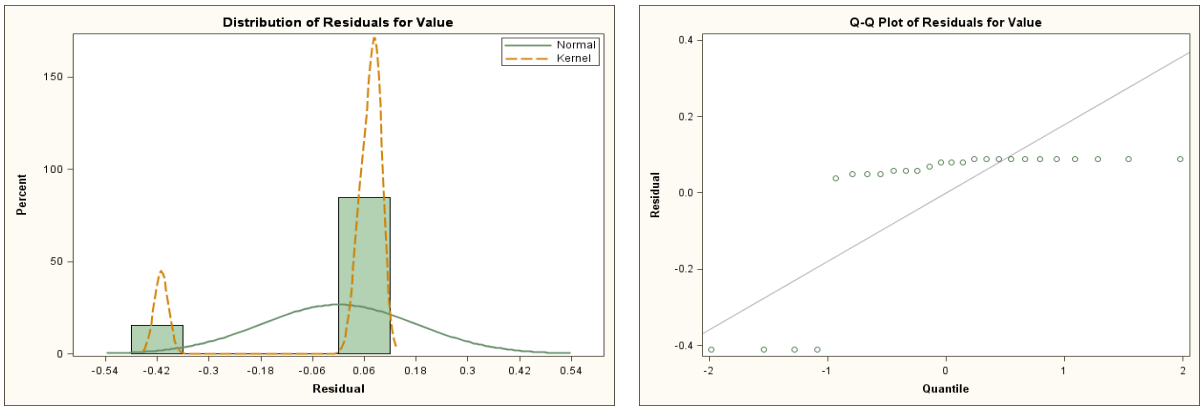


Figure 6.7d: Networked model practice domain (BIM)

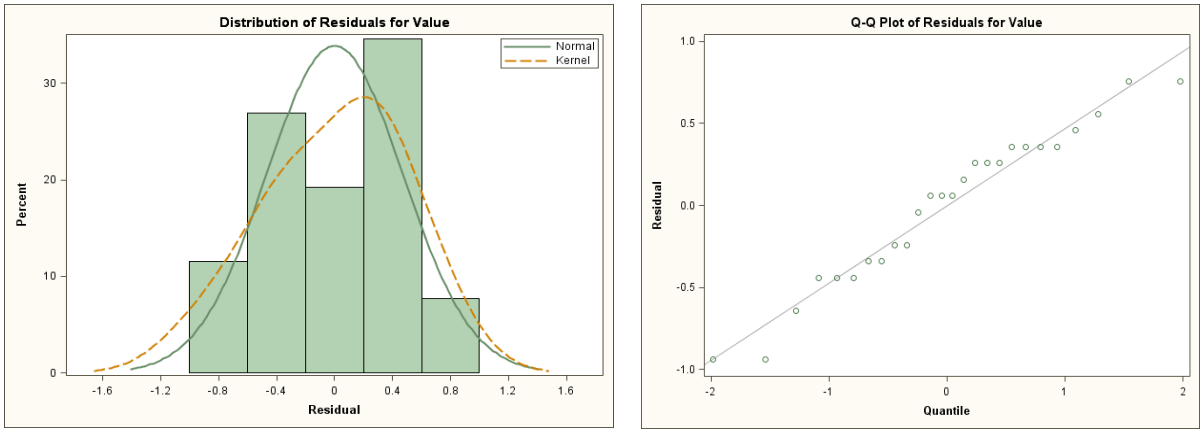


Figure 6.7e: centroid model (BIM)

Appendix 3b – Canonical Plots for the DA on 3D CAD and BIM estimating

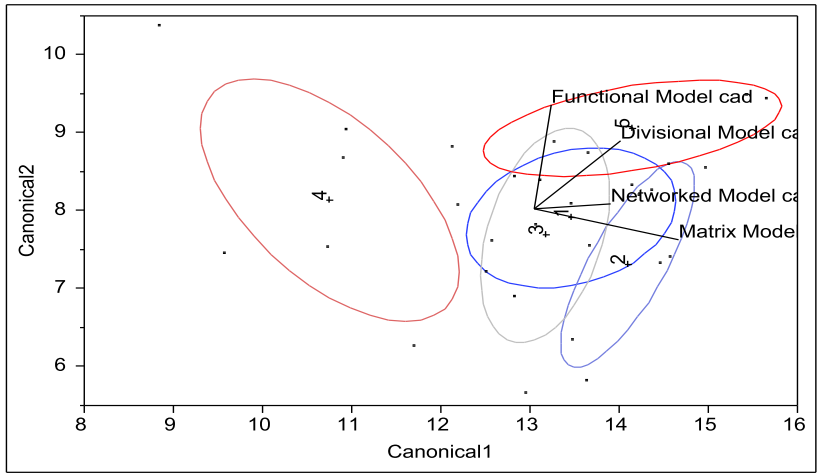


Figure 6.8a: Canonical Plot for 3D CAD estimation (pre-reliability test data)

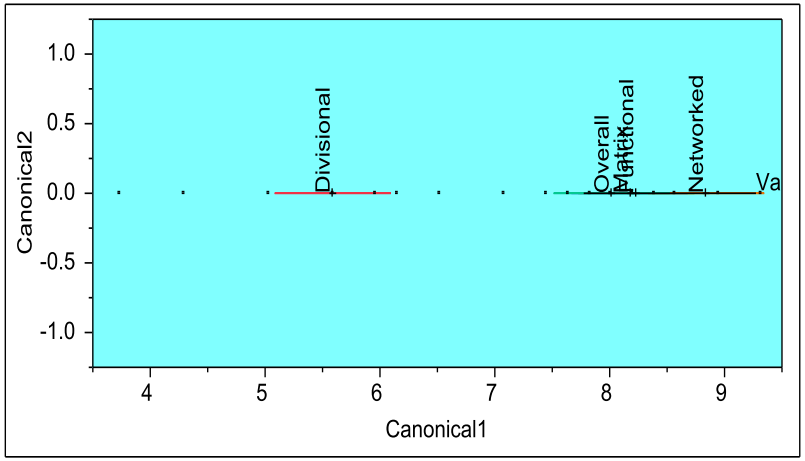


Figure 6.8b: Canonical Plot for 3D CAD estimation (post-reliability test data)

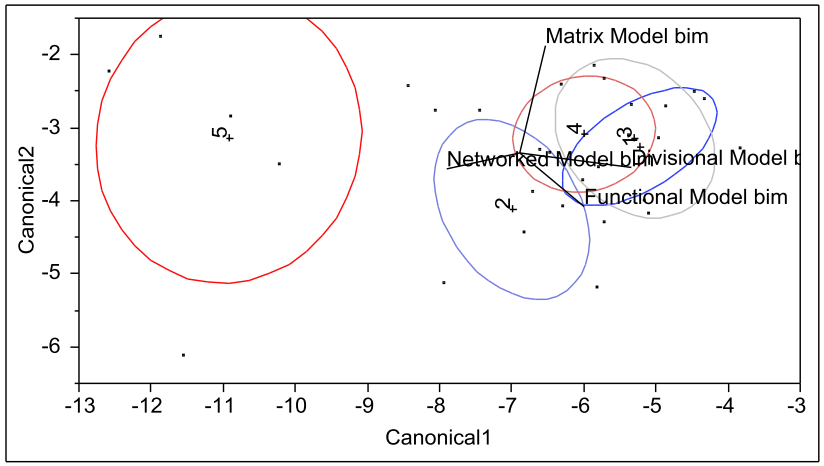


Figure 6.9a: Canonical Plot for BIM estimation (pre-reliability test data)

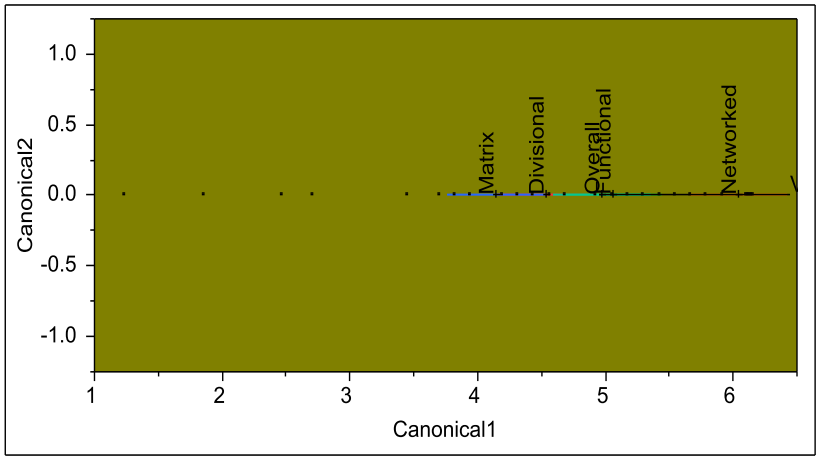
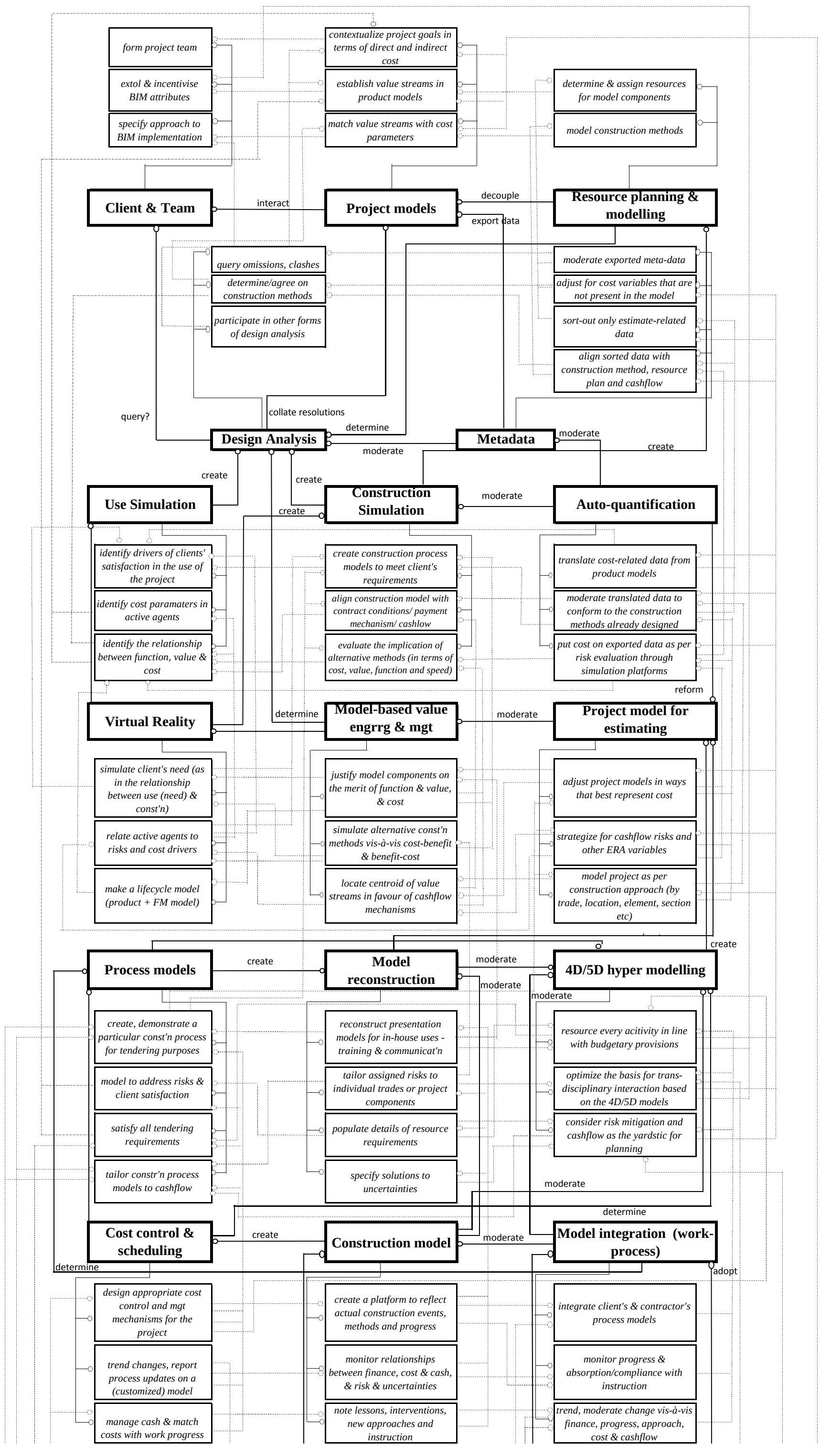
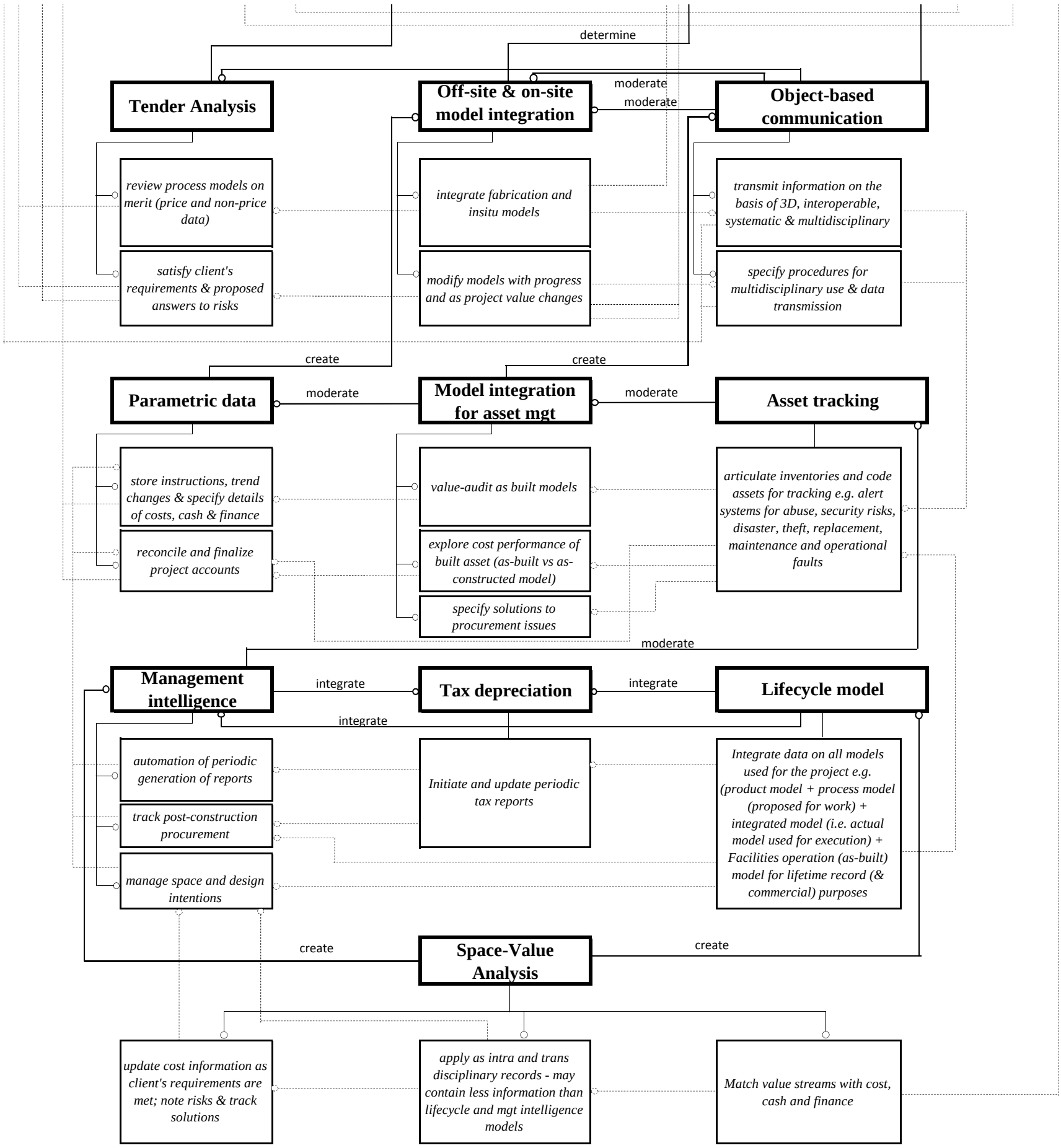


Figure 6.9b: Canonical Plot for BIM estimation (post-reliability test data)

Appendix 4: Illustrative secondary EXPRESS-G model for BIM estimating


form project team
extol & incentivise BIM attributes
specify approach to BIM implementation
contextualize project goals in terms of direct and indirect cost
establish value streams in product models
match value streams with cost parameters
determine & assign resources for model components
model construction methods
Client & Team
interact
Project models
decouple
export data
Resource planning & modelling
query omissions, clashes
determine/agree on construction methods
participate in other forms of design analysis
moderate exported meta-data
adjust for cost variables that are not present in the model
sort-out only estimate-related data
align sorted data with construction method, resource plan and cashflow
query?
collate resolutions
determine
Design Analysis
moderate
Metadata
moderate
create
create
create
Use Simulation
Construction Simulation
moderate
Auto-quantification
create
identify drivers of clients' satisfaction in the use of the project
identify cost paramaters in active agents
identify the relationship between function, value & cost
create construction process models to meet client's requirements
align construction model with contract conditions/ payment mechanism/ cashlow
evaluate the implication of alternative methods (in terms of cost, value, function and speed)
translate cost-related data from product models
moderate translated data to conform to the construction methods already designed
put cost on exported data as per risk evaluation through simulation platforms
reform
Virtual Reality
determine
Model-based value engrrg & mgt
moderate
Project model for estimating
simulate client's need (as in the relationship between use (need) & const'n)
relate active agents to risks and cost drivers
make a lifecycle model (product + FM model)
justify model components on the merit of function & value, & cost
simulate alternative const'n methods vis-à-vis cost-benefit & benefit-cost
locate centroid of value streams in favour of cashflow mechanisms
adjust project models in ways that best represent cost
strategize for cashflow risks and other ERA variables
model project as per construction approach (by trade, location, element, section etc)
create
Process models
create
Model reconstruction
moderate
4D/5D hyper modelling
moderate
moderate
create, demonstrate a particular const'n process for tendering purposes
model to address risks & client satisfaction
satisfy all tendering requirements
tailor constr'n process models to cashflow
reconstruct presentation models for in-house uses - training & communicat'n
tailor assigned risks to individual trades or project components
populate details of resource requirements
specify solutions to uncertainties
resource every acitivity in line with budgetary provisions
optimize the basis for trans-disciplinary interaction based on the 4D/5D models
consider risk mitigation and cashflow as the yardstic for planning
moderate
determine
Cost control & scheduling
create
Construction model
moderate
Model integration (work-process)
determine
adopt
design appropriate cost control and mgt mechanisms for the project
trend changes, report process updates on a (customized) model
manage cash & match costs with work progress
create a platform to reflect actual construction events, methods and progress
monitor relationships between finance, cost & cash, & risk & uncertainties
note lessons, interventions, new approaches and instruction
integrate client's & contractor's process models
monitor progress & absorption/compliance with instruction
trend, moderate change vis-à-vis finance, progress, approach, cost & cashflow


determine
Tender Analysis
Off-site & on-site model integration
moderate
moderate
Object-based communication
review process models on merit (price and non-price data)
integrate fabrication and insitu models
transmit information on the basis of 3D, interoperable, systematic & multidisciplinary
satisfy client's requirements & proposed answers to risks
modify models with progress and as project value changes
specify procedures for multidisciplinary use & data transmission
create
create
Parametric data
moderate
Model integration for asset mgt
moderate
Asset tracking
store instructions, trend changes & specify details of costs, cash & finance
value-audit as built models
articulate inventories and code assets for tracking e.g. alert systems for abuse, security risks, disaster, theft, replacement, maintenance and operational faults
reconcile and finalize project accounts
explore cost performance of built asset (as-built vs as-constructed model)
specify solutions to procurement issues
moderate
Management intelligence
integrate
Tax depreciation
integrate
Lifecycle model
integrate
automation of periodic generation of reports
Initiate and update periodic tax reports
Integrate data on all models used for the project e.g. (product model + process model (proposed for work) + integrated model (i.e. actual model used for execution) + Facilities operation (as-built) model for lifetime record (& commercial) purposes
track post-construction procurement
manage space and design intentions
create
Space-Value Analysis
create
update cost information as client's requirements are met; note risks & track solutions
apply as intra and trans disciplinary records - may contain less information than lifecycle and mgt intelligence models
Match value streams with cost, cash and finance