‘Cost as Information’ for Construction Supply Chain Improvements

By

Abigail Robson

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GLOSSARY AND ABBREVIATIONS

Glossary

Glossary for terms used in a specific way throughout this thesis

Costs and Costing: In transactions in a market cost and price are two different things. Cost is the expense that a company incurs in bringing a product or service to market. Price is the amount a buyer pays for that product or service. The difference between the price that is paid and the cost that is incurred is the profit the company makes when they sell. In a technical accounting sense cost and price are two different things. However this research treats the terms 'costs' (numerical data) and 'costing' (the practice of costing) as a term that covers both cost and price, as for practical purposes in construction projects, the two terms are used synonymously to apply to budgets that include profit as well as costs incurred

Cost management: The term cost management covers the project processes of cost estimating and tendering, control of expenditure against a budget and control of payments and cashflow.

Supply Chain: In this thesis the term supply chain is used to refer the main contractor and their subcontractors and suppliers. This includes subcontractors and suppliers across all tiers a main contractor's construction project supply chain. The term supply chain is not used in this thesis to include the construction client and their supply chain of advisers.

Contractors: The word contractor is used to encompass both main contractors and subcontractors where this needs no distinction. Where a distinction between main contractors and subcontractors is needed, those words are used

Notable abbreviations

ABC: Activity Based Costing
BIM: Building Information Modelling
CA: Constraints Accounting
DPP: Direct Product Profitability
ECR: Efficient Customer Response
ETO: Engineer-to-Order

IOCM: Inter Organisational Cost Management

IT: Information Technology

KC: Kaizen Costing

OR: Operational Research

LA: Lean Accounting

OBS: Organisational Breakdown Structure

PBS: Product Breakdown Structure

MTS: Made-to-Stock

SCA: Strategic Choice Approach

SCM: Supply Chain Management

SODA: Strategic Options Development and Analysis

SSM: Soft Systems Methodology

TA: Throughput Accounting

TC: Target Costing

TCE: Transaction Cost Economics

TOC: Theory of Constraints

TVD: Target Value Design

VE: Value Engineering

WBS: Work Breakdown Structure

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ABSTRACT

The construction industry is challenged to improve its work processes and reduce costs. Contractors have the clearest view of work done and how costs are incurred as they estimate the cost of work to be carried out, agree costs to a client and then carry out the work. However, in construction subcontractors' undertake around 70% of a project and so work done and project costs must be considered as a supply chain. This being the case, improvements in site operations and a reduction in costs require working collectively between the main contractor and their supply chain. The advent of Building Information Modelling (BIM) has been presented as enabling more detailed information and analytical modelling capabilities. In BIM, cost is just another item of information that can be created and manipulated within the model giving advantages of automation, detail and rich data access. However, to take advantage of BIM, the nature of the costing process needs to be clarified and made robust. This encouraged an exploration of "cost as information" in the construction project supply chain by analysing current practices of creation of cost information deep within the supply chain; the flow of cost information through the supply chain and the effect of cost information on recognising improvements in site operations.

Supported by a UK main contractor, the project was given access to their estimating, operations and supply chain. The research firstly investigated, via non-participant observation, semi-structured interviews, document reviews and workshops, how cost information is created and flows from forecasts of work to be carried out, to costs to a client. The research then investigated the effects of contractors' current costing practices on decision-making about improvements through the supply chain.

The study provides data on the actual practices of estimating and cost control in a unique investigation that makes connections between costing practices within individual organisations and across the supply chain. The findings reveal that despite cost information being presented in formal cost models, detailed estimates of costs created in organisations are lost and corrupted as cost information flows through the supply chain. People recognised that, despite being presented as hard information in formal cost models, cost information is used in a soft negotiable world in which subcontracting is run as a set of commercial decisions in which price bargaining is a key aspect in bidding for projects and in delivering projects. The findings also revealed that project scheduling also involved much negotiation in which planning and re-planning of work packaging and construction methods was undertaken in the

delivering of projects. Participants viewed formal cost models as effective for tendering and payment purposes. But the incompatibility between the formal and informal routines of cost handling and project delivery mean that formal cost models are not trusted for reflecting improvement. This has implications for immediate moves to automate the current process of costing in BIM, as this may produce non-viable results and so cannot be justified for the assessment of improvement.

This thesis uses the information-use model of Beynon-Davies (2011), involving the data aspects of cost (forma), the communication of costs (informa) and the system of costing (performa), to interpret both the methods of costing and the system of costing. Through the lens of "cost as information" this thesis proposes a systemic change in costing processes and the use of new representations of cost that better represent work done in the supply chain to provide meaningful, manageable and measureable. The softness and negotiability inherent in the process means that hard representations such as cost are surrogates for evaluations and actions. Thus, for an effective representation in BIM research needs to refocus from the pursuit of greater detail in current formal cost models towards finding and agreeing a new surrogate.

This thesis proposes an information ontology, which represents costing of the system of construction delivery. This will be called a *systems ontology* of costing. The ontology includes measurement of dependencies that can support collaborative decision-making, using soft system approaches, about improvements deep in to the supply chain. This systems ontology of costing in the supply chain is argued to be of value in developing new analytical models of costing in BIM that can link design, programming and management for identifying, evaluating and costing real improvement in work done. As the thesis found that project scheduling also involves much negotiation, future work to analyse and evaluate "construction planning as information" would provide data for specifying the nature of future measurements of dependencies in the continually changing conditions of construction projects, that would better link costs to work done.

CHAPTER 1

INTRODUCTION

1.1 Research scope and background

The construction industry has been heavily criticized over a long time for poor performance and high costs. Egan (1998) in the UK and Flyvbjerg *et al.* (2002) looking internationally, write that the perception of poor performance comes from high profile projects suffering from cost overruns, programme delays and poor productivity. In the UK, both government and contractors agree on the need for improvement. Government interest is driven by the political importance of the construction industry to the wealth of the UK and by government spending. Construction is a major contributor to economic output (6.5% of the total economy in 2014); a major employer (6.2% of the total in 2015) and a major contributor to growth (Rhodes, 2015). Government is also a major client for buildings and infrastructure with an interest in spending tax revenue efficiently.

Requirements for improvement similarly come from the industry itself in response to the competitive requirements of the market and shareholders' requirements to become more profitable (Lansley, 1987 and Hillebrandt *et al.*,1995). The dissatisfaction with the status quo by government and contractors has motivated a broad and long debate on construction improvement. The debate has most often been driven by government-backed reports. The Cabinet Office (2011) in the 'Government Construction Strategy' called for a reduction of construction costs of 20%. BIS (2014) in 'Construction 2025, The Industrial Strategy of Government and Industry, then called for a 33% reduction in both the initial cost of construction and the whole life cost of assets (from 2010/09 levels). Farmer (2016) in 'The Farmer Review of the UK Construction Labour Model' sees the industry at a "critical juncture" at which deep-seated structural problems and poor outcomes on productivity and predictability need to be addressed together.

The industry is faced with these calls to deliver projects to tighter budgets and shorter timescales at a time of increasing pressures from the growing complexity of construction projects. Complexity is arising from new technologies, new specialist trades and the more complex organisational structures that result. This diversification is a problem in all industries. However the extent of subcontracting and its use in construction to reduce costs makes an integrated delivery more difficult. Thus collaboration is more of a problem in the construction industry where many small local firms work together in short term project-based relationships with separation between design and construction, in which the project relationships between the many firms are mediated by market-based transactions with an overriding adversarial culture (Hillebrandt, 1984; Hughes and Hillebrandt, 2003)

In recent decades, successive government-backed reports have put forward solutions to bring about improvements. Before the millennium a series of reports built on each other. Latham (1994) in ‘Constructing the Team’ advised the construction industry to adopt a less adversarial culture by embracing more cooperative and trusting relationships, with “partnering” as a solution. Egan (1998) in his report ‘Rethinking Construction’ went further than partnering and advised the construction industry to adopt “supply chain management”, “lean construction” and “benchmarking”, a set of standard goals across construction projects. He also advised the industry to adopt a less short-term focus by forming “long-term alliances” instead of one-off project partnering. Egan (2002) in his subsequent report ‘Accelerating Change’ built on the preceding reports, specifically suggesting that it is possible to achieve better “value” by integrating clients and suppliers.

Since the term BIM entered the industry around 2003 (Eastman *et al.* 2011) successive government reports (Cabinet Office, 2011; BIS, 2014 and Farmer, 2016) all advocate BIM as an enabling technology for improvement. Building Information Modelling (BIM), is a term used in may ways to cover a technological step change from computer-aided design to computer modelling and an organisational change towards increased collaborative working. New computer modelling applications can provide visualisation and simulation of project designs and construction processes. They also have the capability to contain analytic decision support tools. It requires and assists a change in relationships between project participants, from adversarial to more collaborative working (Succar, 2009; Eastman *et al.* 2011). BIM has already diffused across the UK construction industry. The Government Construction Strategy (Cabinet Office, 2011) has brought BIM to all public sector projects. BIM is just one of many emerging digital technologies with potential applications to the construction industry. Across all industrial sectors Information and Commutation Technology (ICT) is developing rapidly and different technologies are converging. The ‘UK Digital Transformation Strategy’ (Brown, 2017) promotes ICT and other digital technologies in the drive to speed up work and provide new products and services. McKinsey and Company (2017) argue that the construction industry is “ripe for disruption” and is playing catch-up with other industries. PWC (2016) foresees BIM converging with other contributing digital technologies encompassing big data, the internet of things, wearable technology, survey drones, gaming technology, artificial intelligence, machine learning and 3D printing. This is part of a groundswell of interest from contractors for technology that disrupts the sector, boosts productivity and changes the way the industry works. Thus also mitigating against a skills shortage and providing an environment that attracts young, technologically skilled people to join the industry.

Amongst the digital disrupters, BIM is promoted as a solution to achieve greater efficiencies through increased collaboration. The use of BIM technologies and the inherent collaboration difficulties in the industry therefore need to be addressed hand in hand. This is not easy. Dossick and Neff (2009) (2011) found that the introduction of BIM technologies “tightly-couple” information from project participants in a single, online “consolidated models” (BIS, 2010) and make organisational connections visible. They argue that although organisational connections are made visible, the organisational connections themselves remain “loosely-coupled” as participants retain competing obligations between project goals and their firm’s own goals. They conclude that, in order for BIM to achieve its aims of better collaboration, organisational goals need to be accounted for alongside the introduction of technologies.

Organisational goals in relation to money generate an extremely strong obligation to a firm’s financial requirements. Construction is project focused, but delivered through firms. From supply chain management, the relationship between the firms that deliver projects on the supply side is known as the *supply chain*. Several *tiers* of firms are common in construction project delivery. To distinguish between the different firm-to-firm relationships, the *first tier* firm with a direct relationship with the client is known as the *main contractor*. The term *subcontractor* then is used to distinguish the set of firms who do not have a direct relationship with the client. Several layers of subcontractors are common in the *multi-tiered supply chains* that deliver construction projects. In individual projects, individual contractors prioritise profit maximisation but individual contractors also continuously balance resources and profitability across different projects.

The profit margins and liquidity of construction firms, compared to other industries, are low (Boukendour and Hughes, 2014). This limits the money available in the industry. This business model is also self-reinforcing. Contractors predominantly operate on a credit-based business model in which they fund work in progress, eased by staged payments to provide working capital. Nevertheless there is a lag between outlay and income and this model incentivises lowest price and latest payment of subcontractors throughout the supply chain (Boukendour and Hughes, 2014). Latham (1993) in his interim report 'Trust and Money' recognised the problem of the effects on downstream subcontractors. In his final report 'Constructing the Team' Latham (1994) condemned delays in making payments, including *pay when paid terms*, in which contractors hold subcontractor payments until they themselves have been paid. He also condemned delays in releasing *retention money*, percentages of money due held back under contracts for security for contract performance. Progress has been made on tackling this example of bad practices in the industry. But Latham (1993) was also making a bigger point that money has a fundamental role in any industry and the flow of money is more of a problem in the construction industry where cashflow predominantly provides contractors with working capital. Dossick and Neff (2009) similarly make the point that money has a fundamental role. They conclude the ability to balance profit obligations to the firm against obligations to a project is one of the "sharpest conflicts" within project teams.

Thus, an exploration of money in the construction industry is fundamental to a better understanding of the working better in projects and an assessment of the relevance of money for the more integrated, collaborative decision-making that will be possible in BIM to support change.

1.2 Research rationale

The link between technological tools and the people and organisations that use them is of increasing interest to academics working in information theory (Mingers, 2014; Floridi, 2011; Beynon-Davies, 2011). This link between technology and organisations is of critical interest in construction projects (Dossick and Neff. 2011); where multi-organisational teams come together temporarily in projects and where the work of many individual people and organisations is imported and exchanged in integrated computer systems, known as *consolidated models* (BIS, 2010); digital models that consolidate 3D drawings from different design disciplines.

In the UK, construction project cost models are traditionally and still predominantly presented in the form of detailed bills of quantities. As cost information moves into BIM, it is valuable to take an information view of cost. This research uses the terms ‘cost’ and ‘costing’, not in their technical accounting sense, but in the sense that they are used in construction projects, to apply to budgets as well as costs incurred. The literature on cost management in BIM shows that costing applications in BIM have to date focused on BIM’s ability to automate current practices. The nature of cost information that is produced by current practices is therefore important. Current cost information needs to be understood against its purposes, which are threefold; estimating, cost control and supporting analytic decisions on improvement.

A body of research exists into how cost information is created and used for the first two purposes. This research is contained in literature on the formal cost estimating and cost control processes of contractors (Towey, 2012; Greenhalgh, 2013; Kirkham, 2015; and Brook, 2017) and some research covers cost control practices of main contractors (Brook, 2017; Ross and Williams 2013). However, very little research has considered the cost estimating and cost control practices of subcontractors in the multi-layered supply chains of construction projects. Main contractors operate in tier 1 of construction project supply chains and typically subcontract around 80% of their work. This makes subcontractor’s costing practices critical to understanding how overall costs are built up and controlled in construction projects. Specialist trade subcontractors, such as mechanical and electrical services subcontractors operating in tier 2 of construction project supply chains also typically subcontract around 60% - 70% of their work. So the costing practices of their subcontractors in tier 3 of a supply chain and below are also critical to understanding how overall costs are built up and controlled. In addition, little research has documented contractors’ commercial practices in estimating and cost control. Research that does, such as Brook (2017), Ross and Williams (2013) and Laryea and Hughes (2010), recognise a wider range of forces acting on cost information than literature on contractors’ formal routines report. This literature suggests that the cost information presented in bills of quantities is ‘corrupted’, in the sense that it is changed by many assumptions, so that it does not well represents work done. In cost management in general, Johnson and Kaplan (1987) drew attention to the shortcomings of conventional management accounting in the same way, arguing that it had become uninterested in direct measures of activities in the firm, relying instead on what they call ‘surrogate’ financial numbers, thus reducing the instrumental value of cost information in providing management with a tool to better manage a business.

There is little research into how cost information is created and used in construction for the third purpose for cost information, that of supporting analytical decisions on improvement. The improvement debate in the business of commerce in general and in construction projects in particular is wide-ranging and contentious. From the array of improvement interventions across industries, supply chain management and lean thinking potentially draw directly on the expertise of contactors in mobilising resources in construction projects. The introduction and uptake of these models in their originating industries and their importation into construction are widely covered in literature (Mentzer *et al.,* 2001; Pryke, 2009).

Across disciplines, an understanding of systems is seen as fundamental to developing complimentary interventions. In today's world it is very common for a vast array of problems to be described loosely as 'systemic', including many management situations. The systems movement provides a general way to study situations through a set of principles. The Soft Systems movement, which considers systems that involve human activity in dynamic situations, is relevant to the multi-tiered supply chain of organisations and people who deliver construction projects. Gunderson and Holling's (2001) understanding of the construction system as a complex adaptive system provides a metaphor to understand how the construction system transforms and hence how complimentary improvement remedies are, or are not.

Under any model of improvement, an associated requirement for cost information to account for improvements becomes critical. Demonstration projects in construction have used the new pricing basis of Target Costing (Kato, 1993; Ansari *et al.* 2006) supported by *Open Book Accounting*, in which firms share information on costs and margins. In theory open book accounting is used to establish actual costs and works by reimbursing contractors for actual costs incurred. Open book accounting is underpinned by cost information created by contractors. Only Nicolini *et al.* (2000) and Zimina *et al.* (2012) have looked at how contractors' current cost information motivates improvements under Target Costing and both report significant limitations.

In management accounting across commerce in general, there is a body of theory on standard costing and on new methods of costing to support analytic decisions on improvement. A wave of new costing methods arose out of the increased competition from the globalisation of supply chains in 1980s. The principle methods are Activity Based Costing (Kaplan and Cooper, 1998), Lean Accounting (Maskell and Kennedy, 2007), Resource Consumption Accounting and Throughput Accounting. They each, in different ways, seek to more 'accurately' trace resources; through work done, to products. These new methods of costing have been used within firms and have also been adopted for inter-firm accounting across supply chains (Surowiec, 2013). The aims, limitations and uptake of these models in other industries is of interest for their introduction and uptake in construction.

Better information on costs is presented as an end point for developments in BIM. Developments in contractors' cost modeling in construction projects have traditionally encompassed more 'accurate' cost estimating of work done and increased predictability of costs. But how contractors currently build up a price and control costs across the supply chain is not simple and not well articulated in literature. As cost information moves into BIM, this encouraged an exploration of the nature of current use of 'cost as information'.

To gain access to the costing practices of a main contractor and their supply chain for empirical investigation, this research arose out of a collaboration that was set up between the research institute and the Midlands regional division of a UK national main contactor. The collaboration involved the main contractor's sponsorship of a three year PhD studentship, which was formally established in February 2013. The collaboration provided a vehicle for accessing data and drive for creating a practically relevant outcome. The ethical issues that the collaboration raised and the decisions taken about research design to overcome the ethical issues will be discussed in detail in section 3.3.

The Collaboration Agreement with the main contractor is attached in Appendix A1.1 and identified the research aims and objectives that are set out in section 1.3 below.

1.3 Research aim and objectives

This research aims to develop a framework of costing that supports more efficient work in the supply chain through the use of BIM. In order to achieve this aim the following objectives were set:

1. Determine how current approaches to supply chain costing affect supply chain operation and overall construction costs in a project.

2. Determine how different approaches to costing of supply chain operation can be used to deliver efficiency and cost savings in projects.

3. Examine costing through the lens of information theory to identify different, more useful costs of supply chain operation throughout projects.

4. Develop a schematic information model of costing that represents the whole system of costing in the supply chain to inform the development of information approaches such as BIM.

1.4 Thesis structure

As set out above, formal methods are prescribed for how contractors should estimate and control costs in construction projects. However the realties of how contractors deep into the supply chain create cost information and how cost information flows through a project supply chain in not simple and little articulated in literature.

Chapter 2 explores the literature of others on formal models for contractor cost estimating and control and a comparatively small amount of literature on contractor's commercial practices that explore the actual processes of contractor costing. In seeking to establish how cost information can be used to incentivise improvement across the supply chain, the chapter reviews the small amount of literature that has looked at incentive contracts and conclude contractor's lack of basic knowledge on costs is a major barrier to rewarding improvements through incentivising pain / gain sharing agreements. Chapter 2 then explores the literature on the contentious subject of construction improvement; from pull from the demand side of the industry (clients and their advisers) and push from the supply side of the industry (main contractors and their supply chain). Supply chain management and lean construction are identified as the two main improvement remedies on the supply side, both originating in manufacturing. Literature on the development and uptake of each is presented from manufacturing, before literature is presented on the development and uptake in construction. Chapter 2 then looks at alternative cost models in manufacturing and their limitations. Chapter 2 switches focus to the arrival of BIM in construction and the move of cost information into BIM. It focuses on how BIM models the world of construction and deals with approaches to construction improvement and costs. The chapter then pans out to take a broad outlook on systems modelling and its implications for information requirements in BIM. The chapter finally focuses in on information theory in order to better understand information models and their relationship to problems in the real world.

Chapter 3 shifts emphasis to the primary research. The chapter explains the methodology adopted for the primary research. The philosophical perspective is discussed and the ethical issues addressed. The chapter describes and critiques the case study approach and the interviews, observations and workshops undertaken. It describes how the empirical research with a main contractor and subcontractors provided a single case study of a notional supply chain. The chapter describes the abductive approach taken to the case study research using Dubois and Gadde's (2002 and 2014) *systemic combining logic*. The research framework, against which the case was mapped out, is described. The influence of both the empirical findings and theory on the direction of the research is described. Finally in this chapter the research journey is described, outlining the direction and redirection of the research and the learning of the researcher.

Chapter 4 deals comprehensively with the primary research. The results of the research are presented in quotations that show data on the realities of contractor costing deep into the supply chain. The quotations are presented against the research framework providing the analysis of the findings, which identifies problems with the nature of cost information created. It presents a picture of information that is created on costs and retained within firms in the supply chain that is disconnected from the information that is passed between firms in formal cost models. It also presents a picture of cost bargaining in construction bidding and delivery. The findings show that commercial buying is the cornerstone of supply chain operations. It also shows the extent of planning and preplanning of work packaging and construction methods that was undertaken in the delivering of projects. Construction delivery was found to be negotiable as well as construction costs.

Chapter 5, the discussion, provides a confrontation between the primary research and relevant theory. Drawing on information theory and soft systems theory it theorises the problems of the nature of cost information created and explores better accounting for improvement through BIM. Using Beynon-Davies (2011) idea of forma, informa and performa it analyses both the methods of costing and the system of costing. It concludes that data distortion in cost information results from a mixture of direct measures, standard rates, bargaining, judgements and intentional errors in the creation and use of cost information. It thus reveals the problematic nature of the cost information created in the supply chain as information that is not agreed on to account for improvement, even though it is agreed on for establishing a price and making payments. This prompts a description of the costing system and its feedback loop, and the conclusion that the feedback loop in the current system of contractor costing creates stability but maintains the status quo. The discussion compares the reality of contractors' cost information with improvement views and their associated methods of costing from literature. This leads to a redefinition of the problem from the pursuit of greater detail in cost models to simpler cost models that are more useful for improvement deep into the supply chain. A new approach then is presented.

Chapter 6 brings the thesis to a conclusion, providing a summary of the thesis, reflecting on the research's achievements of its original aims, identifying the research contributions, identifying limitations of the study and finally making recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Information is a key ingredient in the organisation of societies and in today's world information technology is a key channel for the presentation and flow of information and a key driver of change in society. Information on cost appears everywhere in life. In life in the construction industry, Best and Meikle (2015) observed that construction project cost models differ around the world, but construction everywhere is criticised for its high cost. Cost reduction is a frequently cited, but not uncontentious, aim in the improvement debate in construction. Although there is no universal agreement in the improvement debate about what improvement looks like, the idea that there is room for improvement is agreed across the industry.

This chapter starts by drawing on literature on the sources of the cost information created by main contractors and their supply chain and the use of the information created. This draws on literature on the theory of construction project estimating and tendering and its associated formal project cost models. Literature more influenced by practice is then presented on the commercial cost management practices of contractors and subcontractors and its influence on formal project cost models.

This chapter then looks at the role of the construction improvement debate in motivating contractors to achieve improvements and the ability of the industry to cost and reward for those improvements. Literature is presented that shows that the construction improvement debate appears to be geared more towards pull from the demand side of the industry through new forms of procurement and design decisions, than push from the supply side of the industry: main contractors and their supply chain. Literature suggests that in manufacturing the concepts of *Supply Chain Management* (SCM) and *lean thinking* are the main interventions towards improvement in manufacturing supply chains. Literature is presented on the uptake of these two interventions in manufacturing industries. Literature is then presented their application and uptake in construction. Finally literature from construction is presented that points to the nature of cost information created as a limiting factor on efforts to cost and reward improvements through SCM or lean practices.

In this light, it is relevant to see how other industries have developed cost information associated with SCM and lean. Literature is presented from management accounting standard costing methods and refinements through Activity Based Costing, Lean Accounting, Resource Consumption Accounting and Throughput Accounting. Costing design led change through Value Engineering and Target Costing is then presented. Costing process led change through ABC, Lean Accounting, Resource Consumption Accounting and Throughput Accounting is then presented. Lastly literature from supply chain costing is presented to aid strategic decisions across supply chains. These stem from Transaction Cost Economics and include, ownership costs, customer response costs, and overhead cost (through activity based costing).

The chapter moves on to the arrival of Building Information Modelling (BIM) in construction. Literature is presented on how BIM models the world of construction and deals with approaches to construction improvement. Literature is also presented on how cost management in BIM fits into this picture.

In order to better understand the nature of the situations that BIM is seeking to intervene in, this chapter looks upwards and introduces literature from the field of management science on the idea of systems thinking and its associated metaphors of hard and soft as two different ways to model the world and approach change. Literature is then presented that has used the distinctions of hard and soft systems in the improvement debate in construction.

Finally, this chapter looks forward and literature from the field of information theory is presented that explores the nature of information, in order to better understand *nature of measurable information* in general and the value of computer modelling in working on problems of construction improvement and motivation of improvement through financial reward.

2.2 Contractors' costing practices

2.2.1 Standard project costing methods

Ashworth *et al.* (2013) explain that in the UK, there are detailed and specialised accounting conventions to measure construction projects. They explain that today's measurement conventions first emerged in the industrial revolution when contractors compiling competing bids for a project started to jointly employ a surveyor to measure quantities from the drawings. This eliminated the previous duplication of effort by competing contractors. Subsequently, construction clients took on the task of measuring quantities themselves by employing a measurement surveyor, a practice that continues to this day. Davis *et al.* (2009) explain that measurement conventions arose and today projects are measured in accordance with either *formal*, detailed, standardised methods of measurement presented in a *bill of quantities*; more *informal*, less detailed, methods of measurement that are specific to a firm; or a mixture of both. The formal and detailed conventions for the measurement of work as the basis of a project cost model, reside substantially in quantity surveying textbooks. In the sphere of quantity surveying measurement, textbooks such as Seeley (1997), Cartlidge (2017), Ashworth (2013) and Ostrowski (2013) draw on UK's industry standard methods of measurement such as The Royal Institutution of Chartered Surveyors, New Rules of Measurement 2 (RICS, 2012) or its predecessors. Ross and Williams (2013) point out that although formal bills of quantities are in decline, most contractors adopt measurement conventions that are at least loosely based around standard methods of measurement. Winch, (2010) notes that the measurement conventions set out in standard methods of measurement take the form of a *Product Breakdown Structure* (PBS*)*: a breakdown of a project into individual, measured items (also referred to as objects or components) that together make up the whole building. Ross and Williams (2013) argue that what is significant is that, irrespective of the type of measurement conventions used, the resulting priced document is given the functions of establishing a price to the buyer, a budget to the seller and an agreed payment schedule.

The conventions by which competing contractors estimate the costs of the measured work is explained substantially in estimating and tendering textbooks. In the sphere of estimating and tendering, these textbooks (such as Towey, 2012; Greenhalgh, 2013; Kirkham, 2015; and Brook, 2017) draw on the Chartered Institute of Building's Code of Estimating Practice (CIOB, 2009). The conventions set out in estimating codes for contractors take the form of *Work Breakdown Structures* (WBS): a breakdown of the project into processes such as bricklaying, plastering and roofing with their associated temporary work (Winch, 2010). Winch (2010) notes that WBSs are process orientated and based on the contractor's Organisational Breakdown Structure (OBS), which breaks work down between different trades. Winch (2010) notes that the difference between object orientated PBSs codified in standard methods of measurement, and process orientated WBSs used by contractors for estimating costs, can cause problems of integration.

Winch (2010) describes how contractors create WBSs for both work planning and cost estimating purposes and approach the task of building up a cost estimate from the bottom up. Texts on estimating and tendering (Towey, 2012; Greenhalgh, 2013; Kirkham, 2015; and Brook, 2017) identify the same three categories of sources of information for estimating and tendering. These three categories are described as: estimates of the use of a contractor's own resources, quotations for work from subcontractors and overarching strategic tendering decisions. Kirkham (2015) contends that regardless of the *project delivery method*, the approach to construction procurement on a project, main contractors and subcontractors have the same task of building up a tender price from these three distinct categories of cost information.

Greenhalgh (2013) analyses the three categories of cost that build up to the costs presented in the formal cost model. Firstly in terms of a firm's estimates of the use of their own resources: Greenhalagh (2013) explains that cost estimates for work directly carried out by a contractor can be built up from *first principles:* the activities that consume a firm's own internal resources of labour, materials and plant. These internal resource costs can be allocated to either *preliminaries* (site overheads) or *measured items*. He explains that a measured item, such as a square metre of a brick wall, is a component of the finished building with a measured quantity and a specification that influence the resources required. The materials required are calculated by a simple mathematical relationship that includes allowances for material waste. The labour and plant required are based on standardised rates for labour productivity and plant utilisation come from either a standard rates within a firm or industry standard price books. The estimator then uses their expert judgement to adjust these rates for project factors. Greenhalagh (2013) argues that how a contractor makes best use of their internal resources is the main competitive differential between competing contractors.

The second type of cost information that builds up to the costs presented in the formal cost model described by Greenhalgh (2013) is comparative prices for packages of work provided by competing subcontractors in each trade. Here, Greenhalgh (2013) asserts that the calculations and judgements made about the use of labour, material and plant (as covered in the paragraph above) and the size and apportionment of risk contingencies, overheads and profit (to be covered in the next paragraph) are usually hidden from the receiving buyer. He says that the buyer can therefore only compare subcontractor quotations, negotiate and include the most favourable quotation on the basis of either lowest price or best value. He reports that before negotiation, subcontractors are required to have included any recognised, standard *trading discount* for their trade.

Greenhalgh (2013) describes the third type of cost information that builds up to the costs presented in a formal cost model: the overarching strategic tendering decisions that convert an estimate into a tender. He describes how contractors and subcontractors must make expert judgments and best guesses about allowances for design and other risk contingencies and about the required *margin* or *mark-up* to recover a contribution to indirect, a firm's overheads and earn a profit. He says that the allocation of the indirect overheads of a firm is based on the use of internal resources and allocated to a project using a calculation based on a prediction of the firm's annual turnover across all of a firm's projects. He says that the allowance for design and other risk contingencies is based on thinking about the degree of project uncertainty and the allowance for profit is based on thinking about competition within the construction market.

2.2.2 Commercial pricing decisions: their influence on standard project cost models

Researchers who have documented contractors' commercial cost management practices recognise a wider range of forces acting on cost information. Firstly, information about the use of resources may not be created in the first place. Brook (2017) documents his experience of how contractors' standard estimating conventions are used in practice and argues, "sometimes contractors have difficulty finding time to apply first principle costing to tenders". Ntuen and Mallick (1987) noted that there is a branch of alternative, informal, less detailed methods of building up costs of a project that rely on an estimator's experience and judgement. He calls these *experience-based estimating*. Law (1994) found that in practice contractors use their own informal methods of estimating that are specific to their firm. Skitmore and Wilcock (1994) found that small contractors presented with formal, detailed cost models to price for tendering, estimate the costs of around half the measured items using formal, detailed methods of estimating and estimated the costs of other measured items using informal, experience-based estimating.

Secondly, information about the use of resources may be obscured in a model by commercial behaviour. Ross and Williams (2013) draw on their experience and past research on commercial accounting in construction firms to look at the flow of cost information through the supply chain from the firm that will do the physical work to costs to the client. They identify that it is unlikely that first principle cost information that shows how a subcontractor plans to use their internal resources will pass up the supply chain. So a contractor may not have a detailed understanding of their subcontractors' costing basis. They also point out that as cost information flows up the supply chain many contractors are guarded when it comes to conversations about risk and margins. Laryea and Hughes (2010) in research into the actual process of how contractors price risk show that even within one organisation assumptions about contingencies for risk, overheads and profit may be obscured in the allocation of costs across a cost model, as different individuals and teams influence pricing levels at different stages of a bid.

Others have shown that as information flows up the supply chain from the subcontractor who will do the physical work to the client, information about use of resources may also be obscured when the allocation of costs across a formal cost model is treated as an opportunity to maximise income or cash flow. Kenley (2003) and Cattell (2012) in empirical studies found that many contractors implement tactical pricing by using weighting strategies across a cost model to manipulate cashflow in their favour. Harris and McCaffer (2013) explore contractors' pricing strategies and identify *frontloading* as another distortion applied to cost models to maximise positive cashflow: moving contingencies, overheads and profit and sometimes labour, material and plant costs from later to earlier items in the cost model, for example from painting to excavation items or preliminaries. They also identify *loading* of specific rates: moving costs to items where increased quantities are expected in variations or claims. Rooke *et al.* (2004), in an ethnographic study of contractors, similarly found a culture of loading specific items that were known to be under-measured at contract stage in order to claim later when the quantities were re-measured. In extreme instances illegal practices may be used to distort cost models; such as *bid shopping,* in which the lowest price is disclosed to competitors who are invited to beat it (Vee and Skitmore, 2003) or *overpricing*, also known as *cover pricing*, an extreme instance of which is the illegal practice of *collusion* (Lowe and Skitmore, 2006). These examples show how cost information that is reliably tied to resources may be either not created in the first place by the contractor who will directly provide the resources, or be lost in the cost model when it is obscured before it is passed between one firm and the next.

The increase in the extent of subcontracting increases information loss across the boundaries between organisations. In a review of subcontracting Hughes *et al.* (1997) explain that main contractors' general reduction in directly employed workforce and general increase in the level of subcontracting has been driven by technological, political, social and economic change since the 1970s. In a review of the construction industry structure from government statistics, Abdel-Razek and McCaffer (1987) suggest that success in obtaining tighter and tighter quotations from subcontractors during the recession of the early 1980s is amongst these factors contributing to the increase in the extent of subcontracting. Fryer *et al.* (2004) found that subcontractor quotes made up the majority of a main contractor's costs with main contractors typically subcontracting over 80% of their work. Ross and Williams (2013) argue that this fundamental change in the industry's structure means that contractors' skill in negotiating quotations with subcontractors is "a significant competitive differential between competing contractors". However Hughes *et al.* (2006) suggest that the imperfect market, in which main contractors negotiate within a limited pool of subcontractors, acts as a limit to the competitive differential between main contractors. This, and the work of Ross and Williams (2013), contrasts with Greenhalgh's (2013) assertion that "contractors main competitive advantage lies in how they make best use of their internal resources". It is common for the price basis of subcontracts to differ from the price basis of the firm they are contracting with. Winch (2010) outlines the price basis of *spot contracting*, an agreement to carry a defined piece of work for a lump sum. Known as *sequential spot contracting* when rates of pay are agreed task by task. The most common form of payment agreement under this practice is project-by-project agreement of a lump sum for a specific task. The lump sum is paid on completion of the task, not on time spent. Winch (2010) points out that this practice is part of the industry's standard business model.

Ross and Williams (2013) describe how, once a contractor has won a project, the site team has the job of post-contract cost control: to build the project within the budget they have been given through the contract. They describe how the site team will often get new material and subcontractor quotations and compare these to the budget. They explain that this opportunistic, but standard, practice of undertaking a *secondary competitive tendering process* with subcontractors and suppliers nearer the start on for each trade, often requires subcontractors to give an *additional trading discount* on top of the standard trading discount offered by subcontractors in the first competitive process. As new prices are obtained, the site team carries out regular reconciliation of costs to completion against the budget allowance in cost *value* *reconciliation*. Ross and Hughill (2006), in an empirical study that involved a detailed examination of contractors' post-contract cost reporting processes in practice, found that the effectiveness of modelling *actual* or *outturn* costs during the post-contract stage is reduced due to "entanglement of cost and price data". They further argue that few organisations have formalised systems for collecting and analysing data from site to refresh the databases they use in estimating. Al-Hasan *et al*. (2006), in a survey of subcontractors, found that around half of the subcontractors involved did not have any historical data collected in their firm about labour and plant productivity from observations on site because there was a lack of confidence in structured feedback from site, relying instead on judgement and experience.

2.2.3 Alternative price basis in procurement: moves towards financial incentives for improvements

Hughes and Kabiri (2013) note that approaches to construction procurement are complex and often described in an incomplete way. They developed a procurement framework that comprehensively defines the range of procurement options available to clients for project delivery. The framework has six dimensions: source of funding, selection method, price basis, responsibility for design, responsibility for management and responsibility for supply chain integration. They give examples of different price bases such as cost-based labour and materials, single price for a whole building, lease of a managed facility, or competitive dialogue. Winch (2003) notes that despite options in procurement, pricing documents in the form of detailed bills of quantities still play a crucial role as a model for presenting a contract price, setting the contract budget and establishing stage payments. He notes that projects in which a contractor has responsibility for design the contractor presents the contract price in a model that is a summary *contract sum analysis:* a series of lump sums of money against defined elements, trades or stages of a project.

In a significant move away from the requirement for project cost models to provide only for establishing a price, budgeting and payment, the debate on construction improvement has moved to building financial incentives for improvements into the price basis of projects. The ability of cost information to account for improvements becomes critical under these methods. *Target Costing* (TC) (Ansari *et al.*, 1997) became widespread as a strategic management tool in manufacturing as a method for controlling costs to a target. A target cost is set by the client as an alternative to controlling costs to a fixed budget in a contract sum. TC has been adapted to construction through *Target Value Design* (TVD) (Zimina *et al.*, 2012). Zimina *et al.* (2012) explain that TVD requires early contractor involvement in design, and looks for efficiency savings by rewarding contractors and key subcontractors with a financial gain share. It achieves this by using a *cost plus incentive fee* method. It establishes *actual* costs through open book accounting (as described in Section 1.2) and shares the difference between target cost and actual cost. Amongst the body of research into TVD in construction (Ansari *et al.*, 1997; Ballard, 2011) there is a strand of empirical research that takes the contractors' perspective. These empirical studies report significant limitations. Nicolini *et al.* (2000), in a study of two demonstration projects that used TVD, conclude that "UK commercial cost management practices are a major barrier to rewarding efficiencies through a pain/gain sharing payment process as contractors were not able to cost alternative design proposals due to a lack of basic knowledge of costs on the construction supply side". Pennanen *et al.* (2011) looked at TVD in theory and conclude that more transparency of cost information is needed to gain commitment, but do not address specifically the problem of the nature of the cost information available. Zimina *et al.*, (2012) looked at TVD in practice and conclude its application is limited by factors including the cost information available for setting a target cost.

A similar, but simpler way to set up financial incentives though a new construction delivery model, is the decoupling of profit margins from cost reductions in a lump sum contract through *Supply Chain Cost Management* (Holti *et al.*, 2000). Used in conjunction with early contractor involvement in design this facilitates design savings by decoupling margin from each measured item in the cost model so that reductions costs can be made without eroding contractors margins. This means that contractors and key subcontractors are guaranteed a total margin upfront. Ross and Williams (2013) argue that this way to reduce costs directly addresses the disincentive in standard project delivery models, where cost savings lead to lower turnover hence lower margin. However they conclude that lack of transparency in UK costing practices is a major barrier to rewarding cost reduction through a payment process that protects contractors' margins.

Where incentive based contracting is used, Saad *et al.* (2002) note that cost reduction tends to come from product design decisions. Examples of savings that come from process improvement decisions about the way a project is constructed are rare. Authors have also found that change brought about by incentive-based contracting has been limited by the continued use of lowest price competitive tendering. Nicolini *et al.* (2000) report that incentive-based contracting is based on lowest price competitive tendering with add-on incentives for collaboration. They contend that this means that there is no reallocation of risks and rewards to subcontractors in a way that may otherwise motivate them to identify improvements. Saad *et al.* (2002) similarly report the continued use of traditional arms length buyer-supplier relationships. They contend that this means that there is no change in demand-side behaviours that may otherwise motivate change in supply-side behaviours towards greater collaboration and mutual benefit.

2.3 Perspectives on construction improvement

2.3.1 The broad debate

This Section takes a broad overview of the sources and definitions of construction improvement in literature and its context in the macro-economic environment. The literature establishes that construction improvement is geared more towards pull from the demand side, the client, than push from the supply side, the contractor and their supply chain. From this overview *Supply Chain Management* (SCM) and *lean* approaches are established as the main focus in literature for improvements by the main contractor and their supply chain. Section 2.4 explores these two improvement concepts in more detail, their origins and uptake in manufacturing and application and uptake in construction. This sets the scene for an exploration of alternative cost methods, from management accounting that relates to SCM and lean approaches in the following section 2.5.

As set out in the Introduction (Section 1.1) in the UK the construction industry is under continuous pressure from government and best practice groups to reduce costs as a measure of improvement. Farmer (2016) is the latest in a series of reports. Farmer (2016) sees the industry at a “critical juncture” at which deep-seated structural problems and poor outcomes on productivity and predictability need to be addressed together. Alongside this push from best practice bodies, academics Lansley (1987) and Hillebrandt *et al*. (1995) found that contractors and subcontractors themselves are constantly seeking cost reduction strategies in order to be more competitive and profitable. Cost reduction is a frequently cited aim for improvement through BIM. Both the Cabinet Office (2011) and Business Innovation and Skills (BIS) (2014) promote BIM to enable change to meet cost reduction aims. Dissatisfaction with the status quo has motivated a broad and long debate on construction improvement.

The macro-economic environment provides the backdrop to the construction improvement debate. Green (2011) critiques a century of political change and attempts by successive governments to shape the performance of commerce in general through the macro-economic environment. He reports that the big shift in the economy was one from a more stable, state-controlled economy post WWII to a more cyclical, neo-liberal, free-market economy since the late 1970s. As set out in the Introduction (Section 1.1) Hillebrandt (2000) extensively charts the resulting market structure in the construction industry. She describes the industry's boom-and-bust macro-economic cycles and the resulting fragmented market (many small local firms including a separation of design and construction expertise in different firms) working in short term project-based relationships, mediated by market-based transactions with an overriding adversarial culture. Love *et al.* (2004) concur that the resulting industry structure is fragmented with many small companies responding to discrete projects in a cyclical market.

2.3.2 Improvement concerns and their focus on pull from demand-side action

As set out in the Introduction (Section 1.1) in recent decades successive government-backed reports have sought to motivate improvement in the construction industry. Latham (1994) in 'Constructing the Team' advises the construction industry to adopt a less adversarial culture by embracing more cooperative and trusting relationships, with "partnering" as a solution. Egan (1998) in his report 'Rethinking Construction' goes further than partnering and advises the construction industry to adopt *supply chain management* and *lean construction* and sets goals for improvement through *benchmarking*: a set of standard goals across construction projects. He also advises the industry to adopt a less short-term focus by forming *long-term alliances* instead of one-off project partnering. Egan's (2002) report 'Accelerating Change' builds on the preceding reports, specifically suggesting that it is possible to achieve better *value* by integrating clients and suppliers.

Turner (2004) noted that these successive reports advocate mainly client-led action to motivate improvement through their expertise in project procurement, also known as project delivery, in other words from *pull* from the demand side of the industry. Langford and Murray (2006) argue that contractors take new procurement led initiatives on board. But in practice, the macro-economic environment that the construction improvement debate operates in presents barriers to be surmounted in fully realising the intended benefits of new procurement led initiatives. Section 2.4 will therefore turn to procurement led initiatives in construction improvement and the barriers to be surmounted by contractors and subcontractors in implementing these.

BIS (2013) shows that, measured by investment in research and development, the evidence of improvement from action by contactors, their subcontractors and suppliers, in other words *push* from the supply-side of the industry, is relatively low compared to other industries. BIS (2013) and Pries and Doree (2005) found that the main source of research and development funded improvement and innovation in the industry from the supply side arises from product innovation driven by the expertise of suppliers. They explain that by suppliers they encompass suppliers of materials, components, modular units, tools and machinery. They attribute this firstly to the fact that suppliers are driven to innovate by the market as these firms are compelled to be *price-makers* in their market. Secondly, to the fact that suppliers have a manufacturing-based business model that allows for relatively high upfront investment in research and technology and thirdly, to the fact that suppliers are heavily influenced by innovations from other industries. Sergeeva and Radosavljevic, (2010) found improvement from the expertise of contractors and subcontractors to be rising but limited and restricted mainly to incremental process improvement and some new technologies. They attribute this to the fact that contractors are not compelled to be price-makers in the market as there is little differentiation between contractors. In the Introduction (Section 1.1) the credit-based business model of contractors was outlined (Boukendour and Hughes, 2014). Boukendour and Hughes, (2014) argue that the credit-based business model adopted by contractors does not allow for high upfront investment in research and development.

BIS (2013) also identifies that research and development in the sector arises outside of formal research and development budgets through investment in more intangible activities, such as design and construction expertise and new technologies. Design expertise and hence design-led improvement, traditionally sits on the demand side of the industry, with the client employing the designers. The industry is criticised for a lack of integration between design and construction expertise (Latham, 1994; Egan, 1998 and Farmer, 2016). In response design expertise can be integrated with construction when design expertise moves to the supply side through procurement models, such as design and build, that hand over decisions on design to the contractors. Alternatively Early Contractor Involvement (ECI) (Mosey, 2009) allows contractors to influence design decisions using their construction expertise. Some authors have articulated potential advantages of ECI. Grey (1983) points out that design details can be difficult to construct unless the expertise of the contractor is taken on board. Langford and Murray (2006) noted that the management expertise of contractors and subcontractors is key to decisions about construction method. ‘Designing for Buildability’ (CIRIA, 1983; Adams, 1989) encompasses design and construction, but is led by changes to design. ‘Constructability’ (Griffith and Sidwell, 1995) also straddles design and construction, going further than Buildability in scope by being led by changes to both design and construction methods.

The next section shows that literature suggests that the concepts of supply chain management and lean are the two main remedies for improvement in construction. The potential of the adoption of these new approaches in BIM to support improvements is later discussed in section 2.6

2.4 Perspectives on supply chain improvements

2.4.1 Introduction

From the array of improvement efforts *Supply Chain Management* (SCM) and *lean* approaches potentially draw directly on the expertise of contractors and subcontractors in mobilising resources in site operations to deliver construction projects. This section charts the emergence of SCM and lean approaches in business and then their adoption in construction.

This Section firstly explores responses to SCM in commerce through a review of definitions of SCM and then its uptake in practice. The literature finds that even in the manufacturing industry, where uptake is driven to a large extent by the existence of long-term relationships, the uptake in practice is reported to be limited in the extent to which it is used within firms, and the extent to which it involves the lower tiers of the supply chain. Given that promoters of SCM advocate large advantages to be gained, the relative scarcity of moves to SCM in manufacturing suggest that there are major hurdles to overcome. The shift from traditional buyer / seller relationships through competitive tendering is seen as a major hurdle.

The Section then looks at efforts to import ideas of SCM into construction. Use of the same term SCM in construction suggests that it is possible to adopt SCM into construction from other sectors without significant adaptations. Hence this Section contextualises SCM in construction industry with its short-term, one-off, project–based relationships, fragmented supply chains, adversarial relationships and lack of integration between design and construction expertise. The additional hurdles that this context presents to the uptake of SCM in construction are discussed. It is shown that the contractors' business model may reduce the degree of cooperation in relationships between companies. The challenge of estimating costs that evidence savings is also seen as a potential additional hurdle.

2.4.2 Supply chain management in commerce

The supply chain has been a concern in the commerce, mostly in manufacturing and its associated retail sector, for decades. Many authors trace the origins of SCM to the textile and grocery industries in the mid 1980s (Lummus and Vokurka, 1999) in response to increasing competition and complexity from globalisation. Harland *et al.* (1999) describe the emergence of interest in SCM by commerce. Harland *et al.* (1999) note that interest in SCM originated in logistics, the flow of goods in and out of firms, in manufacturing industries in the late 1980s and early 1990s. Porter (1985) states the key concerns for SCM as integration and competitive advantage. He argues that previous cost cutting drives had taken out available cost savings from within firms, so further savings must lie in aligning or integrating the boundaries between firms. Harland *et al*. (1999) identify that the field of SCM broadened out from the field of logistics into a set of beliefs in which "each firm in the supply chain can directly and indirectly affect the performance of all other supply chain members, as well as overall supply chain performance".

Like many popular concepts in commerce, SCM has been defined in numerous ways, from a number of perspectives (Lambert *et al.*, 1998). Mentzer *et al*. (2001) conducted a review of SCM literature. They identified more than 100 definitions of SCM and conclude that this diversity of definitions creates a difficulty for firms trying to make sense of SCM. They found that the supply chain itself is defined in different ways. Viewed from the perspective of an end-product, the supply chain is defined as encompassing the network of companies who carry out activities associated with the complete processing of a product: from raw materials to purchase of the end-product (Lambert *et al*., 1998). Viewed from the perspective of an individual firm an *organisational supply chain* encompasses the network of firms around a focal firm. The depth of the supply chain taken in any definition also varies to incorporate one or more of the lower tiers of the supply chain. Based on their overall review, Mentzer et al. (2001) give a broad definition of the supply chain as '"a set of three or more entities (organisations or individuals) directly involved in the upstream or downstream flows of products, services, finances and / or information from a source to a customer". Mentzer *et al.* (2001) also observe that in all definitions of a supply chain there is an inherent, but not explicit, assumption that there is one focal firm.

Mentzer *et al*. (2001) illustrate that the diversity of definitions of what a supply chain is, is followed by a greater diversity of definitions of what SCM is. This led Mentzer *et al*. (2001) to view SCM in its broadest sense as "a systems approach to viewing the supply chain as a single entity, rather than a set of fragmented parts each performing its own function". From their review of hundreds of definitions of SCM Mentzer *et al*. (2001) identify several types of activities that help to define the scope of SCM. The first is integrated behaviour (Bowersox et al., 1996) in which partners flexibly respond to the needs of end customers. The second is mutual sharing of information (Cooper *et al*., 1997; Ellram and Copper, 1990) in which firms share tactical information, primarily on marketing strategy and sales forecasts, to reduce uncertainty between firms. The third is mutual sharing of risks and rewards (Cooper and Ellram, 1993) to achieve competitive advantage over the long term. The fourth is cooperation through joint product development, planning, control and evaluation. The fifth is sharing the same goal and the same focus on serving the end customer (LaLonde and James, 1994) in a form of policy intervention. The sixth is integration of processes (Stevens, 1989), which covers sourcing, manufacturing and distribution. The seventh is forming partnerships and alliances (Cooper *et al*., 1997) in which firms build and maintain long-term relationships.

Many practices have sprung up to address one or more of these activities. The three main areas are *agile* practices in distribution (Christopher, 2000), *lean* practices in production (Womack *et al*., 1991; Ohno, 1998) and *Strategic Procurement* in sourcing and managing subcontractors and suppliers (Porter, 1985). There is also a *philosophical* branch of SCM thinking that looks at the prerequisites for better relationships between firms, such as trust, good communications, cooperation and collaboration. Mentzer *et al*. (2001) point out that implicit in all definitions of SCM is the fact that supply chains exist, whether or not they are managed. Most often the term SCM is used in commerce to promote change and concerns what should happen to result in improvement. However, sometimes the term SCM is used as purely descriptive term. Mentzer *et al*. (2001) contend that this confusion, on top of

the plethora of definitions, adds to the difficulty for firms seeking to make sense of SCM.
Of the main practices under the banner of SCM in commerce, *lean* (Womack *et al*., 1991) emphases the elimination of waste across the *value stream:* from design through manufacturing to sale. Like SCM, the theoretical scope of lean production (Womack *et al*., 1991) ranges from a single firm (across functional departments, such as sales and marketing, design, operations, logistics and administration) to activities between firms (such as e-commerce and sharing of information on anticipated demand). Womack *et al*., (1991) explain that lean is synonymous with *business process reengineering* in its focus on eliminating waste and improving efficiency through continuous process improvement. Lean will be outlined from literature in more detail in relation to *lean construction* in Section 2.4.3 below. In commerce Green and May (2005) critique the diffusion of lean practices in UK car manufacturing as ranging from change through unique innovation, lean as a catalyst for change in current practices and lean as an add on to existing practices.

Mentzer *et al*. (2001) contend that the difficulty in making sense of SCM may contribute to the limited uptake of SCM in commerce. Emberson and Storey (2006) carried out a three-year study of six international supply chains of blue-chip corporations across manufacturing and retail. They find that SCM is at best, still emerging in terms of both theory and practice. They find SCM was applied in pockets of practice with some direct suppliers, rather than across the whole firm and reaching into the lower tiers of the supply chain. They observe that this piecemeal adoption makes SCM practices vulnerable to being abandoned. They challenge the thinking about the maturity of SCM in manufacturing. Emberson and Storey (2006) found that maintaining the status quo in traditional buyer and supplier relationships was a significant limiting factor to SCM adoption. They found that “didactic buyer-supplier relationships remained the mainstay of supply interactions”. This contrasts with Christopher’s (2000) description of SCM in business as involving significant change from traditional, arms length, adversarial, buyer and supplier relationships.

2.4.3 Importing supply chain management into construction

As explored in Section 2.3.2, a key concern for construction improvement is integration between firms in a supply chain and as explored in section 2.4.1 a key barrier to this is the fragmented industry structure. One branch of SCM is concerned with a fundamental switch from distant, one-off relationships to closer, longer-term relationships in order to initiate greater cooperation and bring mutual benefits for continuous improvement through organisational learning (Tennant and Fernie, 2013; Bresnen, 2009; Cox and Ireland, 2002). However literature finds that the formation of long-term relationships in construction is very limited in practice. Strategic, long-term partnerships and alliances are few. Some long-term alliances have been formed in small parts of the industry such are materials suppliers (Agapiou *et al*., 1998) but efforts towards long-term relationships through strategic partnering are limited. Eccles (1981) viewed SCM from the perspective of the long-term relationships that a main contractor has with its network of subcontractors. He called this the *quasi-firm.* He described the contractor as the integrator for SCM across the quasi firm. Fernie (2005) finds that some contractor-led efforts towards long-term relationships with their network of subcontractors through 'organisational SCM' have been made, such as information sharing on pipeline and e-tendering.

Despite some small moves towards long-term relationships, overall, the construction industry remains fragmented. In this context the most common focus of SCM attention has been efforts towards integrated behaviour in discrete projects (Love *et al*., 2004). King and Pitt (2009) note that client-led efforts towards integrated behaviour in *Project SCM* are the most common form of SCM and driven by procurement. Hughes and Kabiri (2013) point out that construction procurement is complex and there is a wide range of options available to procurers. Amongst the options Love *et al.* (2004) advocate *early contractor involvement* in the design stage of a project through procurement options such as *Design and Build*, *Management Contracting* and *Design, Build and Operate*. Cox and Thompson (1997) pick a different procurement option and advocate procurement for collaborative buyer / supplier relationships. They describe this as a move from *contractual* to *relational* contracting, such as, *partnering*: which seeks to foster better relationships in projects. Nicolini *et al*. (2000) advocate collaborative supplier / buyer relationships as a motivating tool in *Building Down Barriers*, an example of efforts to extend better integration between firms throughout the design, build and operate stages of a project using *single point of responsibly* procurement. Hughes and Kabiri (2013) similarly advocate *incentive* procurement, mutual sharing of risks and rewards in which savings are shared between client and contractor which incentivises the contractor to seek cost reductions.

Gosling and Naim (2009) and Gosling *et al*., (2015), looking at the application of supply chain thinking in construction, define construction as an *Engineer-to-Order*

(ETO) supply chain alongside other project based manufacturing sectors such as shipbuilding and aerospace. They describe ETO supply chains as supply chains that encompass a diverse range of companies who come together to deliver a one-off, complex product, or project. They contrast very customised ETO supply chains with very repetitive *Make-to-Stock* (MTS) supply chains. They emphasise the importance of the *decoupling point* (Hoekstra and Romme, 1992) in supply chains and describe how, in ETO supply chains, the *decoupling point* is located at the end of design stage. They argue that this separates the design and production activities and procurement options tend to be driven by this separation. Williamson (1985) taking an economic view of supply chains in general calls this point the *fundamental transformation*, the distinction between pre-contract and post-contract relations. Winch (2010) applying this economic view in construction concurs. He sees this as non-trivial, as capital sunk into a project by a client cannot be easily switched from this point. As do Flyvbjerg *et al*. (2002).

Contractor-led efforts towards integrated behaviour in SCM in projects focus on greater involvement of subcontractors and suppliers in the construction stage of projects. In this respect, O'Brien *et al.* (1995) consider the logistics of materials management from the materials supplier off-site to where the materials are needed on site. Other authors have charted contractor-led efforts in SCM. Cox and Townsend (1998) advocated increased use of standardised materials and components. Vrijhoef and Koskela, (2000) advocate increased use of off-site manufacturing, the transferring of on-site activities off-site. Authors such as Koskela, (1992) and Vrijhoef and Koskela (2000) consider planning activities in the production stage of construction. This is a key aspect of *lean construction*.

Lean construction (Koskela *et al*., 2002) emphasises better control of the site operation processes of a construction project through a focus on elimination of waste, efficiency and quality. Koskela *et al.* (2002) sees lean construction as inspired by lean practices in the production stage in manufacturing, but responsive to the specific context of construction. For example Koskela (2004) takes Toyota's seven categories of waste in production and adds an eighth category of waste of *making do*, namely starting or continuing a task when not all inputs are present. This additional category recognises the greater uncertainties in a construction on site compared to a manufacturing. Ballard and Howell (1994) work on *last planner* as a collaborative planning practice that anticipates the challenge of making do and tries to eliminate it by ensuring that tasks only start when preceding tasks are fully complete. However Winch (2006) points to the fact that work will come to a stop if full completion is not available. Green (2011) points out that last planner is further compromised by the fact that construction planning tends to be dictated by subcontract packaging rather than the immediate needs of the day-to-day activities of construction.

Fellows (2009) questions the fit of construction industry culture to the diversity of improvement efforts that operate under name of SCM and lean construction. He notes that Latham (1994) identified a real concern in relation to advocating cultural change and Egan (1998) identified a real concern in advocating process change. Pryke (2009) notes that in practice, change in both directions has been limited to very large, high volume, more progressive clients. Bresnen (2009) and Saad *et al.* (2002) find that contractor-led supply SCM efforts do not extend beyond first tier subcontractors and suppliers. Dubois and Gadde (2002) and Hartmann and Caerteling (2010) perhaps get to the heart of the matter when they note that contactor led, competitive pricing remains the prevailing means of subcontractor selection.

Winch (2003) comments on the differing contexts of manufacturing and construction and the effects this has on efforts of SCM and lean construction. He notes that SCM and lean theory and practice are advocated in construction, despite the fact that manufacturing and construction are quite different. Pryke (2009) argues that in manufacturing the existence of long term supply relationships and the relatively intense management of these relationships has been central to the emergence and practice of SCM. He observes that in contrast, in construction the fragmentation of the industry has been seen as a key driver for the growth of SCM as a form of practice. This is because increased fragmentation offers considerable scope for applying theories of SCM in construction. Green (2011) argues that SCM has grown in practice in construction because it legitimises the reliance on subcontractors and acts as a sense making mechanism. King and Pitt (2009) disagree. Pryke (2004) contends that there must be an implication that by using SCM you are doing something more complex than managing a group of subcontractors and suppliers and requires communication with organisations that are not directly joined by contractual conditions.

2.5 Theories and methods of costing in commerce

2.5.1 Developments in management accounting

Management accounting first emerged in commerce in the industrial revolution and its theories and methods remained much unchanged throughout the first seven decades of the 20th century (Van Der Merwe, 2007a). Van Der Merwe (2007a) describes commerce (whether for profit of not) as dealing with “the flow of goods and services, acquired for and consumed in a conversion process to produce outputs (goods and services) in the market place”. Van Der Merwe (2007b) describes the tradition of management accounting within commerce as centred on value (money) saying, “Money is the meta-language of quantitive economic activity and expresses the quantitive flow of goods and services”. Ahrens and Chapman (2007) identify the role of management accounting within commerce when they say that management accounting “can generally be considered as set of methods that link accounting and organisational objectives.” Van Der Merwe (2007b) similarly identifies this link, saying that in commerce, managers are asked to “influence the flow of goods and services to achieve organisational objectives in an optimal way”. He says that the primary principle of management accounting is therefore *causality*. Management accounting aims to provide a “definite relationship to the cost of production”, rather than an “arbitrary and artificial” relationship.

Johnson and Kaplan (1987) in their seminal work in the field of management accounting drew attention to limitations of conventional management accounting in achieving this this aim of quantity-based causal relationship and the need for change. They argued that management accounting had become uninterested in direct measures of activities in the firm, relying instead on what they call *surrogate* financial numbers (Kaplan and Cooper, 1998), which distances a cost model from the thing being modelled, and reduces the value of a cost model as a tool to better manage a business. At this time increasing competitive pressures and complexity from globalisation triggered a period of rapid growth in theories and methods in management accounting.

This Section firstly explores standard methods of costing and then explores the new methods of costing and cost management that have arise since the mid 1980s to provide new cost perspectives. Section 2.5.2 describes the conventional, cost estimating methods that are used in management accounting to model the consumption of resources, establish estimated costs and a budget against which to control costs (Kaplan *et al.*, 1989). This will be seen to be similar to the processes used in construction project costing set out in the earlier section 2.2.1. The next section, 2.5.3, explores new directions in cost management that have emerged since the mid 1980s, responding to concerns of motivating and evaluating improvements across both design and manufacturing processes in commerce. This includes perspectives on cost management between firms that inform cost management in supply chains. In each of these sections, the purposes of these cost perspectives, the sources of the cost information they draw on and their limitations on are set out through literature. Their adoption into construction is also set out through literature.

2.5.2 Modelling consumption relationships and decision support

Kaplan *et al*. (1989) explain that businesses predominantly use *standard costing* (also known as *full-cost pricing*, *cost-plus pricing* or *absorption costing*) to establish the costs of products and add a profit to establish a price in the market**.** They explain that a traditional, volume-based estimate is created to develop a full product cost by combining (a) costs that can be directly traced to the product such as *labour* and *materials* (allocated on volume-based resource cost allocation rates) (b) contributions to *factory overheads* (costs such as labour, materials and machine time that are indirectly allocated to a product based on volume of the product) (c) contributions to *general overheads* (also called *company costs* that are indirectly allocated to products based on volume). Added to this cost is a target *profit* percentage. They argue that by using standard costing, the pricing calculations become straightforward and senior manager input is only required to except to adjust the profit margin. They note that cost-plus pricing places a firm at a disadvantage when competitors with excess capacity try to win business by excluding overheads. They also note that conversely, if demand is unexpectedly high and a constant mark up rule is applied, a firm would not maximise profits. Kaplan *et al.* (1989) conclude that standard costing has remained common practice because it is simple and easy to use. Most firms face thousands of pricing decisions, so it is impractical to analyse changing demand and costs for all products. Standard costing simplifies the many pricing decisions that the firm would otherwise have to make. Standard costing also provides stability to pricing decisions. They conclude that standard costing establishes reference points, which are then adjusted to reflect market conditions. They point out the limitations of these reference points for measuring improvements, as the reference points provide data on estimates of standard productivity rates for labour and plant and standard allowances for waste of materials. The fixed productivity rates and budgets do not incentivise improvement. Van Der Merwe (2007c) notes that standard costing is highly structured, depends on its underlying principles of historic causality and standard rates, and lacks the ability to help managers with decision-making about improvement opportunities. In construction there have been recent efforts to increase the accuracy of some elements of standard costing. Peleskei *et al*. (2015) pursue probabilistic work to more accurately cost risk contingencies. Smith *et al.* (2000) explore stochastic calculations for the performance of excavators in earthworks.

Activity Based Costing (ABC) was developed by Kaplan and Cooper (1998), through a concern to more *accurately* allocate general overhead costs to individual products. They noted that the treatment of general overheads is limited in standard costing, where contribution to fixed costs (which could be factory overheads or company overheads) is calculated by annual total and allocated by volume to different products. IMA (2006) argue that this method of allocating overheads to products works well at an aggregate level of the firm, because an aggregate level is not sensitive to the different demands that different products make on the overheads. But they argue that this does not work well at a disaggregated level of individual products. Turney (1992) says that this became to be seen as a major disadvantage under the competitive pressures from globalisation in the 1980s. So to improve pricing decisions about the contribution that different products should make to the fixed costs of overheads, more detailed measures were developed to examine what causes *overhead costs* to arise. They identify the main cost drivers for a firm's overheads as transactions not volume**.** Kaplan and Cooper (1998) argue that this led to the measurement of previously unmeasured activities within a firm, such as number of set ups, inspections, or payments. They describe how these *transaction costs* (see page 40) can be allocated to individual products. Thus, ABC describes a costing method that traces transaction processes to activities and then to products, in order to provide greater detail for costing of overheads. This top down disaggregation has rules to establish when to stop so further disaggregation only occurs if there is a significant difference in costs. Maskell and Kennedy (2007) argue that ABC provides information of value only in mass-production and is not useful in customised-production. Van Der Merwe (2007c) notes that ABC is highly structured, depends on the underlying principles of historic causality and standard rates, and, like standard costing, lacks the ability to help managers with decision-making about improvement opportunities.

Tsai (1998) presents an exception to this, giving an example of using ABC to help managers decide about the overhead costs of a firm's quality management process. He presents an example of using ABC to measure the *costs of quality*, in which the identification of current costs leads to the re-planning of activities and cost reduction. The problem that is addressed is the reduction of prevention, appraisal and failure activities: the activities associated with a firm's quality management process. Tsai (1998) bases his model on historical costs and comments that the sources of cost information are various. He reports that "some quality costs are readily available from a cost accounting system (e.g. scrap and rework costs); some can be derived from the data of activity reports (e.g. repair and inspection costs). Nevertheless, a large portion of quality costs need to be estimated in some way." He argues that for example, the opportunity costs of lost customer goodwill and lost sales, cannot be directly measured but proxies can be used. He argues that there are other examples of costs, such as the costs of producing excess inventories or double handling materials, which are indirect failure costs and can be estimated by expertise. He notes that calculation of costs needs to include estimates of apportionment of time of people who do not usually record how they spend their time between different activities. He asserts that once all the activity costs of quality have been identified, *Total Quality Management* (a management concern of continuous improvement) or *Business Process Reengineering* (a management concern with big one off changes) can be used to reduce these costs.

In construction, O'Brien and Fischer (2000) carried out a practice-based case study research in a construction firm and applied ABC to calculate the overhead costs that they call the *cost of capacity* and which they define as the fixed overheads that a construction firm carries that have to be shared between projects. Staub-French *et al.* (2003) carried out a practice-based case study in a cost consultant firm. They used ABC to account more explicitly for the cost of design features in construction projects based on the preferences estimators had for when to adjust standard costs. They expanded the range of product features that were identified from the design model and traced costs to these new measured features. This aimed to help estimators customise early stage construction cost information based on design features. They developed a *feature ontology* based on estimator's preference. Lawrence *et al.* (2014) subsequently developed this ontology in BIM as will be seen in Section 2.6.2.

Lean Accounting (LA) (Womack and Jones, 1996) is described by Maskell and Kennedy (2007). They note that whilst ABC focuses on more accurately forecasting overhead costs to individual products, LA has emerged to help managers to track decisions about continuous improvements that are identified through lean thinking. They note that LA emerged in the mid to late 1990s alongside lean manufacturing and lean thinking to provide a measure of the financial impact of improvements that are important in lean thinking, such as just-in-time deliveries. They argue that LA provides information that is useful for customised-production. Cunningham *et al*. (2003) explain that LA considers the activities of *value stream*, as defined in Section 2.4.2 encompassing design, manufacturing and sales. The focus is on the cost of materials. Labour and machine costs are considered as fixed and unavoidable (on the basis that machines are fixed and labour can be deployed elsewhere). There is little or no allocation of overheads. Material costs therefore lead decision making. Costs are typically collected weekly. Materials costs are presented alongside other financial information on other variable costs, fixed costs, revenue, profit and return on sales, and alongside non-financial information such as just-in-time deliveries, days of inventory, process quality and productivity. Maskell and Baggaley (2006) contend that LA brings together a dashboard of *real* numbers and presents them in a simplified model. This information is used for decisions about (a) weekly performance (b) the impact of lean improvements through current state and future (after lean improvement) state and (c) the impact of capital make or buy decisions. LA thus tracks actual costs of materials, and sometimes a few variable overheads and compares these with actual revenues, providing managers with weekly financial information on the actual revenue, cost, profit and return on sales. Maskell and Baggaley (2006) argue that in contrast to standard accounting LA facilitates an analysis of capacity. They argue that as lean improvements eliminate waste they create available capacity in the form of machine time, people's time and physical space. The financial impact on a firm's bottom line comes from decisions about how to use this new capacity. However Maskell and Baggaley (2006) argue that lean's preference for standardisation runs counter to customer demand for customisation. Van Der Merwe (2007c) notes that LA has a simpler structure than standard costing or ABC, but shifts the focus away from causality to *flow*, away from a labour, materials and machinery to materials, and a narrower focus on value stream activities as the cost consideration for management decisions.

Throughput Accounting (TA) and *Constraints Accounting* (CA) are described by IMA (1999) as the costing methods associated with the *Theory of Constraints* (TOC) (Goldratt, 1990). They describe the TOC as concerned with managing constraints that stop the flow of products through the supply chain in machine-paced environments, where the dominant costs in the system are fixed. They point out that reducing the full product costs that are produced by standard costing is not the goal of TOC, so new models of TA and CA are associated with TOC. They describe how each use *real* numbers on sales, material costs, subcontracting costs, direct labour and overheads to consider the role of constraints. TA provides an understanding of throughput, inventory and operating expenses for decision-making about alternatives at the level of the firm. They describe CA as a stage beyond TA, when there is a need to measure physical constraints to operations and whether operational decisions will result in better use of the worst constrained resources. IMA (1999) argue that, similarly to lean, TOC places short-term emphasis on eliminating waste in processes through a planning process, not on reducing costs through a costing method. They argue that as improvements result in better use of the worst constrained resources this will increase total sales and speed up delivery. The financial impact on the firm's net profit, return on investment and cashflow comes from decisions about how to improve throughput. Van Der Merwe (2007a) notes that TOC is a further simplification on LA, relying more on observable information than historical standard performance, therefore having less structure. He argues that this reduces the focus of the range of decisions it is concerned with, as throughput is the only consideration for management decisions.

Two new pricing bases for controlling costs to a target have emerged in management accounting. *Value Engineering* (VE) (Miles, 1961) and *Target Costing* (TC) (Ansari *et al*. 1997) are methods that seek to pinpoint cost reductions, largely from product design changes (Surowiec, 2103). VE (Miles, 1961) is a process of assigning predicted costs to functional properties of a product. It is thus a means of linking functional design to cost. Kaplan *et al.* (1989) note that in VE, value is largely associated with minimum acceptable function to the consumer and reduced cost. They note that VE is usually used on a completed design when cost reduction is needed, but comes into its own when it is used during design. VE underpins TC (Ansari *et al*. 1997). TC is a system of cost control, which uses information on functional properties of a design to force cost reductions. Evidencing potential costs savings in VE or TC centres on changes in design through using alternative materials and components or reducing volume. *Kaizen Costing* (KC) (Kato, 1993) follows on from TC. TC is applied during the design stage and KC is a system of cost control to force cost reductions during the production phase. KC and lean thinking take “shop-floor” modelling as their source of information for decision-making and focus on the seven lean wastes.

2.5.3 Modelling inter-firm consumption relationships and decision support

New methods of cost forecasting and control have been described in Section 2.5.2 above. These methods can be applied both within a firm (intra-firm) and between firms (inter-firm). Surowiec (2013) describes the concept of Inter-Organisational Cost Management (IOCM) as an “extension of intra-organisational efforts to manage costs”. He notes that bargaining over price and quantity is the usual method of cost management between firms, but there are examples where new cost information is shared to enable different interactions in the supply chain beyond bargaining over price and quantity.

Barney *et al*. (1996) report that neoclassical economics largely ignored inter-firm costs until Williamson (1975) produced a theoretical model of *Transaction Cost Economics* (TCE). They explain how TCE views firms and markets as alternative governance structures that differ in their transaction costs. TCE seeks to compensate for flaws in the market-oriented view of perfect competition by focusing on how organisations can avoid dependence and deal with opportunism. Williamson (1989) explains that TCE is concerned with the economics of trust. He assumes that two parties in a transaction start from a position of low trust, assuming that the other party will gain something at their expense. Each party introduces controls using offensive and defensive strategies in self-interest and costs escalate as a result of this. Williamson (1989) therefore contends that major cost reduction opportunities exist in transactions. In this context transaction costs are the costs particular decisions about the governance arrangements of make or buy. Looking at the level of supply chain structures, Williamson’s (1989) theory suggests that transactions costs include both the direct costs of managing relationships and the possible opportunity costs of alternative decisions. Rindfleish and Heide (1997) show that TCE is based largely on qualitative assessment of the degree to which alternative governance arrangements meet a range of behavioural and market measures. TCE has also been criticised for focusing on the solutions of either make or buy, ignoring the possibility of intermediate solutions based on relational contracts (Ghoshul and Moran, 1996). However Surowiec (2013) and Mouritsen *et al.* (2001) conclude TCE did throw a spotlight on the major objective of SCM, which is to increase efficiency across organisations in the supply chain. This Section next sets out the theories inter-firm cost management that grew up alongside operational efforts in SCM.

Kajuter (2002) charts the development of concepts of inter-firm cost management starting with Porter (1980) who introduced the concept of *Strategic Cost Management*, the use of cost data to identify strategies that will provide competitive advantage, and its three strategic ideas of (a) the *value chain* in which cost management efforts should extend across organisational boundaries (b) *strategic positioning* in which cost management efforts should focus on competitive strategy, be that cost or quality leadership (c) *cost drivers* in which cost management efforts should focus on drivers that create cost advantage such as scale and links across organisations. Kajuter (2002) reports that Porter (1980) had identified some important aspects of managing costs in the supply chain, but argues that Porter's (1980) key ideas remained separate. Kajuter (2002) identifies that Cooper and Yoshikawa's (1994) work subsequently introduced a slightly more structured concept of managing costs in the supply of *Inter-Organisation Cost Management* (IOCM). Cooper and Yoshikawa (1994) say that opportunities for cost reduction lie firstly in the relationships between firms, secondly in collaborative product development and thirdly during manufacturing. Kajuter (2002) then identifies Seuring's (2002) concept of *Supply Chain Costing* as work that built on the relationship and product development ideas of IOCM and introduced the idea of transaction costs. Seuring's (2002) concept considers direct costs (labour and materials); activity based costs (overhead labour, materials and machine time) and adds transaction costs (overhead labour time that results from relationships with other firms) and the trade-offs between these three cost categories, i.e. transaction costs may increase to improve coordination but there may be a decrease in direct and activity costs. Kajuter (2002) notes that this framework is limited because the conceptual design of an accounting model for transaction costs is largely unsolved, as described in the earlier in this Section. Kajuter (2002) concludes that there is a considerable gap between the theoretical work to provide a comprehensive, multi-perspective concept of supply chain costing and the practical application of cost management in supply chains.

Alongside the theories of TCE and SCM, the application of ABC, LA, VE and TC (covered in this Section above) have all been expanded to encompass inter-firm costs, costs that arise from transactions between firms.

Kajuter (2002) reports that TC is suitable for inter-firm cost management because it passes cost reduction pressures throughout the supply chain by linking the target cost systems of firms. Seal *et al*. (2004) note that target costing is portrayed as enabling firms to maintain control over subcontracted activities. Lamming (1993) notes that even a forced TC regime may offer mutually beneficial collaboration between firms that forced cost reductions outside of TC do not. Kajuter (2002) reports that, when TC involves more than one firm, it is often used with open book accounting (as described in Section 1.2). Some authors have identified shortcomings in the cost information available in open book accounting. Seal *et al.* (2004) says that commercial information may be used to squeeze subcontractors by threatening them with walking away and going to a competitor. Seal *et al*. (2004) argue that the temptation in supply chain relations is always to go elsewhere. Through a case study they found that whilst TC may be used to build collaboration across the supply chain, there is an inherent tension between sharing commercial information and competitive tendering. They therefore concluded that the impact of extra information is ambiguous as it can lead to more “shopping around” rather than closer relations. Kearney (1995) observed that open book accounting may be hampered by the internal cost information created.

Dekker (2003) reports on the application of LA that has been applied to the supply chain in *Value Chain Analysis*. Here lean’s focus on the value stream is expanded to the value chain to consider the activities and costs between firms.

LaLonde and Pohlen (1996) identify the application of other techniques, including ABC, to inter-firm cost management. They explain how Kurt Salmon Associates’ (1993) *Direct Product Profitability* (DPP) method, that considers the logistics of moving items between supply chain firms, contributes to inter-firm accounting. They describe how DPP responds to management interest in the profit implications of different handling and storage decisions for different products. To analyse this DPP identifies previously unmeasured activities within the firm that are influenced by other firms, such as handling, freight, discounts, allowances, storage and direct labour costs. LaLonde and Pohlen (1996) note that DPP does not consider the fixed costs of overheads. LaLonde and Pohlen (1996) therefore identify Kaplan and Cooper’s (1998) ABC method of assigning accurate costs to products, to pick up these fixed overhead costs. The application of ABC within firms was described in Section 2.5.2. LaLonde and Pohlen (1996) identify Carr and Christopher’s (1992) *Total Cost of Ownership* method that looks at the total costs between two linked firms in a supply chain as a method that draws on how the performance of one firm affects costs in another firm in the supply chain. This draws on previously unmeasured activity costs such as number of product returns, under-shipments, non-conformance or late shipment, in other words tracking the hidden, indirect costs of transactions. Finally LaLonde and Pohlen (1996) identify Weeks and Crawford's (1994) *Efficient Customer Response* (ECR) method that focuses on management concerns of reducing whole supply chain costs through a better transfer of information, automating administration processes and coordinating replenishment cycles. Here methods of communication are strengthened, but in terms of cost information, ECR is not a new costing model and the norm of competitive competition is maintained. Cost savings occur from reduced administration from automating ordering, labour saving from docking inventory, and more efficient use of space. LaLonde and Pohlen (1996) argue that firms may be unwilling to share their cost information or may not have the capability to trace resource costs to specific activities.

The impact of these new methods of costing in commerce has been challenged. The application, both within firms and between firms, of standard costing, ABC, LA and TOC have been considered by Van Der Merwe (2007a, 2007b, 2007c), who questions the impact of these new theories and tools in management accounting since the mid 1980s. He reports that managers largely view management accounting information as important but distorted and that advocates of individual tools do not readily recognise the shortcomings of their particular approach. He identifies a disparity in the focus between the different tools of standard costing, ABC, LA and TOC and sets out an evaluation framework for describing current tools and providing fundamental principles to consider in the development of new approaches.

Dean (1993), working in project cost estimation and control in the aerospace and space industry, takes a similar position concluding that project cost information has little relationship to the work carried out. Dean (1993), asked the question 'why does it cost how much?'. He draws attention to problems in cost management when he describes the 'accounting 'noise' (Dean, 1996) that is inherent in even the most detailed cost models. He identifies a number of variables that obscure estimated costs from a *good* model of work carried out, such as the cost basis of a firm's resources, the buyer a firm will buy from, the existence of trading discounts, the personal skills of negotiation, inflation and market conditions and risk evaluation. Dean (1993) identifies that costs are estimated from a combination of calculation (which he calls "data"), standard historical rates (which he uses as a surrogate for current rates and calls “analogy”) and judgement (which he calls “expert opinion”). This sets a budget and costs are managed against this budget. He advocates that management accounting needs a range of different perspectives on cost in order to analyse a number of previously unmeasured costs that address specific management concerns.

2.6 Building Information Modelling (BIM) and cost modelling in BIM

2.6.1 Developments in BIM

This section moves on to the arrival of Building Information Modelling (BIM) in the construction industry. Amongst the digital disrupters outlined in the Introduction (Section 1.1), BIM is promoted as a set of technological and organisational solutions that will bring greater efficiencies and solve the collaboration problems inherent in the construction industry. This review focuses on literature that shows how BIM models construction projects and deals with approaches to construction improvement and costs. It focuses on the opportunity for BIM to handle a greater volume of information more meaningfully.

Eastman *et al*. (2011) and Succar (2009) in describing the characteristics of BIM, outline that BIM technologies can handle information about the design of a final building and the process of its construction by providing a virtual prototype of a final building and its construction process. They describe how BIM is characterised as *intelligent* modelling that uses *parametric* components: components that know what they are and how they relate to other components. BIM is also characterised as *integrated* modelling: information from different firms in a central hub. Integration requires *interoperability* of information: the ability for the information produced by different firms to come together.

BIS (2011) describe the ambitions of the UK government for a progressive adoption of BIM in the UK through four levels of *maturity*. The starting point, level 0, is taken to be two dimensional (2D) design modelling with no intelligent characteristics and no integration of information between firms. They describe level 1 BIM as 3D design modelling using intelligent modelling techniques, but with no requirement for integration of design information between different firms. Level 2 BIM is described as 3D modelling using intelligent modelling techniques, with *federated* integration of information: different firms modelling their element of the design in their own models, which are subsequently assembled into one federated model. Information in the federated model may include construction sequencing (4D) and cost (5D) information. The UK government requires all central government projects to be delivered to level 2. This requirement has been in place since 2016. BIS (2011) describe two further levels of maturity of BIM. They describe Level 3 BIM as a single, online, *consolidated* model that includes information on from different design (3D), construction sequencing (4D), cost (5D), and project lifecycle (6D) models. Finally they describe level 4 BIM as the addition of multiple decision support tools (nD), which introduces information about stakeholders' preferences, such as environmental standards, to support decision analysis.

BIM is advancing in terms of design visualisation and simulation. There is much promotional rhetoric from government and software vendors. However uptake of BIM to date is slow. Howell and Batcheler (2005) saw the effectiveness of BIM increasing as interoperability between the different elements increases. Four years later Succar (2009) note that the addition of 4D (construction scheduling) and 5D (costs) within level 2 was at an early stage of adoption by the industry. Four years after that Eadie *et al*. (2013) note that BIM is most often used in the early stages of projects. In 2014 Azouz *et al.* (2014) challenged the continued promotional rhetoric of a BIM Utopia. Miettinen and Paavola (2014) argue that BIM is an emerging set of technologies and collaborative practices with a generalised promise of integration with no well-defined end. They argue that there is therefore a need for a realistic view of the complexity of the conditions that the new technologies are implemented in. They argue that to do this BIM development needs to be an expansive process with new solutions.

In the contractors' supply chain, Dossick and Neff (2009) studying mechanical and electrical services subcontractors found that the 3D geometry of BIM linked the subcontractors' design to other project participants' design more tightly technologically. But the mechanical and electrical services subcontractors remained organisationally divided from other project participants and crucial information and decisions were not shared in a timely way. Thus BIM delivered as a technology but not as a process. They argue that the introduction of BIM technologies alone is not sufficient for increased collaboration and whether a project uses BIM or not: organisational and cultural divisions between designers, contractors and subcontractors may stop collaborative working. Taylor (2009) argues that different and more universally agreed solutions to design problems are generated when BIM models enable conversations between designers and contractors. BIM is presented as an opportunity to change work practices, but Hartmann *et al*. (2012) disagree and argue that BIM should be developed to fit existing work practices. An alternative approach to either is presented in information theory in which IT is used to *informate* (Zuboff, 1988) work practices, that is to acquire and create new knowledge in a process of continuous feedback from interaction between the technology and its users.

In rhetoric better information on construction sequencing is promoted as an end point for developments in 4D BIM. Eastman *et al*. (2011) and Succar (2009) find that software that links construction scheduling to the design model, such as Primavera and Synchro, makes a significant step towards this by linking activities, time and space to show visualisations of the construction process. They describe how parametric objects of temporary works are added to the design model and the sequencing model to provide visualisation, or walk through, of the sequential stages of construction on site.

2.6.2 Cost modelling in BIM

Better information on costs is promoted in rhetoric as an end point for developments in 5D BIM. However Goucher and Thurairajah (2012) find that academic and industry research and software development in costing applications in BIM have to date focused predominantly on BIM's ability to automate the current practices. This finding contrasts with the promises made of BIM to provide better information on costs.

Fung *et al.* (2014) researching cost management in BIM in relation to estimating find that the uptake of 5D BIM is greatest by clients' cost advisers who provide early stage estimates. Wu *et al*. (2014) summarise the current cost management capabilities in BIM (i) importing quantities from design models into cost models (ii) providing measurement tools for quantity take-off that sit on top of design models and (iii) linking historical cost estimating databases on unit costs to cost models. They report slow uptake of cost management in BIM in UK quantity surveying practices due to current limitations that include the quality of design models, data exchange issues and a lack of software that automatically supports UK measurement rules, such as the New Rules of Measurement. Outside of the UK Eastman *et al*. (2011) and Monteiro and Martins (2013) see the automation of cost estimating in BIM as problematic because estimating software cannot accommodate the level of explanation and interpretation required in creating cost estimates. Tiwari *et al*. (2009)

recognise these limitations of cost management in BIM, but advocate 3D model based estimating for target costing in particular, as a significant advance on previous practice such as quantity take-off from a 2D design model by hand, digitiser or screen based design. They argue that the quantity take-off process from 3D design models is quicker and eliminates the scope for errors and omissions.

Some authors see potential for BIM to handle new types of information for costing purposes. Foruges *et al*. (2012) see potential for BIM to handle information from contractors earlier in the design process. Sacks *et al*. (2010) and Sunil *et al*. (2015) are interested in the interaction between lean production and BIM and see opportunities for new information from site feedback to be used for costing purposes. Staub-French *et al*. (2003) identify new types of information on design features that expert estimators draw on and Lawrence *et al*. (2014) have mapped these onto design models linked to estimating software in BIM.

2.7 Systems

2.7.1 Systems modelling: hard and soft approaches and their implications for information requirements

The *systems movement* was instigated in the middle of the 20th century as a general way to study systems across any discipline under *systems theory* (Von Bertalanffy, 1950) and later *systems thinking* (Krammer and DeSmitt, 1977). Systems theory and systems thinking are based on the idea that different systems that at first sight appear to have little in common, such as biological systems or systems of human activity, actually have common patterns of things in them that can be described through principles. Beynon-Davies (2011) identifies three key principles that underlie a systemic approach: *holism, emergence* and *purpose*.

The first systemic principle of holism is viewed by Beynon-Davies (2011) as the importance of conceiving of the totality, the whole of a situation. He describes this against its opposite, *reductionism*, the standard positivist scientific method that concerns itself with the parts of a system and assumes that the system is equal to the sum of its parts. He contends that the scientific approach, whilst extremely successful in understanding natural sciences, is often accused as “not being able to see the wood for the tress” particularly in understanding human systems of activity. Holism, in contrast, takes an understanding of the whole from the interaction of its parts as its primary focus. It requires the ability to take a view of the whole, while keeping, not losing, sight of the parts. This requires information on the whole and the parts. He describes the second systemic principle of emergence as how the behaviour of a system emerges from interactions of the parts. He says that any system is dynamic in the sense that its parts potentially influence each other. From this viewpoint he argues that a system has properties that do not belong to any of its constituent parts. The systemic approach is often described by the maxim “the whole is more than the sum of its parts”. Finally Beynon Davies (2011) sees the third systemic principle as an entity that has a purpose, in that there is a defined goal to a system and the behaviour of the system is planned to fulfil the goal. The purpose often sets measures of performance that are part of the system and steer the system to its goals. He uses these concepts of holism, emergence and purpose not in a technical sense, but in a descriptive sense, as they are good for description of reality at every level.

A general feature that is relevant to any system and central to the principle of emergence is the *feedback loop*. Rosenblueth *et al*. (1943) pointed out that all systems have a control process in a feedback loop that collects information about actual performance (outputs) and feeds this back to earlier stage inputs in order to modify operations. The feedback loop thus acts as the control message and is therefore central to communication within a system. Beynon-Davies (2011) describes the feedback loop as an *input-process-output* model in which the processes represent the dynamic elements of the system. He classifies two types of processes relevant to any system, *operational* processes to achieve the systems purpose, and *control* processes to “maintain behaviour of the operational processes in the desired directions, and hence maintain the overall identity of the system.” He says that the communication role of the feedback loop makes it central to systems modelling and learning.

Beynon-Davies (2011) points out that these very general principles and features encompass a vast array of situations and a distinction has been made between two types of system: *closed* systems and *open* systems. He describes how closed systems sit in their *environment* but are seen as sealed from anything outside. In closed systems a decision is made about the objects of interest and their relationships, and all other factors are then excluded. On the other hand open systems must include a notion of the environment. Beynon-Davies (2011) points out that “defining a system means deciding what is to be included in the system and what is to be included in its environment.” Once a system has been defined Ashby (1958) described *variety* as a measure of the complexity of a system. Beynon-Davies (2011) links this idea of variety to the idea of *system states* concluding that systems can be described by their entities and the connections between them, but for many systems, the variety of the system may be too vast to measure, because the number of possible states may be uncountable.

Building on the distinction between closed and open systems, the concepts of *hard* and *soft system thinking* emerged. The two concepts take very different views of the world and the types of interventions that work in the world. Rosenhead (1989) describes a hard systems approach as one that starts by modelling the entities that are within its field of interest and the relationships between them, and assumes that this system is closed to its wider environment. A hard system approach then takes a defined problem and works on finding solutions based on efficiency and optimisation. In terms of the relationship that hard approaches have to information, hard, engineered systems are associated with the machine metaphor (Morgan, 1998) in which there is an assumption of a self-regulating feedback loop that is made up from and learns from hard, quantified data. Green (1999) argues that hard systems have a positivist relationship with information, which is specific and deterministic. Hard systems assume that everything relevant to the system under consideration can be measured and has a thirst for measurement.

In project management, Greenberger *et al.* (1976) analysed the work of the RAND Corporation. They had applied hard systems thinking in different business sectors including aerospace and public heath. Greenberger *et al.* (1976) concluded that an approach of optimisation of parts had been successful in environments where there was agreement about a unitary purpose, a hierarchical structure and well-defined, repetitive tasks that provided certainty and feedback mechanisms that provided reliable data. They concluded that the work of RAND had not been successful in environments that did not meet these conditions.

Rosenhead (1989) describes the emergence of soft systems thinking in comparison to hard systems thinking. He describes a soft systems approach as one that starts by modelling the entities that are within its field of interest and the relationships between them, and then assumes there is uncertainty within the system modelled. He also says that it is assumed that the system modelled is open to its wider environment and the wider environment contains uncertainties. In terms of the view of the world, he argues that a soft approach takes the view that individuals will make sense of situations in the world in different ways. He describes how soft system theory starts from a position that the reality of the world cannot be reduced to well-defined problems because peoples' perceptions of problems differ. This has implications for the nature of interventions. In soft system approaches there may occasionally be consensus about "change to bring about improvement" but the norm is "debate and accommodation of different people with different views". Finding an optimal solution is not seen as important; problem structuring and negotiating cooperation in an uncertain environment is seen as important. He describes how, in soft systems thinking, model building concerns itself with problem structuring as a means to wider, social debate and negotiation, not model building as an end in itself. Three such *soft systems modelling* approaches emerged in the 1980s. Friend and Hickling (1987) introduced *Strategic Choice Approach* (SCA), which defines problems against uncertainties and possible solutions. Eden and Ackermann (1989) introduced *Strategic Options Development and Analysis* (SODA) for problem structuring through cognitive mapping possible solutions. Checkland and Scholes (1990) introduced Soft Systems Methodology (SSM) for problem structuring through rich pictures and possible solutions. In soft system modelling the primary purpose is to gain an understanding of a problem situation, without imposing any particular structure.

Rosenhead (1989) considers the relationship between soft approaches and information. He notes that systems that involve human activity are based on the assumption that they are open to their wider environment and embedded in the context of their environment, hence they are soft. He argues that soft approaches have a relationship with information that is underpinned by social constructivism, in that they take account of plural views and are non-deterministic. Soft approaches assume that not everything can be measured because people make sense of the world in different ways and not everything can be known and measured.

Beynon-Davies (2011) is concerned with the category of soft systems that involve human activity. He links system approaches to information theory when he says "the decision about what to include as within a system, and what to exclude, is a decision for the system modeller". He points out that system modelling is a process of abstraction, resolving what are the constituent parts of the environment, system, subsystem and so on. He also points out that system modelling is inherently hierarchical. Systems can be viewed "on various levels, each level of which can be can be conceptualised as a system. Hence, the environment of a system may be viewed as a system in its own right and a process, which is part of one system, may be treated as a system in turn, and so on".

In the construction industry Winch's (2010) specific theoretical framework, illustrated in *Figure 1*, is one way to describe the construction system as a whole and a hierarchy of systems within systems. Taking a systems thinking view, he sees the construction system as one that encompasses something both greater than its parts and constraining the performance of its parts. He develops what he calls a *tectonic approach* to illustrate the dynamic nature of the construction system he is describing. He illustrates the *process* level of a construction project as shaping and being shaped by a *governance* level, which in turn shapes and is shaped by an *institutional* level.

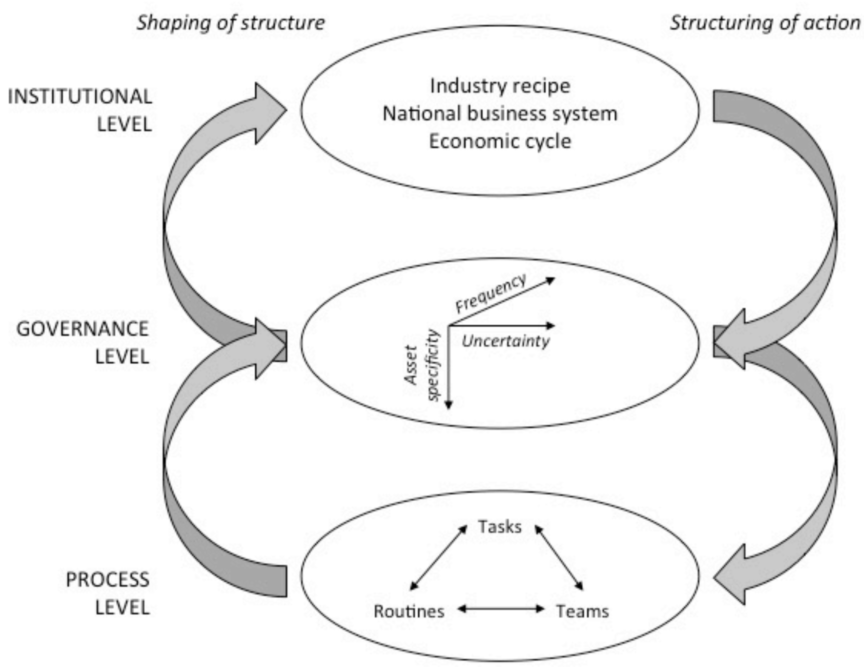

Figure 1: The tectonic approach (source: Winch, 2010, figure 1)

Winch (2010) illustrates the tectonic interactions within and between the different levels using the analogy of a river. He describes construction operations at the process level as a flow of information in a river, where the flow is shaped by and shapes the bedrock and banks of the river. The banks of the river are formed from issues of governance. The bedrock of the river is formed by institutional factors. He contends that the process of construction, the flow, can only be indirectly managed by managing the context in which it flows. Thus construction is conceived as a system that is interacting on many levels, from the site operative working with concrete, to the government policy maker working with ideas and the market responding to the wider environment. Winch (2010) also sees the project process as a reduction in uncertainty through time in which all information is eventually processed at completion.

Winch's (2010) framework of the contrition system characterises the overall system of the construction in a similar way to the seminal work by The Tavistock Institute (1966), who characterised the overall construction system as one of *interdependence* and *uncertainty*. They identified the importance of interdependence as a key characteristic because they saw that any decision taken sets in train a chain of consequences that could change the decision. Thus decision and actions depend on one another. They identified uncertainty as the second important characteristic because they saw uncertainties throughout the construction process; from doubts about information to faulty information and limited attempts to plan. Dubois and Gadde (2002) similarly observed the industry to be a *loose-coupled system* that operates through negotiation. These authors all identify the sociological aspects of the building process as of key importance. Fernandez-Solis (2009) seeks to understand the systemic nature of construction as an industry and argues that construction should not be viewed in the same light as manufacturing, through a machine metaphor of efficiency, control and optimisation. He draws on studies that have highlighted differences between construction and other industries already cited in this literature review: namely unique one-off projects delivered by project specific supply chains made up of multiple firms. He suggests that a biological metaphor is more relevant to understanding the construction system following Gunderson and Holling (2001) theory of adaptive change that explores how complex social systems transform. He sees a new understanding of the construction system as fundamental to developing complimentary interventions.

2.8 Information theory

2.8.1 Representation: signs as something of significance in the system they appear in

This thesis focuses on contractor's methods and systems of costing, within the wider construction system. It sees costing as open to its environment and it sees its environment as a series of interacting systems that are sociological as well as technical, as conceived by Winch (2010). This thesis therefore sees implications from soft systems thinking on the nature of problems and interventions as central to cost information requirements. This thesis draws on information theory to more explicitly discuss, and begin to open up, the private costing practices of contractors in a way that examines the social as well as the technical aspects of cost information.

Information theory is a general way to study what information is, why it is important, and the value of information systems. Some authors who are working on trans-disciplinary concepts of information are Brier (2008), Floridi (2011) and Beynon Davies (2011). This thesis chooses Beynon-Davies' (2011) ideas as a framework to analyse construction cost information because Beynon-Davies' (2011) framework links soft system approaches to information theory, in that he works in information theory seeking to better understand problems in today's world and the value of computer modelling in working on those problems. He says that information is commonly seen as a critical concept for 21st Century but it's meaning is poorly defined and understood. He notes that the word information is generally treated either narrowly as the transmission of binary digits, or in a broad way that is taken for granted but vague and undefined way. His central concern with the meaning of information is in accordance with the views of soft systems methodologies, such as Checkland and Scholes (1990), who view information as data plus meaning. This concept acknowledges the soft system assumptions that situations involve multiple-views and uncertainty. Mingers and Willcocks (2014) are similarly concerned with how meanings arise. They also draw a clear distinction between information and meaning saying that "information is objective, in the sense of being independent of the sender or receiver, and must be true to be information". They say that meaning is "inter-subjective, in being at least partly dependent on human interpreters, and generated from information. Thus information systems, which store, process and transmit information, are only part of a wider system (or systems) of meaningful human communication."

Taking a position of information as data plus meaning, Peirce (1978) argues that a *sign* brings with it two effects, the entity that it represents and the idea that it generates in an interpreter. He thus views a sign as a combination of meaning and representation. This has been developed by Falkenberg *et al*. (1998) and Hesse *et al*. (2008). They illustrate this by reference to the *semiotic tetrahedron* that shows the relationship between a *thing*, a *meaning* and its *representation* along three corners of a triangle (*Figure 2*). They show that the relationship from the representation to the thing is an indirect one, as it is dependent on the *actor's interpretation*. Any symbol-concept relationship is, in essence, the interpretation of an individual actor who sits on top of the triangle making a tetrahedron.

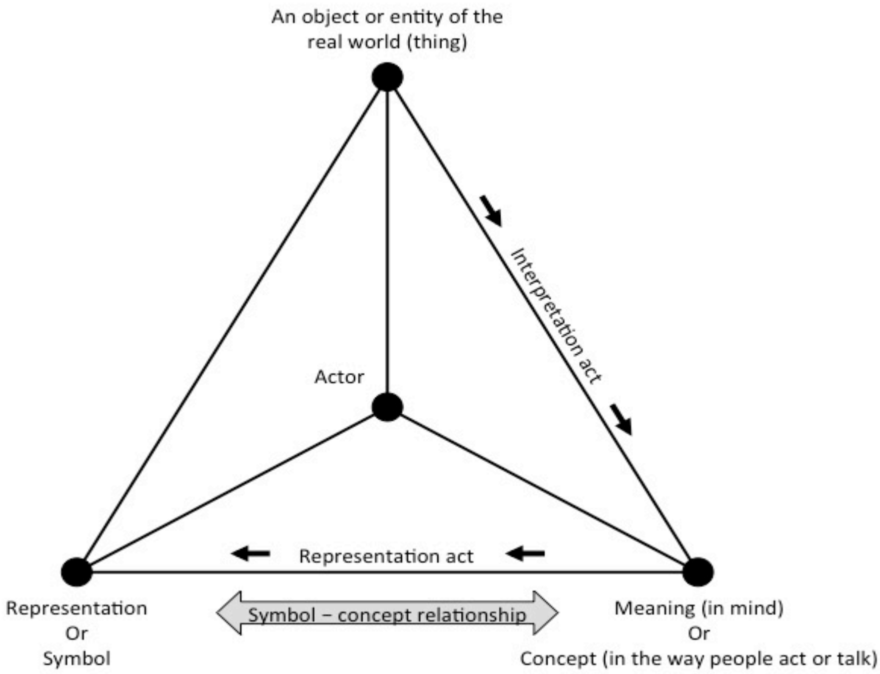

Figure 2: Adapted from Pierce's (1978) semiotic tetrahedron Falkenberg et al. (1998) and Hesse et al. (2008) as used by Rosenkrantz et al. (2013)

Beynon-Davies (2011) holds a similar view in his conception of signs as representations of something of *significance* or meaningful to represent in the system it sits in. To illustrate the nature of information Beynon-Davies (2011) sees the physical form, or representation, of a sign as the top of the four rung semiotics ladder of Stamper (2001) between the social and physical worlds. The rungs of the ladder encompass meaning, structure and finally physical form of a sign. He uses an example of 13th to 16th Century Inca culture to illustrate the ladder. In this example, the social realm provides the purpose for information, in this case to distribute labour across the Inca Empire: *pragmatics* (the activity system that provides a purpose for signs) is the infrastructure of roads and trained runners that channels messages around the empire, *semantics* (the information system that provides meaning of signs) is provided by a system of cords and knots grouped in *khipu* in ways that represent numbers, *syntactic* (the information system that provides a structure or coding system of signs) is provided by the agreement on knot groups as symbols for numbers, and *empirics* (the data system that provides the form of signs) is the physical artefacts of cords, their placement in relation to each other, the construction and colour knots and their placement on the cords. The artefact of the khipu (an assemblage of coloured, knotted, cotton or wool cords) then exists in the physical realm.

Mingers (2014) notes that there are multiple choices at each of the semiotic levels that can affect meaning. In other words communication is heavily dependent on its context. Any form of communication is therefore highly complex and open to different interpretations. This illustrates what Beynon-Davies (2011) calls the "enactment of significance" and supports the view of Mingers and Willcocks (2013) that it is necessary to distinguish between the system of symbols that allow messages to be sent and the meanings generated by the information and its representation.

Beynon-Davies (2011) has built a concept of significance around the centrality of action; from the formative act of the decision of what is significant to represent; to how that significance is represented in a *record*, used through communication and acted on. This is illustrated in Figure 3. Beynon-Davies (2011) takes Dietz's (2006) three perspectives on the sign: *forma, informa* and *performa* and views them as the glue on the semiotics ladder and the link to the systemic domain. Forma deals with the physical nature of signs and spans from the physical to the syntactic (coding system) levels on the ladder, informa deals with the meaning of signs and forms a bridge across the semantics rung of the ladder, and performa deals with the use of communication to make decisions, bridging the pragmatic and social level of the ladder.

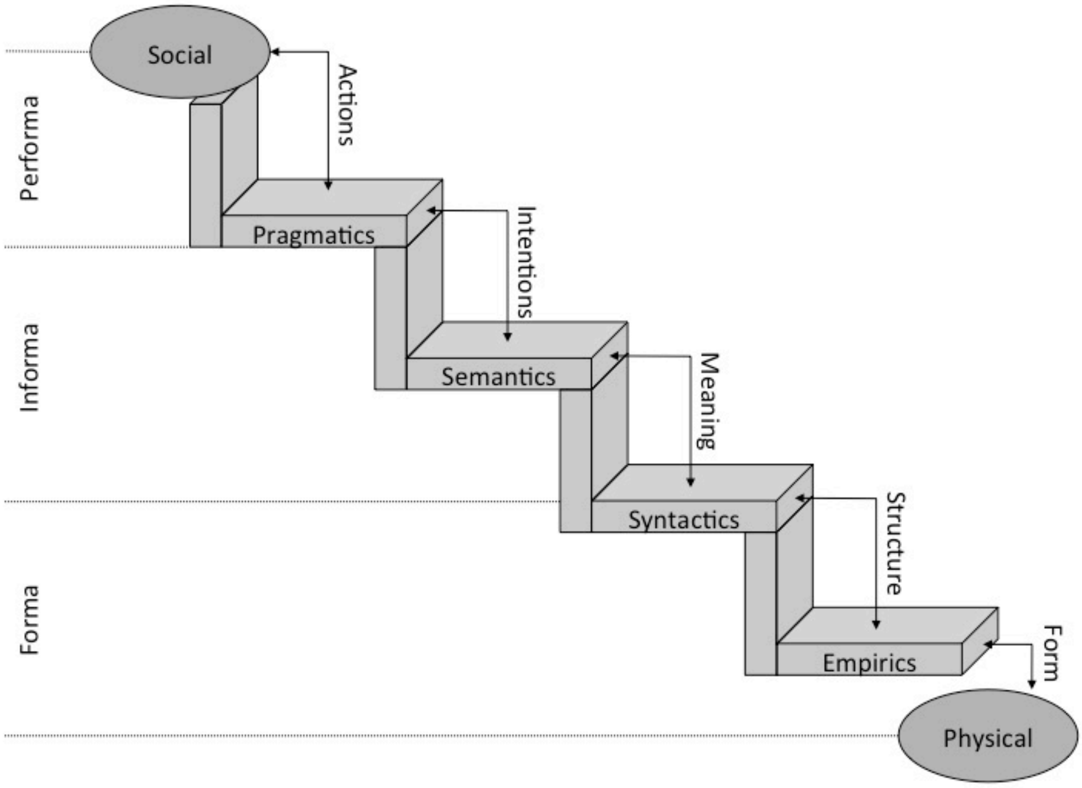

Figure 3: Adapted from Beynon-Davies (2011) The semiotics ladder Figure 2.2

Beynon-Davies (2011) considers action at a number of points, making the distinction between three forms of inter-related action: *formative action, informative action* and *performative action*. He argues that the "patterning of such action within data, information and activity systems is the essence of what we mean by organisation, particularly human organisation".

Beynon-Davies (2011) encompasses the encoding of data into artefacts, be that khipu of the 13th to 15th Centuries or digital computers of today, using a "mutually understood *ontology*: a shared set of representations of the world". He notes that different cultural groups choose different constituents of the world as significant to code with a set of symbols for communication. But whatever the choice of constituents, the collection of symbolic patterns is an ontology. He notes that the term ontology originated as a branch of philosophy that is concerned with the nature of reality and is today used in Computer Science and Cognitive Science. He says that the importance of ontologies arises from the fact that symbols as social constructs "rely on a shared ontology amongst a group: the context within which a group of signs is used in continuous communication by a social group or groups.

Hence a shared ontology is a necessary pre-condition for joint communication and effectively frames or controls such communication."

There is much more to Beynon-Davies (2011) work, and others working in information theory, than is presented here. The ideas presented have been chosen as a framework that links the real world in its entirety to the physical form of information, and is therefore chosen as a way to analyse cost as information in the world of construction projects. The ideas of forma, informa and performa will be used in Chapter 5, as the framework for discussion of the analysis of primary data and literature.

2.9 Summary

This review has shown that literature on contractors' costing is presented largely uncritically in standard textbooks on contractors' estimating, tendering and cost control routines. But the actual processes that contractors go through in their costing routines are not simple. There is a small amount of critical literature that seeks to better understand the effect of contractors' commercial management on cost information (Brook, 2017; Ross and Williams, 2013; Laryea and Hughes, 2010). But the realities of contractor costing remain little understood in literature.

Critical research on contractors' perspectives on cost reductions in demonstration projects (Nicolini *et al.* 2000; Zimina *et al.*, 2012) that seek to bring about change using target costing as an incentive for improvement, suggests that beyond price bargaining, costs cannot be readily attached to changes in a way that is agreed as improvement through the supply chain. The findings of this literature implies that if current models of costing are imported into BIM, BIM will not advance the problem of motivating and rewarding improvements through the supply chain. They also imply that the ability to estimate costs that evidence change that is agreed on as good through the supply chain, would better motivate improvements. The challenge of estimating costs of improvement through the supply chain is little addressed in construction literature.

Before considering literature that has looked at where solutions to estimating costs of improvement though supply chains may lie, this Chapter set out the large topics of construction improvement and supply chain improvement. Construction improvement was shown to be a large and contentious subject in literature. The topic of supply chain improvement was shown to be larger subject still. Supply chain management and lean thinking were found to be the two main improvement interventions advocated for the supply-side of industry in literature. However critical literature argues that the uptake of these two interventions is limited, even in the manufacturing industries that they arose in. Efforts to import ideas of supply chain management and lean thinking into construction were presented with additional contextual hurdles and literature was presented that found that the evidence of cost reductions is anecdotal.

Literature was then presented that considers how management accounting has tackled the challenge of motivating improvement through costs in commerce generally. Even in manufacturing, critical literature finds a considerable gap between the theoretical foundations and practical relevance of cost management methods, both within firms and across supply chains. Across supply chains literature identifies the continued use of price bargaining between firms in all industries.

Better information on both construction sequencing and costs are promoted as end points in the literature presented on the progressive adoption on BIM in UK construction. Literature that promotes the adoption of BIM as enabling significant change towards greater integration is tempered by literature that takes what it sees as a more realistic view and sees a more limited role for BIM. Dossick and Neff (2009) illuminated this stance, saying that whilst BIM can tightly integrate design technologically, firms in a construction project supply chain remain organisationally divided. Literature on construction sequencing shows a significant step change from project Gantt charts that show activities and time, to visualisations that show activities, time and space. Literature was presented on the adoption of costing in BIM that sees the aim of BIM as the automation of current practice, with a few exceptions, where authors see potential for BIM to handle new information to support costing. Literature was also presented on the adoption of construction scheduling in BIM.

Since the industry's focus is on BIM, the meaningfulness of cost information in BIM is crucial. This requires further thought on the nature of problems of costing in construction and the value of computer modelling in working on those problems. Literature by Rosenhead (1989) was therefore presented, theorising in soft systems thinking on the nature of problems in situation of human activity in a social world, in which people make sense of the world in different ways. Rosenhead (1989) argues that these situations require solutions that acknowledge uncertainties and incomplete information and accommodate different interests. This theory runs counter to the assumptions presented in literature of hard, formal and complete information. Winch’s (2011) theoretic framework was presented as one way to describe the construction system along with the Tavistock Institute (1966) characterisation of the construction industry as a system of interdependencies and uncertainties and Dubois and Gadde’s (2002) definition of construction as loose-coupled system that operates through negotiation.

Finally, consideration of the value of computer modelling in working on problems in construction costing prompted the presentation of Beynon-Davies (2011), working in information theory, who provides a concept of significance for examining the link between information and the organisations that information is used in. This literature was presented for later use in seeking to understand the meaningfulness of cost information against its uses, as the basis for deciding what information to include and what to exclude in computer models.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The primary research of this thesis was guided by a pragmatist philosophy. It investigated the costing processes of a main contractor and subcontractors to gain knowledge of how a construction supply chain approaches costing; how it creates and uses cost information. This chapter focuses on the methodology used to carry out the primary research. It begins by discussing the research philosophy and methodological problems. It then looks at the ethical issues surrounding the research topic. The chapter moves to the various methods used to carry out the primary research. It offers a critique of the methods, identifying their strengths and weaknesses. The chapter describes how the methods were applied in this research to minimise their weaknesses and finally summaries the researcher's personal research journey.

3.2 Philosophical perspective

This research takes a *critical realistic* methodological stance (Bhaskar, 2008). This approach accepts the existence of an *intransitive* domain of objective knowledge but also accepts that access to this can never be purely unmediated since access to this domain is always through a *transitive* domain that is socially constructed and subject to change. This is appropriate for research into construction as it both establishes an acceptance of the hard reality of the physical world, of work done by contractors, of BIM and of costing, but also involves an acknowledgement of the considerable stakeholder negotiation in the means and ends of projects, in the ways in which construction costing practice is carried out and given meaning, Others have used this approach for research into costing work in the field of alternative management accounting research (Baxter and Chua, 2003). Alternative management accounting research uses *non-positive* language, a broad set of alternative discourses, to understand accounting in the broader context of the social sciences.

Grounded in practice, this research drew on a range of different ways of knowing as identified by Mingers (2008) from a critical realist perspective. Mingers (2008) presents four different forms of knowledge, each grounded in a different concept of truth. These are: *propositiona*l, (hard, reproducible and factual), *experiential* (based on previous experience), *performative* (associated with how things are done), and *epistemological* (concerning deeper understandings and explanations of why things are as they are). The relation between accounting numbers and the concept of hard reproducible and factual forms of knowledge is viewed in accordance with non-positive approaches to accounting research, which includes followers of Latour (1987, 1993, 1996) who are concerned with how accounting sits in the context of human and non-human *actant* and argue that numbers are *fabrications* (Preston *et al*., 1992) and *built* to take on the appearance of *facts*.

Using this methodological viewpoint, costing practices are seen as fixed reference points in construction projects, which are given meaning by people to a significant extent. Improvement, as offered by BIM, sets new reference points but these are open to negotiation. Thus, grounded in an *interpretivist* approach, the methods of this study seek to provide an understanding of the meanings that people place on their actions in order to know what organisations and individuals do and why they act as they do (Easterby-Smith *et al.,* 2008). Thus, the exploration of documents and software applications draw on hard, propositional knowledge, whilst the exploration of how costing practices relate to their context, draw on experiential, performative and epistemological knowledge.

The research uses the concept of "cost as information" to challenge the basis and practicalities of costing practices. Cost, then, is merely a representation of resources, purchasing possibilities and risk, but this is made problematic when costs are given meaning by people and become fixed reference points in construction projects. This research did not therefore start from propositional knowledge of current practices, but rather looked at the variables behind cost information, where that cost information is derived from and how it is used, seeking to better understand what cost information means to different people. The research did use propositional knowledge from costing documents and software applications but explored these from an experiential and performative perspective. This allowed the study to explore narratives from the calculative world of costing. Its objective was to explain current approaches to costing and explore potential directions for accounting for improvements.

3.3 Research tasks and their relationships

The empirical research in this thesis addresses the first three objectives set out in Section 1.3, of firstly to determining how current approaches to supply chain costing affect supply chain operation and overall construction costs in a project, secondly to determine how different approaches to costing of supply chain operation can be used to deliver efficiency and cost savings in projects, and thirdly to examine how BIM can be used to produce different, more useful costs of the supply chain operation through projects.

This research exists between the social realm of the construction project and the technical realm of information systems. It also exists between the realms of construction practice and the knowledge base from theory. The task of carrying out empirical research was therefore organised alongside the task of carrying out a literature review. The organisation of these two parallel research tasks was informed by Dubois and Gadde's (2002 and 2014) *systemic combining logic*, in which new approaches evolve through *confrontation* throughout the research between case study analysis situated in its specific context and relevant literature.

Figure 4 shows a schematic diagram of the research process. The collaboration agreement with the main contractor identified the initial problem. This informed the starting point for the problem analysis. The problem analysis was carried out in two parallel strands; from the primary data and from the literature review. In this way problem analysis arising from the empirical investigation came into continuous contact and interaction with problem analysis from theory. The analysis of the primary data (Chapter 4) came out of what people said when describing the real world problems though a case study. The parallel analysis of the knowledge base in literature came out of the literature review (Chapter 2). The literature review began by looking at current project cost models in construction and general supply chain management principles and their associated cost models in other industries. The literature review then looked upwards to the origin of supply chain management ideas in system approaches and forwards to realisation of ideas through information theory. In the discussion (Chapter 5) the problem will be redefined from a confrontation between primary data and theory, and a new approach to costing that is useful for improvement deep into the supply chain is proposed.

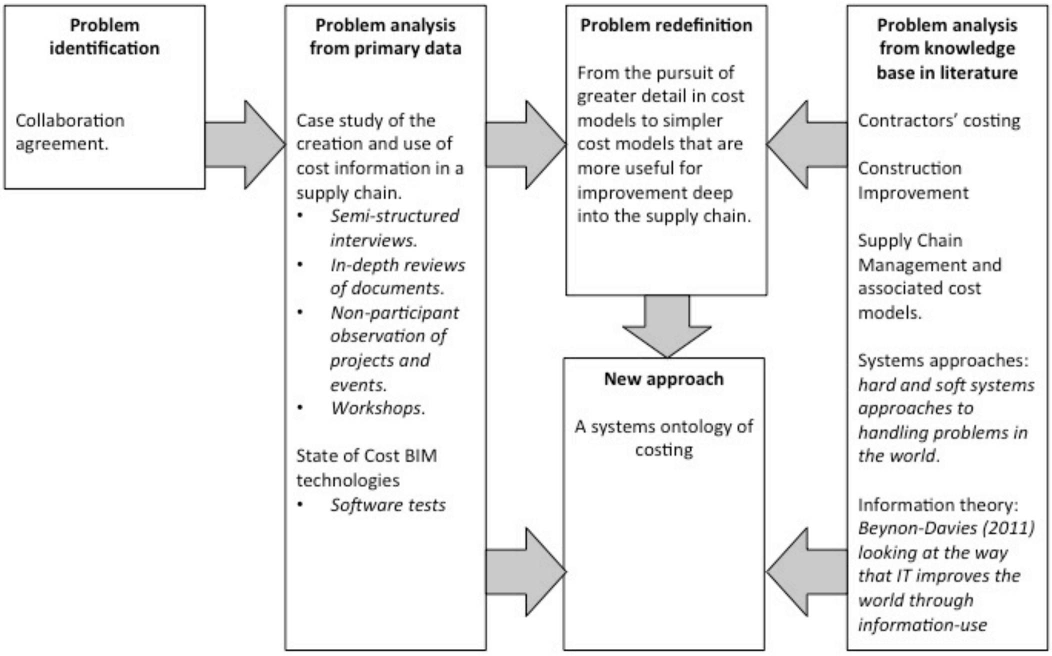

Figure 4: Methodological approach adopted

3.4 Ethical issues

This research was a collaborative project between the research institution and the Midlands division of a national main contractor in the UK construction industry. The collaboration involved the main contractor's sponsorship of a three year PhD studentship which was formally established in February 2013. This collaboration provided a vehicle for accessing data and a drive to creating a practical outcome.

How access to a particular organisation is gained affects the validity of the findings, and whilst collaboration provided access to people and documents, it also posed a potential problem of stakeholder influence on the research purpose. A common purpose between the research institution and the main contractor was found at the outset of the research. The academic and company goals to be achieved simultaneously were explored through discussions on the research proposal and set out in a Collaboration Agreement (Appendix A1.1). Separate company deliverables that involved participation in the company's business were managed and achieved simultaneously, but separately, to the academic goals and are not presented in this thesis.

The collaboration between the research institution and the main contractor provided access to the main contractor and firms in their supply chain to do this through *interrupted involvement* (Easterby-Smith *et al*, 2008) in which the research involved intermittent periods of time with the main contractor and firms in their supply chain. Whilst the collaborative nature of this research facilitated access to relevant interviewees, practical issues of the researcher's presence could potentially inhibit the interviewees' openness. Practical measures were taken to encourage interviewees to share commercially sensitive information by ensuring relevant permissions were obtained. Practical measures were also taken to encourage interviewees to explain what they really think, by ensuring the nature, purposes and confidentiality of the research were made explicit to all participants.

The research collected and used commercially sensitive data in relation to costing. The research also elicited data that is potentially damaging to the reputation of organisations and the personal privacy of individual research participants. The researcher exercised due ethical responsibility by holding all data securely, in line with best practice in data protection, and by not publicising or sharing any information that was likely to harm the interest of the organisations or individual research participants. Easterby-Smith *et al. (2008)* note that organisations may provide access to confidential data provided that confidentially conditions are met. To this end the research institution and main contractor signed a Confidentiality Agreement setting out clear agreement around access, confidentiality, the researcher's right to publish and the main contractor's right to monitor and control certain types of content.

Individual, all research participants were informed about the purpose of the research and the confidentiality agreement and were selected on the basis of the relevance of their job role and expertise. Any information given in confidence by one person during the research was not given to any other person. The research participants were identified only by their job role in the recording of the raw data and full results. Many of the research participants had a unique job role so the research did not set out to provide anonymity in the raw data or the full results. However, mindful of any personally sensitive data, individual research subjects have been anonymised in findings published both internally and externally.

3.5 Data collection

3.5.1 Case study approach

To address the research objectives set out in Section 1.3 this study used a case study of a supply chain involving a main contractor and firms in their supply chain.

Case study research is not new in the field of costing. Baxter and Chua (2003) note that case studies in accounting topics from an alternative strand of research to mainstream quantitative research and can illustrate how numbers are constructed to "accommodate and persuade diverse and changing interests of different stakeholders". Andon *et al.* (2015) similarly argue that it is the people who use management accounting information that make the information useful. This research seeks to study the praxis of costing by studying the creation and use of cost numbers within the UK construction industry, to understand the nature of the numbers that are built on the diverse and changing interests of different stakeholders.

The case study as a research strategy (Hartley, 2004) is widely used in studies of organisations. The most frequently discussed disadvantage is the problem of generalisability but Hartley (2004) points to an increasing interest in context, making the lack of generalisability an advantage where the illumination of behaviour in its context is important. Lukka and Kasanen (1995) note the fact that firms copy best practice and are constrained by the same regulations results in regularities from the way firms and individuals are forced to act, increasing generalisability. Hartley (2004) notes the advantage of case studies in potentially revealing informal behaviour in processes as they occur. He points out that in case studies that involve multiple methods of data collection, comparison between methods can lead to improved data validity. The disadvantage is potentially having an overwhelming amount of data. This is discussed later, under each method of data collection. The high volume of data collected across a case study does pose challenges for analysis. Hartley (2004) points out that without a theoretical framework, case studies tend toward description and lack significance. He argues that to avoid leaping to premature conclusions, the development of categories needs to be carefully managed in case study research. The approach that this research took to data analysis is outlined in Section 3.5.8 below. The theoretical framework of *systemic combining logic* (Dubois and Gadde, 2002 and 2014) used in this case study deals with theory and findings concurrently and lead to emergent theory rather than examined propositions.

In this research, access to people and documents in the main contractor and subcontracting firms allowed mixed research methods to be used to create a case study of a supply chain combining semi-structured interviews, in-depth reviews of documents, non-participant observation of projects and events and workshops. This mixed approach allowed the research to elicit Mingers' (2008) four forms of knowledge that were used, between them, to uncover the rich and varied ways in which people may be said to know.

Many of the practical issues with gaining access to meetings, individual interviewees and documents within the main contractor's organisation were overcome by the collaborative nature of this research that provided board level permission from the main contractor to access relevant interviewees. To overcome the difficulties in gaining access to subcontractors in the supply chain the researcher and the main contractor selected key subcontractors from the main contractor's network of subcontractors that they work with across projects. The subcontractors were chosen to represent different trades. After this the primary selection criterion was a willingness to be involved. The researcher negotiated participation in the research of the main contact from each subcontractor, usually a senior manger. Participation with subsequent supply chain tiers was negotiated in a chain reaction. In other words the researcher and the main contact from each subcontractor negotiated participation in the research of other interviewees in their firm and the main contact from a subcontractor in their network, and so on. In this way the longest chain, for the mechanical and electrical services subcontract, brought together the four tiers of that supply chain.

3.5.2 A case study of a supply chain

A construction project supply chain is a temporary organisational relationship and as such it is difficult to investigate the problems of construction supply chains. A construction project supply is linked to the more permanent supply chain network of each firm in a project supply chain. Thus a web of relationships exists within and around a project supply chain. Throughout the research the researcher was sensitive to the conflicts of interest and the ethics that the research of a supply chain involved. The conflicts of interest were carefully managed, as described in Section 3.4 above, to be sensitive to each contractor's position, in order to gain full access to the reality of their situation.

The research did not attempt to encompass the perspectives of all stakeholders across the whole process of a construction project. The research concerns the involvement of the contractors' supply chain so the research focused on the parts played by the main contractor and subcontractors. The research therefore covers the construction process from the point that the main contractor becomes involved in a construction project, on receiving an invitation to tender for a project, to the agreement of final costs of a project.

The case study involves the sponsoring main contractor, the Midlands division of a UK national contractor, and seven subcontractors across three *work package supply chains* (supply chain for subcontract packages of work) in a *notional* project supply chain. The idea of a notional project supply chain came about near the start of the research. The research originally intended to encompass parts of the actual supply chains working on two of the main contractor's projects. However, in practice, this approach was soon found to be a barrier to access to subcontractors due to the commercial confidentiality of the cost information that the research sought to elicit, and the potential for the research to collide with live unresolved issues. Practical measures were therefore taken to gain access to confidential information and encourage participants to explain what they really think. This was achieved firstly by taking a different project for each subcontractor as the subject of the in-depth review of documents and associated semi-structured interviews. This was achieved secondly by assembling a notional supply chain in a workshop, in which participants were brought together who had worked with one or more of the other participants across projects, but the workshop was not focused on assembling part of the actual supply chain for a particular project. However, across all the research methods used to form the case study of a notional project supply chain, the main contractor and subcontractors referred to similarly large, complex, one-off construction projects for education sector clients in the Midlands, in which the client controlled the design phase of the project. Participants established that they used the same project costing practices and written reports across all their similar projects and what they did was similar across all projects.

The case study of a notional supply chain thus encompasses firms from three work package supply chains within a notional project supply chain (Table 1). The three work package supply chains cover the trades of mechanical and electrical services, suspended ceilings and partitions, and movable partitions. The main contractor (tier 1) is a large, national organisation with an annual turnover of over £1bn of which around 70% is spent in a supply chain of around 3,000 firms. The subcontractor (tier 2) in link A is a large, national mechanical and electrical services contractor with and an annual turnover of over £350m of which 60 to 70% is spent in their supply chain. This subcontractor facilitated access to one of their subcontractors (tier 3), who in turn facilitated access to one of their subcontractors (tier 4). The subcontractor (tier 2) in link B is a small, regional suspended ceilings and partitions subcontractor with an annual turnover of under £10m. This subcontractor facilitated access to one of their subcontractors (tier 3).

<table>
<tr><th>Tier</th><th>Organisation</th><th>Size</th><th>Trade</th><th>Ref</th><th>Annual turnover</th><th>Spend in the supply chain</th></tr>
<tr><td>1</td><td>Main contractor</td><td>Midlands division</td><td>General</td><td>MC</td><td>Over £1bn</td><td>70%</td></tr>
<tr><td>2</td><td>Specialist Subcontractor</td><td>Midlands division</td><td>Mechanical and electrical services</td><td>SCA1</td><td>Over £350m</td><td>60 to 70%</td></tr>
<tr><td>2</td><td>Specialist subcontractor</td><td>Midlands company</td><td>Suspended ceilings and partitions</td><td>SCB1</td><td>Under £10m.</td><td>60%</td></tr>
<tr><td>2</td><td>Specialist subcontractor</td><td>Midlands division</td><td>Movable partitions</td><td>SCC1</td><td rowspan="5" colspan="2">Data not collected</td></tr>
<tr><td>3</td><td>Specialist subcontractor</td><td>Midlands company</td><td>Electrical services</td><td>SCA2</td></tr>
<tr><td>3</td><td>Labour only subcontractor</td><td>Sole trader</td><td>Suspended ceilings and partitions fixer</td><td>SCB2</td></tr>
<tr><td>3</td><td>Labour only subcontractor</td><td>Sole trader</td><td>Movable partitions fixer</td><td>SCC2</td></tr>
<tr><td>4</td><td>Specialist subcontractor</td><td>Midlands company</td><td>Electrical services</td><td>SCA3</td></tr>
</table>

Table 1: Turnover and spend in the supply chain of organisations in the case study

The relationships between the organisations is shown in Figure 5 below, where the main contractor is notated as MC and the subcontractors are notated as SCA1, SCA2, SCA3, SCB1, SCB2, SCC1 and SCC2, to reflect links A, B and C and the tiers in the supply chain.

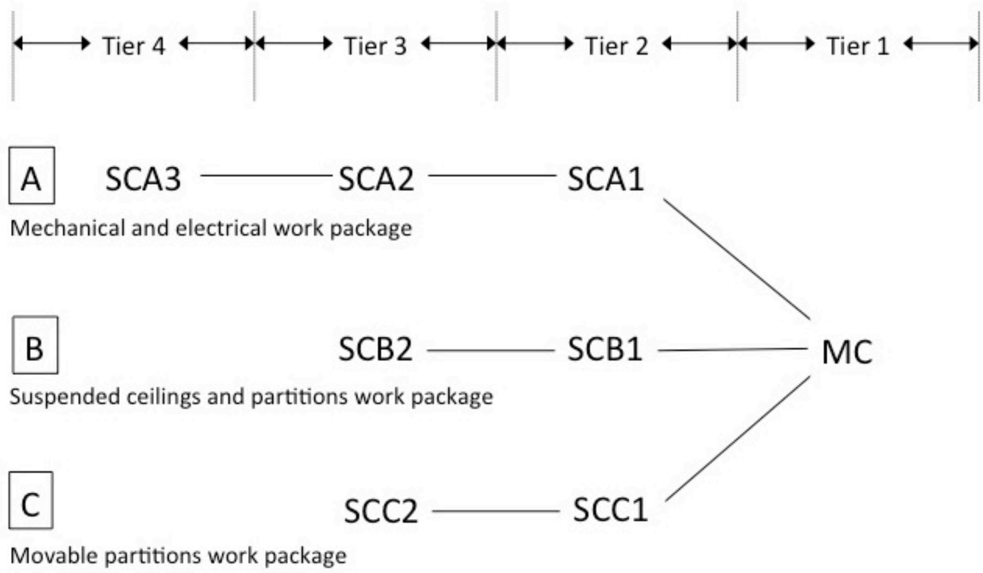

Figure 5: The relationship between organisations in the case study

Thomas's (2011) typology of a case study offers a way to describe the subject and object, purpose, approach and process of a case study. Using Thomas's typology this research uses a case study approach to explain contractor costing (the subject) using the concept of cost as information (the object). The case study subject, contractor costing, was selected because cost is fundamental to motivating improvement in construction projects. The case study object, cost as information, emerged during the research as information technology, with its potential to manipulate more information faster, makes an exploration of costing through the lens of information theory (what this thesis calls cost as information) an appropriate lens through which to interpret the subject, contractor costing. The case study draws on the local knowledge of participants selected for their key roles in contractor costing. It then views the realities of contractor costing described by participants through the analytical frame of cost as information by drawing in ideas from information theory.

The case study thus takes the approach of illustrating contractor costing to provide a rich description of contractor costing, rather a theoretical study of contractor costing. The case study design adopted is a single case study with embedded multiple units of analysis in accordance with the typology of Yin (2014). The single case study is of a main contractor's supply chain. This provides the opportunity to examine how a main contractor's supply chain relates to the context of the construction industry as a whole. Embedded within the single case study of a main contractor's supply chain are three embedded units of analysis, one for each of three work package supply chains A, B, and C as illustrated in figure 5 above. This methodology was chosen in order to view the embedded units, the work package supply chains, both individually and collectively within the unit of interest, a main contractor's supply chain. This approach allowed the practices of costing that exist both within and between organisations to be studied, as individual practices and the inter-relationships are both essential aspects of a supply chain. The approach also used different data collection methods to enrich the case study.

The notional supply chain represents three typical links of a main contractor’s supply chain in the UK. The three trades studied are similarly subservient to the same financial, contractual and procedural control of the main contractor. The first major difference between the trades is that the mechanical and electrical services subcontractor has significant design contribution, which adds vulnerability to the main contractors design programme. The second major difference between the trades is that the mechanical and electrical services subcontractor and the movable partitions subcontractor both provide some custom items that are on a long lead in delivery time; whereas the suspended ceilings and partitions subcontractor provides mainly commodity items that are on a short lead in time. These differences have been taken into account in the analysis of the findings.

The case study encompassed 15 semi-structured interviews; 3 workshops, two with participants from the main contractor and one with participants from organisations across four tiers of the mechanical and electrical services work package supply chain; 9 observations as a non-participant observer, observing, listening and following decisions through the site meetings of two projects as part of the main contractor’s organisation; 6 in-depth document reviews and 9 observations of events. The majority of the research was carried out between January 2013 and July 2015. A final workshop was held in July 2016. The detail of each activity will be described in Sections 3.5.2 to 3.5.7 below and summarised in Section 3.5.8 below.
In summary, the research focuses on the parts played the main contactor and subcontractors in a supply chain during tendering and site operations. The investigation is Midlands based. It covers projects procured by education sector clients through competitive tendering with negotiation. The investigation is thus positioned in the middle ground of construction projects by geography, client expertise and cost basis. This provided a case study across projects and organisations that were neither likely to fail badly nor perform significantly better than

the norm. The research was not exploring demonstration projects that were seeking to improve through the introduction of a specific change. The projects were one-off complex buildings, the most common type of project in the industry, and based on competitive tendering, the most common form of contractor selection in the industry. Throughout participants said that what was observed was normal business.

3.5.3 Main contractor's projects

Part of the access to the main contractor (MC) involved the study of two specific projects in detail. These two projects were used for all the interviews, in-depth review of documents and observation of the main contractor site meetings with participants from the MC. As described in Section 3.5.2 above, these two projects formed only part of the overall case study of a notional supply chain, as separate interviews, in-depth review of documents and workshops with subcontractors add to the case study, but do not specifically refer to the two projects studied in detail with the MC. The research with the MC was limited to two projects to focus on the in-depth insights from a number of interviewees for each project.

Project A was a £30m medical school building for a university in the Midlands in which MC did not control the design stage. It was procured by the client through selective competition with negotiation of a main contractor on a traditional cost-plus price basis. The price basis was a fixed price, lump sum presented in a bill of quantities with provision for client variations and liquidated damages. Responsibility for design transferred to them as main contractor at contract stage through a novated architect. Responsibility for management lay with them as main contractor. Responsibility for supply chain integration also lay with them, as main contractor. They approached supply chain procurement through competitive tender of subcontractors. The selection of subcontractors through competitive tendering was carried within their supply chain policy. This project provided a challenge to supply chain operation and costing as the relationships were short-term and set the limit to the use of BIM for supply chain improvement. Project A was carried out under the JCT Design and Build Contract 2011 (including client amendments) where the liability of quantity errors falls on the main contractor.

Project B was a standard, repeatable, design for a £2.2m primary school building in the Midlands. The school project was a standardised school design from a product range of standard school designs developed by the main contractor and a publicly owned framework procurer. The school project was procured through a framework agreement. Each product could be built to different sizes depending on the size of a school's intake of pupils. The pre-construction estimator explained as main contractor they offered three options for the price basis to schools through the framework (a) a fixed price, closed book, lump sum (b) a cost-based labour and materials open book re-measure (c) a cost-based labour and materials open book to contract stage. Only option A had been chosen by clients to date. In Project B the price basis under option A was, similarly to Project A, a fixed price, lump sum presented in a bill of quantities with provision for client variations and penalties through liquidated damages. The long-term relationships involved in this project provided an ideal opportunity to establish the benefits of new approaches, which can be reproducible in future work. Project B was carried out under the JCT Design and Build Contract 2011 (including client amendments) where the liability of quantity errors falls on the main contractor.

As outlined previously in Section 3.5.2 the subcontractors each chose a different project in the education sector as the subject of their interviews and document reviews. The mechanical and electrical services subcontractor (SCA1) explained their process for compiling a tender using the example of an education sector project using client design. The suspended ceilings and partitions subcontractor (SCB1) explained their process for compiling a tender using an example of an education sector project with contractor design. The movable partitions subcontractor (SCC1) explained their standard practice in compiling tenders across projects.

3.5.4 Interviews

Data collection with the main contractor and three tier 2 subcontractors (Table 2) involved semi-structured interviews to evidence what people do when sourcing and using cost information in different firms. Because the interviewees were chosen on the basis of their job role the interviews were non-directive in order to respond to the participant's position, whilst still remaining relevant to the research objectives.

Interviews offer advantages (King, 2004) to the critical realist approach in that they allow information seeking questions that can be followed up with probing questions that allow different levels of meaning to be uncovered. This is important to this research, which seeks to elicit organisational and personal ties within complex multi-organisational supply chains. He points out that research participants readily accept interviews as a research method and this is driven by the fact that people like talking about their jobs however of interviews are time consuming. This proved a disadvantage in getting people involved, but once involved participants were willing and interested in further participation. The main disadvantage falls on the researcher in managing the high volume of information generated. This was managed by focusing the interview questions on the research objectives through the structured framework for data analysis, which is described later in Section 3.6.

The selection process for interviewees was based on the relevance of their job role and expertise. Within MC this was be made up of nine interviews as Table 2 below. The researcher first asked questions about how each organisation goes about putting a price together for a project and then, once a project has been won, how each organisation controls costs. This aimed to find out what cost information is created and how methods of costing reach through the supply chain. The researcher then asked questions about how key relationships work to find out about organisational behaviour and decision-making in relation to the supply chain. The interviews gave the researcher the opportunity to get participants' ideas, thoughts and intentions on current practice and on changes to current practice. The interview guide is included in Appendix A2.1, the interviews were audio recorded and an example of a transcribed interview is included in the Appendix A2.2.

Reference	Interviewee	Title	Nature of organisation
1	MC1	BIM Manager	Main contractor
2	MC2	Commercial Manager	Main contractor
3	MC1	BIM Manager	Main contractor
4	MC3	Quantity Surveyor site 1	Main contractor
5	MC3	Quantity Surveyor site 1	Main contractor
6	MC2	Commercial Manager	Main contractor
7	MC4	Quantity Surveyor site 2	Main contractor
8	MC5	Project Manager site 1	Main contractor
9	SCA1	Project Manager	Mechanical and electrical services subcontractor
10	SCB1	Manager	Suspending ceilings and partitions subcontractor
11	SCC1	Manager	Movable partitions subcontractor
12	MC6	BIM Manager	Main contractor
13	SCA1	Project Manager	Mechanical and electrical services subcontractor
14	SCB1	Manager	Suspending ceilings and partitions subcontractor
15	SCB2	Cost Manager	Mechanical and electrical services subcontractor

Table 2: Summary of interviews

3.5.5 Document reviews

The documents collected (Table 3) consisted of the full estimating build-ups, priced tender documents and post-contract cost control documents for a completed project from the main contractor and the two tier 2 subcontractors. Access to this confidential data was provided on the basis of confidentiality conditions being met. The documents were used to gather background information, to determine if the documents reflect practice, to help formulate questions for interviews and workshops and to see how firms create information on costs. The documents were reviewed with the interviewee who provided the document to understand the context and content of the documents.

Reference	Documents	Title	Nature of organisation
16	MC3	Quantity Surveyor site 1	Main contractor
17	MC4	Quantity Surveyor site 2	Main contractor
18	SCA3 diary from site	Electrician	Tier 3 Electrician
19	SCB2	Cost Manager	Mechanical and electrical services subcontractor
20	SCA3 diary from site	Electrician	Tier 3 Electrician
21	SCB1	Manager	Moveable partitions subcontractor

Table 3: Summary of document reviews

The documentation of information from site in the form of a qualitative free text, research dairy was used to suit the preferences of the Electrician who participated in the research (Table 3: References 18 and 20). The use of a diary was used for the Electrician to recall the events of a day. It drew on the Electrician's interest in writing and offered advantages in recording the immediacy of everyday events (Symon, 2004). The use of a dairy accepts the relevance of individual accounts and thus fits with the critical realist approach of this research.

3.5.6 Observations

The *natural* context (Steyaert and Bouwen, 2004) of the main contractor's site meetings provided opportunity to observe groups where the participants were already *at work*. Steyaert and Bouwen (2004) see an advantage in the natural group in its usual setting, because all participants give their view on the subject of the meeting and a natural mix of views can be observed. The interaction observed is between participants, not between the researcher and the participants. Steyaert and Bouwen (2004) see a disadvantage in that the information collected may be overly complex or disorganised. However, the use of observations in a natural context fits the critical realist approach of this research.

The researcher observed nine of the main contractor's site meetings over two projects in order to follow decisions over Projects A and B (Table 4). The observations aimed to find out the inherent behaviour of the firm by observing their concerns and conduct in order to understand what was taking place and was used to understand the links between costing practices and site operations.

Ref	Project	Meeting	Nature of organisation(s)
22	Medical school building	CRM	Main contractor's site progress meeting
23	Medical school building		
24	Primary school building		
25	Medical school building		
26	Medical school building		
27	Primary school building		
28	Medical school building		
29	Medical school building		
30	Primary school building		

Table 4: Summary of observation of projects

An example of the field notes recorded during non-participant observation is included in Appendix A2.3. The field notes were supplemented by document collection. The data from the document collection and field notes encompasses data from the documents used at the site meetings that identify data MC's project control activities observed in the research. It also encompasses data from the field notes taken during site meetings that looks at construction and costing problems associated with the two projects and the responses of the research participants to those problems. The site meetings on both projects are called *Contract Review Meetings*, The meetings are MC's primary means of communicating programme and financial information from the site to head office, linking the company level accounting cost control policies to project cost control through monthly meetings held on site. The purpose of the meetings is to report a project's progress against programme and financial position at the end of a month. The meetings are a key part of MC's organisational governance. Two senior managers from head office attend the meetings, the Operations Director and the Commercial Manager. The rest of the participants are members of the site team, the Site Manager, the Site Quantity Surveyor, the Design Coordination

Manager (where applicable) and their assistants. The agenda for the meetings is common across the all MC's projects. The meetings do not include the process of reconciliation (the comparison of cost and net realisable value required for the company's management accounts, called a *cost value reconciliation*). However the meeting does inform the CVC that is subsequently produced by the Commercial Manager, but was not observed.

Data collection with the main contractor also involved observation events (Table 5). This encompassed three supply chain network events, a BIM implementation event and the commercial testing of three alternative costing software packages. These activities involved related deliverables to the main contractor for their internal use (as described in Section 1.3), namely a survey of their supply chain's attitudes to BIM and collation and reporting of feedback from participants from the software testing. The researcher, whilst participating in these events for the company deliverables, also observed the event to find out the inherent behaviour of the firm by observing their concerns and conduct in order to understand what was taking place.

Ref	Event Title	Nature of organisation(s)
31	BIM model health check	Main contractor and design software supplier
32	Supply Chain Forum	Main contractor and regional category A star subcontractors
33	Supply Chain Forum	Main contractor and regional category A star subcontractors
34	Costing software testing	Main contractor and software supplier 1
35	Costing software testing	Main contractor and software supplier 2
36	Costing software testing	Main contractor and software supplier 3
37	Supply Chain Workshop	Main contractor and project 2 supply chain
38	Planning software testing	Software supplier 4
39	Payment software testing	Software supplier 5

Table 5: Summary of observation of events

The observations of projects and events were recorded as field notes.

3.5.7 Workshops

Three workshops were held during the course of the project (Table 6). The *created* context of workshops (as described by Steyaert and Bouwen (2004), where the researcher brought participants together, provided a second opportunity to observe groups. Steyaert and Bouwen (2004) note the advantage of created group contexts, which can provide rich information that is exploratory and generates ideas. But they note that the role of the researcher needs careful consideration. The workshops involved in this research involved the researcher and the research supervisors. Steyaert and Bouwen (2004) note that group processes should steer the progress of created workshops. The researcher therefore facilitated the process, rather than the content, of the workshops.

The first workshop brought together senior managers from the pre-construction and site operation teams of the main contractor. The purpose of the workshop was to test whether the preliminary results from interviews, document reviews and observations chimed with reality, and where true opportunities for improvement could lie, which could have a demonstrable affect on the organisation's costs. The workshop first presented preliminary results from interviews and observations that explored current costing practises. The workshop then aimed to discuss different ways of working that MC may have in the medium-term future. The workshop presented possible causes and effects of inefficiency in site operations that were influenced by lean construction to start debate on possible opportunities to improve site operations in the supply chain and discuss what the order of the cost saving in these opportunities might be in a project.

The second workshop brought together four tiers of the mechanical and electrical services work package supply chain, SCA. This encompassed a Project Site Manager from MC (in tier 1 of the supply chain), an Operations Manager from SCA1 (the mechanical and electrical services subcontractor in tier 2 of the supply chain), an Operations Manager from SCA2 (the electrical services subcontractor at tier 3), and an Electrician from SCA3 (the tier 4 electrical subcontractor). The aim of the workshop was to jointly explore opportunities for improvement in site operations, to help the overall research aim, which was to attach costs to how to do a better job on site.

The third workshop reassembled senior managers from the pre-construction and site operation teams of the main contractor. The workshop first presented final results from interviews and observations that explored current costing practises and potential improvement interventions. The workshop then aimed to discuss and better understand the links between real world problems of contractors' costs and contractors' work plans.

Ref	Workshop	Participants	Nature of organisation(s)
40	1	As above	Main contractor
41	2	As above	Supply Chain
42	3	As above	Main contractor

Table 6: Summary of workshops

The workshops were audio recorded and transcribed. An example of an extract from a transcription of a workshop is included in the Appendix A2.4.

3.5.8 Summary of research activity

The relationship between organisations in the case study was presented earlier in Figure 5 in Section 3.5.2. The eight organisations are represented here in Table 7 below to show the breadth and depth of the case study of a supply chain across organisations and across data collection methods.

<table>
<tr><th>Supply chain</th><th>Tier 4</th><th>Tier 3</th><th>Tier 2</th><th>Tier 1</th></tr>
<tr><td>SCA

Mechanical and electrical services</td><td>SCA3

Documents Workshop 3</td><td>SCA2

Workshop 3</td><td>SCA1

Interviews Documents Workshop 3</td><td rowspan="3">MC

Interviews Documents (Projects A and B) Observations (Projects A and B) Workshops (1, 2 and 3)</td></tr>
<tr><td>SCB Suspended ceilings and partitions</td><td></td><td>SCB2

Information provided by SCB1</td><td>SCB1

Interviews Documents</td></tr>
<tr><td>SCC

Moveable partitions</td><td></td><td>SCC2

Information provided by SCC1</td><td>SCC1

Interviews</td></tr>
</table>

Table 7: The breadth and depth of case study material

The main contractor and the five subcontractors in the un-shaded boxes directly participated in the research. The two subcontractors at the bottom of supply chains B and C in the shaded boxes did not participate in the research. They are included in the diagram to show the depth of each supply chain and because the T2 subcontractors in supply chains B and C gave views on this tier of their supply chain below them.

3.6 Research framework for data analysis

This section describes how the data was summarised and analysed to present and explain the problems found.

As summarised in the previous Section 3.5.8, five methods of data were used to collect data in the primary research. This resulted in a large volume of audio recordings, transcriptions, summaries of documents and field notes. As described previously in Section 1.4 and 3.3, a research approach of *systemic combining logic* (Dubois and Gadde, 2002 and 2014) was used as the main approach to keeping track of the volume of data collected. Systemic combining logic follows a procedure of *matching*: going back and forth between theory and data gathered. This *abductive* approach generates a “tight and emerging” research framework.

The researcher built an initial, rather sketchy and general research framework that emerged from theory on the sequential nature of standard contractor estimating and cost control processes. The chronological sequence of the costing system served as this initial framework in order to describe, understand and explain contractors’ current approaches to supply chain costing and compare these to concepts in literature.

- Cost handling during tendering
- Costs at contract
- Cost handling during site operations
- Cost handing at final account

The researcher then developed the framework using concepts from estimating and tendering practice (Towey, 2012; Greenhalgh, 2013; Kirkham, 2015; and Brook, 2017) (i) estimates of the use of resources and its further division into labour, material plant, contingencies, overheads and profit (ii) quotations received and (iii) strategic tendering decisions. This expansion of the research framework by the researcher explained some of the methods of costing, organisational behaviour and decision-making that had been found. As the empirical data collection continued to find out about current approaches to controlling expenditure during site operations, the researcher further developed the framework from emerging observations that identified examples of methods of cost control. From observations, the researcher further divided cost handling during site operations into the concepts of keeping to budget, keeping to time and cashflow. The researcher further drew of concepts from theory in construction improvement and supply chain management (Mosey, 2009; Koskela et al., 2002; BIS (2013) and Pries and Doree, 2005), and participants' experience and views on the link between costing and improvement. The concepts from theory that participants had experience of and views on in practice were early contractor involvement, collaborative planning and innovations in materials, plant and equipment. The researcher therefore encompassed these in to the research framework. These efforts to match theory and reality created two higher-level concepts that were recurring in theory and in observations: money and work done. These were added to the framework. The final framework that arose from concepts in literature and from what people said is set out in Table 8 below.

<table>
<tr><th>Initial framework</th><th>Expanded framework from abductive matching</th></tr>
<tr><td rowspan="3">Cost handling during tendering</td><td>Use of resources</td></tr>
<tr><td>Quotations received</td></tr>
<tr><td>Strategic tendering decisions</td></tr>
<tr><td colspan="2">Costs at contract</td></tr>
<tr><td colspan="2">Value engineering</td></tr>
<tr><td rowspan="3">Cost handling during site operations</td><td>Keeping to budget</td></tr>
<tr><td>Keeping to plan</td></tr>
<tr><td>Cashflow</td></tr>
<tr><td colspan="2">Cost handing at final account</td></tr>
<tr><td rowspan="3">Improvement interventions</td><td>Early contractor involvement</td></tr>
<tr><td>Collaborative planning</td></tr>
<tr><td>Innovation in materials plant and equipment</td></tr>
<tr><td colspan="2">Money</td></tr>
<tr><td colspan="2">Work done</td></tr>
</table>

Table 8: The research framework for data analysis

The framework was used to built up a multi-tiered picture of cost handling in construction projects that will be used in Chapter 4 to show how forecasts of costs are created and how actual cost are incurred and flow between organisations in the supply chain.

3.7 Research journey

This research, as described in Section 3.5 above, originated in an agreement forged by the research supervisor, between the research institution the main contractor for the contractor's sponsorship of a research student for a period of three years, to undertake work of mutual interest in "contractor costing in BIM". The main contractor and the research institution jointly chose the researcher. The researcher is a chartered quantity surveyor with 24 years' experience in practice in Local

Government. The researcher took voluntary redundancy to pursue this research due to her interest in what academic research has to offer in this practical study with an industry partner. The researcher was familiar with the process and practice of costing, with 12 years experience acting in the roles of quantity surveyor, employer's agent and design team manager. In embarking on the research project she was returning to the field of quantity surveying, having spent her latter 12 years' as a senior manager in social housing policy and practice in Local Government, and a non-executive director in Housing Associations. Thus the researcher had a full grounding in the practices and jargon of construction costing, experience of working in organisations (and thus managing the research partnership), and a fresh outlook on the research subject, with no professional bias, having moved away from quantity surveying practice in the latter 12 years of her career.

The first task for the researcher was to shape the research proposal by setting out the objectives of the partnership. The researcher, research institution and main contractor were all interested in studying contractors' costing practices in light of the change to digitisation of information that was on-going in the industry. The original, outline research proposal was to gain an understanding of how real supply chain costs are built up through a project; how supply chain knowledge can be used to deliver better projects; costing methods in BIM, particularly comparing object costs with production activity costs, with an intention of creating theory on supply chain integration for construction using BIM. The main contractor's intention was to take account of the research as they started to use BIM technologies for cost management of projects across their business.

Discussions based on the research proposal fed into a Collaboration Agreement (Appendix A1.1) and a timetable of company and academic deliverables. The studentship was formally established in in February 2013. The researcher carried out tasks specifically requested by the main contractor, parallel to, but separately from, the academic tasks. Between April and July 2013, as a task for the main contractor, the researcher carried out a survey of the subcontracting companies in the main contractor's supply chain network. The survey aimed to uncover subcontractors' attitudes to BIM. In July 2013 the researcher delivered a survey report to the main contractor. During August and September 2013 the researcher carried out commercial tests of proprietary software for cost estimating for the main contractor. The researcher carried this out with members the main contractors' pre-construction estimating and site quantity surveying teams. In October 2013 the researcher delivered a report on the comparative functionality of five different software applications tested. This thesis does not report on these two company deliverables. However, the activities contributed to data collection for the academic deliverables.

In March 2014 the research team published an academic paper based on the survey of the main contractors' supply chain members and concepts of construction improvement and supply chain management in literature. This conference paper "UK supply chain attitudes to BIM" (Appendix A3.1) concluded that the subcontractors saw successful BIM implementation as conditional on strategic changes from short-term project-based relationships to more long-term relationships with main contractors. However literature showed that in practice new ways of working in construction supply chains have taken an operational approach. Subcontractor's desire for strategic change was also contradictory to the advantages of the *dynamic capabilities* (Green *et al.*, 2008) that subcontractors gain from short-term project-based relationships. These early findings started to reveal that the research problem of finding a new model of costs to account for supply chain improvement could not be isolated from wider systemic issues in the industry.

The researcher undertook interviews with participants across the main contractor's organisation. Access to the subcontractors who became involved in interviews for the study came from different routes. The researcher recruited one subcontractor through networking at the main contractor's supply chain forums. A Director in the main contractor facilitated introductions to two of the subcontractors and the research supervisor facilitated introduction to the fourth subcontractor. A Director in the main contractor identified the two projects and facilitated introductions to the site teams. The researcher then carried out interviews and observations. In this phase of the research, the costing routines in different firms were analysed in detail and compared between firms. The results were presented to the main contractor in the first workshop and discussed in relation to improvements in site operation.

In September 2015 the research team published a second academic paper "Are contractors' cost accounting practices up to the job of establishing improvements in site operations?" (Appendix A3.2). This conference paper marked a redirection of the research. The paper reported that literature showed that Activity Based Costing was the main source of new information on costs associated with methods of work in commerce. This brought construction activities in to the picture. But the research showed that in construction supply chains, cost information on construction methods that would be useful in rewarding improvement was either not created, or lost as cost information passed between firms. This led the research in a new direction, from pursuing more detail in current costing practices, to a consideration of the connection between the context of construction and its operations, as the fundamental direction for a solution.

This change in direction of the research required new theory from literature and new research into the realities in site operations as experienced through the supply chain. New literature by Johnson and Kaplan (1987) showed that a loose relationship between work done and s*urrogate* costs had been seen as a problem in commerce since the 1980s. Dean(1993) showed that accounting for improvements persisted as a problem in the space and aerospace industry, not just construction. Data collection continued with a new focus and the researcher put together a second workshop that brought four tiers of a supply chain together to talk about their every-day experiences on site and where they thought opportunities for improvement might lie. In June 2016 the research was published in a journal paper "Studying cost as information to account for construction improvement" (Appendix A3.3). The paper concluded that "The problems with costing and the actual management practices in the industry require a systemic change to effect improvement involving not just new templates, but new cost information and changed supply chain relationships." This required new research into "cost as information" given the move into the information world of BIM.

The search for complimentary theory continued after the final phase of data collection, guided by the empirical findings. Particularly useful theory would emphasise the systemic nature of supply chain operations and explore the nature of information in order to link IT to the organisations it is used in. The research from this point drew on the Tavistock Institute's (1966) work on the characteristics of the construction industry that need to be taken into account in any model of the construction process: interdependence and uncertainty. It also enrolled Winch's (2010) *tectonic* model of the construction system. It drew on Rosenhead's (1989) soft systems theory as a general framework for analysing social organisations. It then drew heavily on Beynon-Davies' (2011) framework of forma, informa and performa as a general theoretical foundation in order to illuminate the link in construction between costing systems, projects, organisations and IT, that were not yet fully realised at this point. These concepts were used to redefine the research problem from the single pursuit of greater detail in costing to simpler cost models that are more useful for improvement deep into the supply chain. This has brought the impact of construction planning into focus and the insights from theory put future research into construction planning in construction supply chains as a starting point for further research, as will be discussed in Chapter 6, the conclusion to this thesis.

This research journey illustrates how the focus of this research changed as findings from the data collection came into confrontation with theory. This is the essence of Dubois and Gadde's (2002 and 2014) *abductive* research approach that was taken of *systemic combining logic*.

Through the research, the researcher set out to learn about both the research process and the research subject. During the process the researcher learnt from both the theoretical frameworks enrolled in the research and from the empirical findings. This researcher found a great value in this interplay between findings and theory. From a background in practice, where policy is established and then not reconsidered as it is carried out, the researcher learned the value of openness to dialogue inherent in the research approach taken. The research process as carried out supported the researcher's intellectual development and understanding of what academic research is and what it has to offer. The research process supported the researcher's realisation that it is possible, and indeed common, to carry out a role in practice, without really understanding what you are involved in. The researcher was privileged to work with some participants who had a rich understanding of what they were involved in and said "we are mad if we are still doing it this way in ten years time."

CHAPTER 4

FINDINGS AND ANALYSIS FROM A CASE STUDY OF A SUPPLY CHAIN

4.1 Introduction

This Chapter reports at the findings obtained from the primary research that was undertaken as a case study of a supply chain, encompassing a main contractor and seven subcontractors across three *work package supply chains* (supply chains for subcontract packages of work) as described in Section 3.5. The data was collected though semi-structured interviews, in-depth reviews of documents, non-participant observations, and workshops as described in Section 3.5.

The research framework is used in this Chapter to structure the presentation of the problem and its analysis in this Chapter. The evolution of the research framework from both theory and the empirical data collected was described in Section 3.6. The framework is part chronological and part thematic. The chronological element of the framework covers cost handling during tendering, at contract, during value engineering, during site operations and at final account, each with thematic subsections. The framework then covers improvement interventions, again with thematic subsections.

The empirical data presented in this Chapter primarily reflects the first research objective: to determine how current approaches to supply chain costing affect supply chain operation and overall construction costs on a project. The empirical data touches on the second research objective, to determine how different approaches to costing of supply chain operation can be used to deliver efficiency and cost savings in projects, where that was within the personal experience of participants.

The findings are presented in this Chapter against the research framework with supporting quotations selected to illustrate specific examples. The presentation of the findings that follows takes a view from the lower tiers of the supply chain upwards, in that it presents illustrative quotations from subcontractors (tiers 2, 3 and 4 of the supply chain) first, in the left hand column, and presents comparative illustrative quotations from the main contractor (tier 1 of the supply chain) afterwards, in the right hand column. All quotations are notated to identify the tier, the work package and the organisation that they come from. Figure 6 below is represented here from Section 3.5.2 to show the notations used for each organisation and the relationship between organisations.

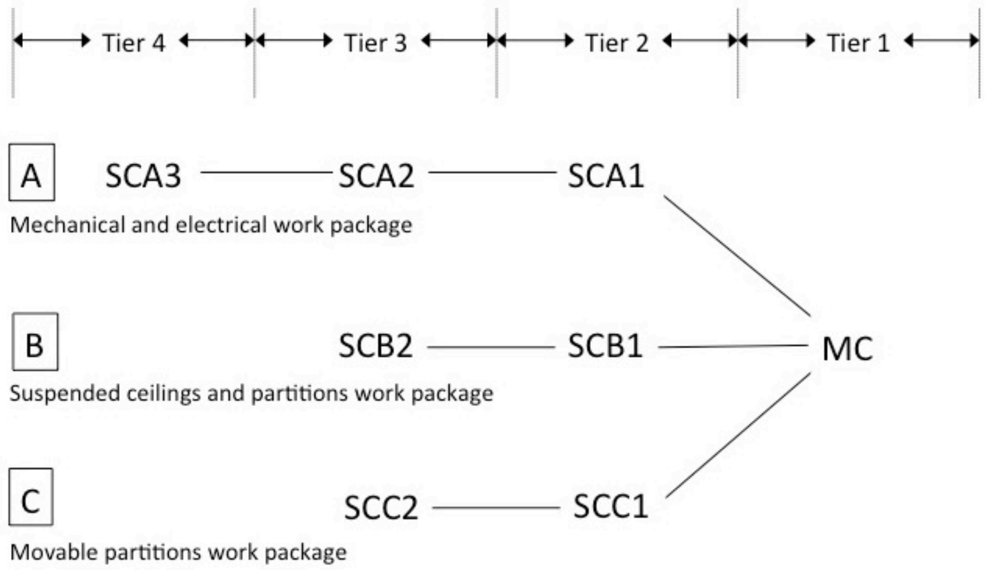

Figure 6: The notations for organisations and relationship between organisations in the case study

All the quotations presented in the Chapter are also cross referenced to the specific interview, workshop, site meeting or event that they come from, using by the reference numbers for each research event (1 to 42) that were established in Section 3.5. This Chapter ends with a summary and analysis of the findings against two higher-level concepts, money and work done.

4.2 Cost handling during tendering

4.2.1 Competitive tendering

This first Section considers how, in a tendering situation, contactors and subcontractors address the problem of estimating the costs of the resources a project is forecast to absorb. The client sets the timeframe for the tendering exercise. The client also chooses the format for the model that costs are to be presented in. The cost model is usually the industry standard bill of quantities in which, as set out in Literature Section 2.2.1, costs are presented against *measured items* of work or lump sums for preliminaries and contingencies. Contributions to a firm’s general overheads and an expected profit are spread across each of these. The estimating process starts when a main contractor receives an invitation to tender for a project from a client. The main contractor splits a project up into *work packages*: subcontract packages of work. and invites subcontractors to tender for work packages. Subcontractors may split their work package into smaller parts and so on. This produces a supply chain of firms tendering for a project.

This section explains how estimators across the supply chain go about forecasting the resources a project will absorb. There is an industry standard *cost-plus* project costing method, in which each firm in the supply chain estimates their input costs of labour, materials, plant, equipment and project overheads. They then add a proportion of their firm's general overheads and allowances for risk contingencies and profit. Forecasts of costs are built up though the supply chain towards the full cost of the project in a main contractor's bid. Across the supply chain most firms have the same three categories of cost: use of own resources, quotations received and strategic tendering decisions. These three categories are used to present the findings in this section that seeks to uncover covers cost handling practices during tendering.

4.2.2 Use of own resources

Estimators across the supply chain may create cost information using *first principles:* the activities that consume a firm's own internal resources of labour, materials and plant as described in literature in Section 2.2.1. The findings show that contractors created cost forecasts of the use of the labour, materials, plant, equipment and project overheads for physical work they will do on site using their firm's own resources

Forecasting the amount of labour required for the tasks that are absorbed by measured items is less straightforward. Estimates of the amount of labour forecast are mostly historically-determined norms, with project specific adjustments. Participants explained that they forecast the amount of labour based on industry standard sources of historical rates of labour productivity for different tasks, or their firm's own internal standard rates. Estimators then adjust rates of labour productivity for the particular project based on design features, such as working in open or restricted spaces. In SCB the full risk of exceeding or falling short of the expected labour productivity rate is passed on to the labour-only subcontractors at the bottom of their supply chain, SCB2. SCB1 engages SCB2 on an *output related incentive scheme*: a price basis in which a daily payment is set based on an expected output.

In this case the risk of delivering to the forecast is transferred to SCB2 in the lowest tier of the supply chain.

At T2 in SCA, SCA1 explained ”*On our estimation software we have site factors, which is what we use against labour… it might be a big warehouse, and everything’s 10 metres in the air and we’re working off large towers, so we add ten or fifteen per cent onto our labour costs for that… If we’ve got conduit running right the way down long corridors, straight runs, that’s fantastic, we’ll have a rate for that. But then when we’re doing toilet blocks, where it’s all little fiddly bends and all sorts, we change the rate.” SCA1 (15)* At T3 in SCB, SCB1 explained that they transfer the risk of labour productivity to their labour-only subcontractors in T3 by negotiating a lump sum for labour. *“All the labour, instead of being paid on day rate is paid on price, so basically, the more they put up, the more they earn.” (10) SCB1* explained (14) that they negotiate with T3 to agree a lump sum for T3 to put up a set area of ceiling. They explained that the calculation starts with an assumption of what a good fixer can put up in a day. This varies between projects based on the size of the job. A fixer who puts up 40 square meters per day earns more in a day than a fixer who puts up 30 square metres.” *(14)*	At T1, MC explained that the number and time requirements of directly employed managers is decided and the total is allocated to an item for site management in the preliminaries. The quantity is thus time related to the contract period.

Quotations 1: Forecasting quantities of direct labour

Forecasting the cost for direct labour is a relatively straightforward, technical exercise based on agreed pay rates. Costs for directly employed labour are derived from annually updated schedules collated by the organisation of the salaries that they pay, usually based on national wage agreements and salary on-costs. The degree of exposure of rates of pay to the market differs between trades. Rates of pay in the main contractor’s site team are fairly stable but rates of pay for specialist tradespeople at the bottom of the supply chain vary, even project by project, in response to demand for their work in the market. Predicted rises in demand for a specific trade gives rise to specific increases in rates of pay. Firms at the bottom of

SCB and SCC, sole traders in temporary employment as either an individual or a gang, experience the most volatile rates of pay.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCA, SCA1 explained that the costs of directly employed managers and operatives are based on '*company costs'* (15) At T2 in SCB, SCB1 explained that they do not directly employ any operatives and the costs of managers are based on salaries plus on costs (14) At T3 in SCB, SCB2, the practices of the labour-only subcontractors who directly employ operatives, were reported by SCB1 who said that they start with the industry standard skilled labour rate for the trade and negotiate with SCB2 on each project in accordance with the going market rate and loyalty in the relationship between the two firms. SCB1 explained that last year they could say to SCB2 *"this is what I managed to get out of the job"*. Now they were asking their best labourers *"what do you want?" (14)*	At T1, MC explained that the costs of directly employed managers are *"salaries plus on costs and planned uplifts"* (7)

Quotations 2: Forecasting costs of direct labour

Forecasting the quantity of materials that are absorbed by measured items is the most straightforward calculation made by estimators and is based the quantity of materials, plus their firm's standard or an industry standard percentage for waste. Forecasting the amount of plant required for the tasks that are absorbed by measured items is based on plant utilisation rates that are derived from either a firm's standard or industry standard rates based on previous project experience.

Forecasting the cost of material and plant is similar across the project supply chain. Forecast costs of directly owned plant comes from a firm's own schedules. Forecast costs of regularly used materials and hired plant are derived from a firm's regularly updated schedules of negotiated prices from suppliers. The costs of materials and hired plant are relatively unstable in response to demand across the project supply chain. But the length of time that prices are fixed does vary between and within different trades. As projects across the industry compete for the same resources any forecast rise in demand for specific materials or plant, such as tower cranes, gives rise to increased costs.

At T2 in SCA, SCA1 explained that *“We’d buy all the electrical materials ourselves. So lighting, power, containment, cables: we’ll buy all that through our own supply chain arrangements with lighting companies or wholesalers…when we’re tendering we would always be using the latest figures that we can buy that equipment for” (9)* At T2 in SCB, SCB1 explained that *“we'll get a material list together, put it onto a spread sheet, we'll then send that material list over to the distributors, they'll then send prices back for the materials and we've got formulas set up in Excel for different systems and so we'd just price from there… ninety per cent of our business goes to one, we still go out to two or three, just to make sure their price is competitive.” (10).* SCB1 explained that they consult the labour only subcontractor about material specification and quantities *“in the office we may think something's going to be built one way, on site the fixers might think it's going to be built another way. At the end of the day, they do it day in, day out; they're going to be the best people to know what material to use to do the job. So there is always a conversation there, and we both agree on what's needed.” (10)* At T2 in SCC, SCC1, the specialist component subcontractor, explained that they can fix prices for component parts a year in advance with their supplier *“we have established exclusivity agreements with recognised and high quality manufacturing partners…we have …a software package which is synchronised with [component manufacturer], so it’s kept up to date, they don’t change the prices on a day to day basis, it’s sort of an annual thing with plenty of notice.” (11)*	At T1, MC explained that the cost of plant is based on internal or external hire rates.

Quotations 3: Forecasting quantities and costs of materials and plant

First principle costs are created in this way by the firms that will do the physical work. This is the textbook method. MC explained how a groundwork subcontractor told them that they do not use first principle estimating for pricing manholes: forecasting costs of labour, materials and plant based on detailed quantities of brickwork, pipework and the other parts of each manhole. Instead they rely upon '*experience-based models'*: alternative, informal, less detailed methods of building up costs of a project that rely on an estimator's experience and judgement. This was described in literature Section 2.2.2. Participants also called this "back of the envelope" estimating.

At T2, MC were asked about their knowledge of the way their subcontractors price the bill of quantities. The main contractor's quantity survey observed that not all subcontractors have the costing systems to allocate resource costs to activities. *"[we asked a subcontractor] how do you price a manhole? Do you get the cost of the concrete, brickwork, pipes and manhole cover and work out how much? No. We put five hundred quid in for each one. So how do you know that works? Well, we know it works and when it starts not to work we put our price up" MC (5)*	

Quotations 4: experience-based estimating

4.2.3 Quotations received

The costs of the physical work that firms will do on site are passed up the supply chain in quotations. The main contractor estimated that 70% of the cost information building up to their costs comes from quotations received from subcontractors. SCA1 and SCB1 also subcontract as much as 60% to 70% of their work by turnover. Thus the extent and therefore importance of quotations is significant as a source of cost information.

Lower Tiers of the Supply Chain	Main Contractor
At T2, SCA1 explained that the size of their direct labour force is not fixed and influenced by the market and regional practices. *"direct labour force...how we'd prefer to deliver a project, because you've got much better control over the quality, and the people, and who's doing what, etc. But you can appreciate that when it turned down, and suddenly you've go 200 guys and you've only got work for 100, you just can't carry them….the Northern region has mostly direct delivery with few subcontracts. Ductwork would always be subcontract, and the specialist security and fire systems, but the electrical lighting, the power, and the pipework are all direct delivery. That reduces a bit in the Midlands. In London it's pretty much all subcontract, That's just traditionally the market in London." "on the mechanical side we would always subcontract ductwork: that's a supply and install package. Pipework, that varies: we carry our own direct labour but we would also often subcontract pipework systems, and we might subcontract materials and labour because there's an element of risk with delivery issues." (SCA1 9)* At T2 SCB1 explained that they do not directly employ any labour. *"All of our labour is sub-contract… thirty, forty blokes, we've been using for at least five, ten years… they are all self-employed, or they have their own limited companies, or they're sole traders…A gang would be…anywhere between four to ten people…The majority of supervisors are also fitters, so they're normally working supervisors" (SCB1 10)* At T2 in SCC, SCC1 explained *"We do use quite a lot of subcontractors, the reason we do that is predominantly the best guys have set themselves up as sub contract companies in their own right…We have got current plans to actually take on our own fitting teams. We have got our own Service Engineers." (11)*	At T1, MC explained that they directly employ site managers but no operatives. They explained how the size of their management team on a project is not fixed, it is influenced by the market. They described how the recession had driven them to resource projects with *"Five managers to about 400 operatives on site." (41)*

Quotations 5: Extent of subcontracting through the supply chain

Across the supply chain estimators, sometimes called “buyers”, receive quotations. The estimators compare the quotations they receive from competing firms. To compare quotations estimators make technical comparisons between quotations. They also use “buying skills” such as judgements about the track records and loyalty of competing firms, knowledge of the levels of *standard trading discounts (*discounts they expect to get that recognise trade business), and knowledge of competition in the market for specific work packages. They used their negotiating skills depending on the level of completion in the market. For example competition in the market for mechanical and electrical services work package is limited as there are a limited number of firms available to compete for this subcontract package of work, so scope for negotiation is limited in these circumstances.

At T2 in SCA, SCA1 illustrated the lack of competition in the mechanical and electrical services work package. They described the tension between MC’s desire for an exclusive arrangement (described as a back-to-back agreement) at tender stage, and their own desire to be part of all the competing tenders for a project. *“we might get asked by two builders or three builders to go back-to-back with them. Again, potentially because of our name and because of our reputation, we sometimes find ourselves in that situation. And then at other times we just end up saying we’re just going to bid everybody because we’d rather have a competitive bid in the market. If you will want to name us then that’s fine, but we’re not going to just go back-to-back with you, because we end up in a position there where if the main contractor loses the project because they’ve done a bad bid, we might have done the best M&E bid out of everybody, but the main contractor’s bid is two million over, and that’s it: we’ve lost the job because of it. So there’s this whole backing the wrong horse or backing the right horse, which is awkward, but a lot of large contracts require you to tender that way” (9)*	At T1, MC illustrated the lack of competition in mechanical and electrical services work package. They described how the limited size of market makes it hard to secure competition between mechanical and electrical services firms when demand rises. *“So when I've got an order to let for a twelve million M&E package and I really want to go to three or four big players in the Midlands, they're all going to be busy.” MC (40)*

Quotations 6: Limited competition for mechanical and electrical services

Findings show that it is standard practice across all tiers of the supply chain for quotations to be selected for inclusion in a tender on the basis of lowest price through competitive bidding. This Chapter will return to the category of costs sourced from quotations in section 4.5.1, where further findings show that the subcontract work package quotations received in a competitive tendering situation at the client's tender stage, are revisited through a secondary tendering process, by a main contractor, if and when a main contractor wins the tender.

4.2.4 Strategic tendering decisions

Once estimators and buyers have created forecasts of costs from estimated direct costs and subcontract prices they pass this on in their organisation for senior manager input. A commercial manager, or equivalent, reviews the information and establishes the project mark-up. The mark-up is created for their expert opinion on (i) anticipated costs for contingencies for the level of uncertainty and risk in the project (ii) a margin to recover a proportion of the firm's general overheads and (iii) a level of profit expected to be earned from the project. MC explained how mark-up cost information relies heavily on risk analysis and market knowledge to inform a figure that best accounts for project uncertainties and what the market will bear. Participants explained the realities of their intense discussions about contingencies, overheads and profit. The "vigorous debates" by senior managers over strategic tendering decisions contrasts with the relatively straightforward decisions that are made by less senior people about use of resources and quotations. Thus experience and judgement are the main ingredients of decisions about risk and margins.

Lower Tiers of the Supply Chain	**Main Contractor**
AT T2 in SCA, SCA1 *"We apply risk costs, overheads and profit, as agreed in the settlement meeting with directors and this form [the tender settlement] becomes the financial record of our tender. If successful this passes to the project delivery team as a record of decisions made at tender stage to come to our offer." SCA1 (15)*	*At T1 MC "We've had some vigorous debates about what the correct level of risk contingency should be on those jobs. We've had similar debates on every single job and it's the most subjective point taken…MD adjudicates it and he sits there and says, well I tell you what. We really want this job" MC (40)* *"There are two layers. Some people might take a few bob off to win a job but the figure they take that from is a figure which people have already made assumptions on." MC (40)*

Quotations 7: Estimating risk and profit

Participants described the differing amounts of risk they were prepared to take in respect of the level of design detail reached at tender. The mechanical and electrical services subcontractor, who has significant responsibility for design, puts a protective barrier into their tender by requiring a high level of design detail for their tender estimation. On the other hand, when the main contractor has no control over design information and when trades that do not have any design responsibility they have to take decisions about costs and without interaction with the designers.

At T2, MC explained the difference they saw between their approach to design risk and the mechanical and electrical services subcontractor's more cautious approach to design risk. *"[*M&E *contractors] interestingly…don't start procurement until they've got ninety five per cent technical sign off on the job. Now in a way that's contrary to ours.. we'll lock in some deals... theirs is, let's not lock in deals coz we need to know they're technically right so we don't get caught out by variations in sub-contractors." MC (40)*	

Quotations 8: Reducing risk in mechanical and electrical services

Sometimes, a contractor has particular knowledge of a specific technical problem or a specific site factor that is not stated in tender documents. They either choose not to share this information and hope that they are paid the extra costs when the problem comes to light. Or they choose to share this information by "qualifying" their tender by listing their assumptions. Where contractors chose to share this information through qualifications they reported that it is standard practice for this to be disregarded on the basis that competing firms have absorbed the risk, either knowingly in order to not lose the job, or unknowingly. Good information can be lost in this way.

At T2, SCB1 felt they were asked to take design risks *"We usually list our clarifications and assumptions. Most people ignore that." SCA2 (15)*	At T1, MC They described how they cost reductions or risk can be forced on them *"the ground has got asbestos. You have to put in the quarter of a million pound price in and you then qualify it…. so they've said…remove all your qualifications. Stand by your price…If you pass on that risk and they [the subcontractor] collapse, the risk comes back to you" MC (40)*

Quotations 9: Taking risk

Firms estimate the overall costs of their own work, including what they think will be needed, not just what is described in the tender documents. The estimator checks, and hence improves, information received on quantities and specifications for measured items of work and customises these for work that is under or over-measured, and under or over-specified. The suspended ceilings and partitions subcontractor expressed distrust of the client's quantity surveyor's ability to measure the work in their subcontract package accurately. The moveable partitions subcontractor expressed distrust of architects' ability to specify components satisfactorily in the design information and quantity surveyors' ability to measure it accurately. The mechanical and electrical services subcontractor as described before has significant responsibility for design. They put a protective, arms-length distance between themselves and the bill of quantities. Their work is generally measured as a lump sum against a plan and specification with supporting rates, not as rates against measured items. The main contractor expressed pragmatic acceptance that rates against measured items cannot be considered as accurately representing work done. The bill of quantities carries information about cost between firms. Participants saw a weak relationship between the bill of quantities and the cost information created within firms. All tiers of the supply chain generally thought that the detailed cost model, the bill of quantities, can significantly misrepresent forecast cost against specific measured items as costs can be manipulated across cost items in the model.

T2 in SCB, SCB1 They explained that whether or not the main contractor provides a bill of quantities or not, they measure their quantities from the drawings. *"Nine times out of ten, it's been prepared by someone that doesn't know your specific trade, so it's very generic, lack of detail and half of the time it isn't worth the paper it's written on, unless it's something simple like measuring squares. If there's a bit of detail in it it's written down in a format that you don't understand, it doesn't relate to any drawings and it's just confusing more than anything else…we've done the take off ourselves and then you know you've covered all your details." (10)* At T2 in SCB, SCB1 explained that price the main contractors itemised bill of quantities when they get the job. *We don't trust the main contractor's bill of quantities, we prepare our own" (14)*	*At T1, MC "There is a lot of manipulation in bills and a lot of game playing. So to try and get the truth we'd love to see what the true net costs are. There are so many people playing different versions of the same game it's really difficult to strike a line through and say, that's reality. Because we know that it's the rough with the smooth you don't really entertain that because their opportunity is in the next job too. So that's the drive for the game playing you get." MC (40)* *"you make more money on being paid for what you don't do than what you do do. So if you get paid to hang fifteen doors and there's actually only twelve in there you make a hundred per cent profit on the fitting of three doors" MC (40)*

At T2 on SCC, SCC1 "We try and avoid filling in bills of quantities, the reason we try and avoid doing that is that if it is a bigger job with several walls on it, what is factored into all those prices is a degree of shared costs. So if they then delete one of those items, they don't increase the price of the others that are left, they just take away the one, and that's no good to us because like transport costs are shared." (11) At T2 in SCB, SCB1 explained that they may not create fully detailed information due to lack of time*. "we'd love to, but we don't ever seem to be able to get to that prime cost at tender, because it's done in four weeks sometimes." SCA1 (20)*	

Quotations 10: Disconnection between a client's cost model and contractors' private cost information

4.3 Costs at contract

Literature in Section 2.3.2 emphasised the importance of the cost model established at contract. Findings showed that the costs in the contract documents are based on many assumptions, as at this point in time. Contractors cannot accurately predict what the building process and its costs will be but costs are fixed in a contract against specific measured items. Participants saw their prices as what this thesis will call *commercial rational decisions* about cost commitments, in which all parties accept the uncertainty inherent in what will be required to fulfil their part of the bargain.

4.4 Value engineering

The commercial bargain made between a main contractor and a client is usually based on the client choosing the lowest tender. If a chosen tender is above a client's budget, the client may ask for a *value engineering* exercise to be carried out to reduce costs as described in literature Section 5.2.2. MC explained that this process undermines the assumptions they have made at tender stage. MC explained the difficulty of accommodating changes to design within the commercial decisions they have taken about cost and time to come to their tender figure. MC explained how value engineering to achieve cost reductions is not easily costed because the changes have a broad effect on how the project hangs together that is not reflected in costs for individual measured items.

Lower Tiers of the Supply Chain	Main Contractor
	At T1, MC “When you get involved in the value engineering process, you start off with the job that's been well considered, but then we embark upon this period when we undo all that work and we pick at all the edges of it. So that the coordinated piece of design now has got different assumptions.” MC (40)

Quotations 11: Commercially rational decisions and value engineering

4.5 Cost handling during site operations

4.5.1 Keeping to budget

This Section considers how the main contractor and subcontractors address the problem of building to the constraints of a budget, from a start on site to the agreement of a final account. By this stage the main contractor has already agreed costs with the client. The main contractor’s overall price is a commercial decision, based on many assumptions and an acceptance of the uncertainty inherent in what will be required to fulfil their part of the bargain made in the contract. The subcontractors have provided quotations for work packages, but have not yet been engaged through contracts. There is not yet agreement on work package costs. Once a budget has been agreed with a client in a contract the main contractor’s site team has the job of building to the budget. The focus moves from cost modelling to cost monitoring against the cost model. MC explained that when a contract is awarded the budget is fixed but there are many ways to spent it.

“[the contract sum] determines our income. But there's many ways we can spend it to deliver it and our sub-contractors have exactly the same view.” MC (31)

Participants described the standard practice of undertaking a secondary competitive process on all quotations received from subcontractors and suppliers nearer the commencement of each subcontract package. Requirements for the physical work to be done are unaltered, but contractors throughout the supply chain force cost reductions onto their subcontractors and suppliers by asking for a new quotation that is lower then the quote received at tender. This practice works to subcontractors' benefit in a rising market, but outside of a rising market the contractor has the ability to force a new quotation out of a subcontractor based on the threat of going elsewhere, to competing firms, if price reductions are not given. All participants reported that when they are in the strong position of having won work themselves, they also seek to get lower prices though their secondary competitive tendering using their buying power in the market. Trading discounts again come into play. On top of the *standard trading discount* obtained in the first competitive process for operating in construction trades (as referred to in literature Section 2.2.2 and findings Section 4.2.3), contractors require a further level of *additional trading discount* (as literature Section 2.2.2) in the secondary competitive process. Participants explained how knowledge of additional trade discounts can be treated as a way to obtain competitive advantage in the first round of competitive tendering, before the discount is secured from a subcontractor through the secondary competitive process. Two contractors explained that they usually take the risk that an additional trading discount, or more, will be realised in further negotiations if and when they enter into a contract. Each firm had their own terminology for going back to the market in a secondary competitive tendering process to get a cheaper price from their subcontractors and suppliers, for example "buying gains", "betterment" and "savings through buying".

Lower Tiers of the Supply Chain	**Main Contractor**
At T2 in SCB, SCB1 described how MCs will nearly always ask them for a lower price when the MC gets a job. *"We never get notified whether it's our price being used or whether it's someone else's….they will never go with prices submitted at tender. Well, I say never, they might do sometimes but it's very rare. They always ink them out with the QSs and try and get lower prices." (10)*	At T1, MC, from the observation of the main contractors site meetings, on both projects the quantity surveyor led discussions on price bargaining based on their negotiations with subcontractors. One work package that had not yet been let was the building management system (BMS). The budget included a quote from 'BMS company A' and the quantity surveyor had obtained two alternative quotations The overall aim was to get new quotes lower than the original quotes at tender. *"Carpentry, joinery and ironmongery all have opportunities for savings through buying"* (22) (5 February 14)

At T2 in SCA, SCA1 explained how, when they are asked to provide a better price, discussions are accompanied by the threat of going elsewhere. *"what often happens is that we would put a bid in, say it was £10,000,000, and we'd say that's our best offer. The main contractor would win the work but it wasn't necessarily with a named M&E contractor, it was just that they've used our price. And then they might come back and say 'Right guys we've got the job now, we had to knock £2,000,000 off this entire project to get this job: you need to come along with us, and you need to make some savings and knock some money off otherwise we're going to go elsewhere…"it's a buying gain. It might be badged up as something else but realistically that's what it is. The question is then asked, did they or didn't they really knock that £2,000,000 off? Or are they just trying to get some better margin on our package?" (9)* At T2 in SCA, SCA1 explained how, when they have won a job with a MC, they then go to their subcontractors to get a better price *"what happens is, after the bids have gone in, they say, oh we've been told we're not the cheapest can we do anything with our price? There's always post tender questions…you've excluded this, how much is it going to be to add it in, or, how much would it be to take that out? Then they'll say, well look, we've had to make a commercial decision, we've had to knock five per cent off our price to win the job, so we want you to knock another five per cent off….we give a lump sum to the client but we reprocure every project…there is a commercial benefit for doing that because it might be that if you go out to five sub-contractors, the chances are you are going to find one who needs the work a bit more than the others." (15)* AT T2 in SCB, SCB1 explained that, having secured labour on a lump sum price their only avenue for forcing cost reductions further down the supply chain is with material suppliers *"The only way we're ever going to get down on price is by going back to the distributors, getting better material rates." (10)*	"*We've got a complete breakdown…his ['A Mast Climber subcontractor] surveyor is saying he's committing commercial suicide...but we have found a better price for the mast climber and his margin is at risk if he doesn't hit our budget"* (23) *"He wants 15% overheads and profit on £x. We need to agree a sensible figure"* (23) *"Talk to other subcontractors so he knows he may loose. On 'A Another Project' one day after knowing we were going back out to tender 'A subcontractor' dropped their price by £x"* (23) There was consideration about relationships as well as cost *" 'BMS Company B' offers a saving… but M&E contractor A' says they are difficult to work with on site and "commissioning company A" say they are difficult on site"* (22)

At T2 in SCC, SCC1 a contractor for a specialist component said that when they are the only firm in the market because a client has specified their product by name, MC will create the impression that they can go elsewhere to competing firms. *"we know we are specified, they will put together an enquiry, that doesn't show our name anywhere or our product, it becomes generic, they don't want us to think that we have got any sort of power or any sort of, you know what I mean, they do that, which is fair enough, because it's all a game, isn't it, it's all a game." (11)* Participants described how trading discounts have a unique hold in the construction industry as part of price bargaining *At T2 in SCA, SCA1 "Subcontractors never give their best price first. We pre-discount our price when we put our price in. So we take a discount off their prices so you add all these subcontractor costs. We'll pre-discount ours before we sell it." SCA1 (15)* At T2 in SCB, SCB1, the estimator advised that they deduct a percentage of the resulting cost per square metre for a standard trading discount, and an additional percentage for an additional trading discount for particular main contractors. (14)	

Quotations 12: Competitive tendering bonus round - hard bargaining

Until costs for all subcontractors and suppliers are fixed in contracts, economic uncertainties about changes in the price of labour, materials and plant continually upset cost monitoring. If a tender is won when demand in the market is low and the work is delivered on site when demand and prices are rising, price bargaining strength switches to subcontractors and suppliers. As labour, material and plant prices rise; contractors may end up paying higher rates, overtime rates or agreed rates for specific tasks in order to secure labour when they need it. Contractors may end up being unable to buy materials or hire plant for their forecast costs. Observations of MC's site meetings showed that construction price rises started to materialise on projects during the period of this research. In this situation the focus was on fixing subcontract and supplier prices as early as possible to mitigate against further, later price increases. In these circumstances MC's site staff worked to keep their project within budget, whilst the senior mangers took a pragmatic view of their firm's bottom line across time and across projects.

T2, in SCB, SCB1 *"The only thing we've noticed the recession on is margins [profit for the year]. In the last four years we've grown forty per cent throughout the recession, so we've ridden it pretty well."*	*"[Architectural metal work package] Quotations are up 25% for the feature staircase…ask for help from pre-construction to procure at this price"* (25) (6 June 14) *" Cost inflation is working against us as a business..."* (26) 3 July (14) *"We need to push on with procurement. Its an ever rising market…to get certainty on cost"* (28) (5 September 14) *"The steelwork market rate has gone up"* (29) (3 December 14)

Quotations 13: Competitive tendering bonus round: managing price rises

The case study provided data on the ways in which costs are sometimes handled more flexibly through informal practices that are not found in textbooks. As well as hard bargaining on price to reduce prices without reducing requirements, MC pursued cost reductions by relaxing warranty and insurance requirements placed on their subcontractors or releasing money earlier to subcontractors by reducing requirements for *retention money* (Section 1.1), the money held back as security for contract performance.

	At T1, MC *"We've offered relaxation on the retention amount" (*23)*" 'A damp proof membrane supplier' guarantee…they said you need to be an approved installer…will not give us the full warranty…its an extra cost"* (24)*"We have loosened requirements on the levels of PI [professional indemnity insurance] against the original contracts"* (25) *"New recessed brick design…water will pool on the top of the brick…A brick supplier says it reduces the warranty from 60 to 9 years" "compromise is to take it off the back elevation but keep it where it is ok under the colonnade"* (28)

Quotations 14: Competitive tendering bonus round: soft bargaining I

In some instances cost reductions were also achieved by reviewing assumptions in the original tender and reducing material and component quantities or specifications within the constraints of the contract.

At T2, in SCA, SCA1 "simple thing might be that the original ductwork drawings show the duct coming into this room and it came right to the middle of the room here, and was supplying air under the floor, when actually we only need to just poke it into the room. So we might save a metre of ductwork. If you do that on 100 rooms then you've saved 100 metres and suddenly you see some savings come out the package." (9) *"We're looking at how it's sized originally from the consultant and we think we could let the velocities increase a little bit in the ductwork and actually reduce the size of the ductwork a little bit… if we've got the time we would look at that in that sort of detail" (9)*	At T1, MC in project A "reduced lighting specification" was on the table with the client on 5 February 14 and different design solutions and material choices were being considered in both projects. *"The plasterboard perimeter…show the extra over cost to the client and offer a saving if we use metal planks in the corridor"* (22) *""A piling subcontractor' say there is scope to reduce the tonnage in pile caps…if its £x saving we owe them £x of that"* (25) *'A screeding subcontractor" are going with what the manufacturers recommend" "get 'A main contractor person' to review their method statement'* (27)

Quotations 15: Competitive tendering bonus round - reducing quantities or specifications

Whilst price bargaining was the norm to achieve cost reductions, there were some circumstances in which MC viewed relationships as part of, or more important than, hard bargaining on price.

	At T1, MC considered relationships as well as cost "*If we don't get the right guy from 'A subcontractor' its not worth paying the premium"* (24) *'A person' working for 'A Subcontractor" is superb…worth asking if we can keep him on the contract" "We are particular about the scaffolding subcontractors we use" "'A partitions subcontractor' did a great job on 'A project' around the roof lights…makes sense to leave the job with them"* (25)

Quotations 16: Competitive tendering bonus round: soft bargaining II

4.5.2 Keeping to plan

The project start and finish dates are fixed in the contract and the main contractor's site team has the job of building to the constraints of this timeframe. At tender stage MC's pre-construction planners estimate a weekly programme for a project based on assumptions about subcontract packaging, work packaging, the timing of work packages and allowances for contingencies. The main contractor's site team then has the job of building to the programme. On site the focus is on monitoring performance against the weekly programme. MC explained that the start and finish dates are fixed at contract award, but the sequencing of the weekly programme is not fixed.

"We get paid to work to a timescale that is probably tighter than the ideal…so there's a profit if you can manage it well" MC (43)

Participants explained how a pre-construction programme becomes a target for the site team to plan and monitor activities against, providing time envelopes for subcontract packages on site. Participants explained that there are considerable changes to construction methods and plans during the course of construction. For example, MC demonstrated considerable flexibility in changing the way components are built, to do more work on or off site; changing work methods including a major decision about temporary works, and changing work packaging by combining or splitting subcontract packages. The main contractor explained how they take major decisions about the way they package work for competitive tendering to achieve cost reductions, either splitting down traditional work packages, such as mechanical and electrical services, in to its constituent packages, or removing an element such as materials from a work package. They call this "unbundling".

Lower Tiers of the Supply Chain	Main Contractor
At T2, MC explained how they appreciated how their decisions about how they package work can affect their subcontractors. There were two examples where MC knew that taking the materials out of work packages would make the work unviable for a subcontractor *"[we have an] unbundling strategy…He [groundwork subcontractor] says, you're chasing the only bit I make money on. We make money on buying materials and having deals with people and also getting rid of spoil. He said you want to take off the buying and materials. So I end up with all risk and you end up with all the potential benefit." MC (40)* *"he doesn't make any money on laying floor. He makes all his money on selling me a damp proof membrane" MC (40)*	At T1, MC explained on project B that at the outset of this project on site, the site team had 'unbundled' the mechanical and electrical services work package, splitting it up into its constituent smaller work packages and directly contracting with subcontractors for each smaller work package. This practice had removed the cost of a mechanical and electrical services contractor's overheads and mark up. But produced additional procurement and coordination costs for MC's site team.

Quotations 17: Main contractor's flexibility in construction methods and plans I

All participants demonstrated that in discussions on delivering projects to time the most important factor for subcontractors is to have the site ready for them to start on time. SCA2 described the pressure to start on site when the programme states they should start to show they are trustworthy, whether or not the site is ready for them. They described how they are unproductive at the start and have to accelerate later. All subcontractors said that they put resources into communicating with the main contractor ahead of their work package start date, to try to ensure that the site is ready for them when the programme states they should start. Participants explained that materials or plant delivered too late or too early cause disruption. Interactions between trades cause disruption either from problems of timing, the quality of others' work or damage of work by others.

At T2 in SCB, SCB1 stressed the importance of having a clear and clean workspace to work in. *"the builders will like to sign us up to a contract, where we've taken that betterment on the basis that we're going to have nice clean areas to work, everywhere, but it doesn't happen, and then we end up working the same way as we always work, and we've given betterment that we then can't recover." (15)* At T2 in SCA, SCA1 explained how they put resources in to make sure that work areas are available to them as planned *"Every big job has a logistics controller on the job.. because we appreciate how much time we lose by not having deliveries arranged well, not agreeing with the main contractor who's unloading and distributing all the materials, where it's going to be from and to, what the access route to the site are, and where our cabins are going to be located… what happens is, they end up getting all over the place, and we say, we're supposed to be working in here, it's not ready for us, so we do have to make do, and we go back three visits, to somewhere that we should have been able to do it one. The worst place that happens, and it happens on almost every job, is when we get to commissioning… to do that, we need finished spaces, we need no plastering, no decorating going on, the carpets have to be down, the ceiling tiles have got to be in, 'cause we've got to test the environmental conditions, test the fire alarms, if there's dust and smoke that upsets all that." (15)*	At T1. MC explained *"What do we give the supply chain? We give them a site to work on and we pay them on time. That's about all we do as a main contractor…if we can't give them a site to work on that's ready for them and we cant pay them on time…we accept lots of stuff, but we don't actually manage the site for them to work on very well...that's the bit we need to focus our attention on" (43)* At T1 MC knew that subcontractors experience advantages from clear work areas *"the results of having a misconnection are reduced because you can have the same resources doing the same task in a different location.. you are only incurring the reset up time…most supply chains will say give me half a floor and I'll go for it..they want that flexibility…if its goes better than they expected they don't want to slow their blokes down, so they've got space to spill in to.. Similarly they hit problems and fail they need another day..."(43)*

In T2 in SCC, SCC1 explained how they put resources in to make sure that work areas are available to them as planned *"we will send a site surveyor and sometimes we have to agree with the site personnel where the floor levels are going, or where that stud wall is going to finish up, because we have got to commit to manufacture before it's actually installed. So there is a lot of toing and froing, structural support is important as well, it is not always there at the beginning because the designers haven't allowed for it, so we spend quite a bit of time toing and froing with the site teams, whether it be the designers as well to make sure that when our lads get to site with the materials, they can fit it." (11)* T4 said that the ability to mobilise a labour force to do the work at the time they want it is a serious problem for them. *At T4 in SCA "we have to find that extra labour at short notice, which means employing people we don't know, who don't have any affinity to the job or the company, and that conduits got problems in quality and cost. So all these things do mount up." (41)*	

Quotations 18: Subcontractors' desire for certainty in the long term plan I

Subcontractors explained that the norm is for day-to-day tasks to be disrupted where there are interdependencies between trades. They explained that they absorb this normal amount of disruption within their costs. SCA1 said that they estimate costs assuming that the site will be ready for them. However their outturn costs generally absorb a normal level of disruption, so they do not know how much a project could cost them without any disruption. T4 explained that high churn of labour affects costs as new people can be slower or more disruptive. They explained that delay in the availability of materials or plant causes increased costs.

At T4 in SCA, SCA3 described their everyday experience *"You would come in one day, and he would say to the guys, well, here's what we'll do today, look at the schedule, and you'd sit down for 9 minutes and you'd write out a task brief, where are you going and what access equipment you need, and what hazards there are in the area, and then you get to the job and there's a load of plasterers coming down the corridor and you can't wire this section. You've wasted, I don't know, half an hour or maybe an hour of the day already. And then you say to two guys, well, actually, something needs finishing over there, you go and do that. You don't then go back to an office, sit down for that whole new task briefing sheet go over the new hazards, it's just totally impractical if you try to do that." T4 (41)* At T2 in SCC, SCC1 said that informal relationships with other trades can improve their tasks *"Familiarity with other trades on site is always a bonus. If you know people, just supposing you wanted to use that scissor lift over there that, you know, if you know them you will ask and they will probably say yes. If it is some crew that has never seen you before they will probably say no, get your own. ' (11)* Subcontractors in mechanical and electrical services and internal partition supply chains described their interdependence. *"M&E are always a pain because they work before us, getting all their first fix in and then they work after us and they always wreck what we've put up. It's just the nature of the beast, they just do that, I don't know why" (10)*	At T1. MC recognised that the interdependence of mechanical and electrical services and internal trades *"where we are under a bit of pressure on the envelope, but we start the M&E anyway, we've got the internals going anyway, and now the site team are distracted, they are a bit stretched, then the M&E starts to go off track, it is about a third of the value of the job"* (43) At T1, MC saw advantages in providing connecting tasks with clear work areas but the disadvantages on the time overall. *"If you batch work… you reduce the interfaces…have four rooms ready for the carpenters to get in to.. so if he comes across a problem he didn't foresee he has somewhere-else to go. The painter will have four rooms that the joiner has finished. So you create like a train. But that adds time to the programme" (43)*

Quotations 19: Subcontractors' desire for certainty in the long-term plan II

Different subcontractors had different interests at any one time. There was an impact from different pricing basis between trades. The electrician at T4 in SCA explained that they had no powers to intervene when their spaces to work in were not available as planned, compared to other trades who were employed on a lump sum price basis under *sequential spot contracting* (as explained in literature Section 2.2.2).

At T2 in SCA, SCA1 explained how trades procured on the price basis of a lump sum for a whole piece of work, impact on connecting trades procured on the price basis of cost-based labour and materials *"it is sometimes difficult working with other trades, depending on the basis that they've been employed… too many trades that are based on not just an hourly rate, but they're based on a price, so we get plasterers, and we say, oh you need to leave that bit out, 'cause we've got to get…and he's like, sorry mate, I'm on a price to get all this done, so the quicker I get out of here the better. And there isn't consideration. Our guys aren't like that." (15)* At T4 in SCA, SCA3 gave everyday examples of problems caused to them by connected trades that have been selected on lump sum price (18) (20) (41)	

Quotations 20: Subcontractors' desire for certainty in the day-to-day plan

Client variations, although allowed for in a contract, were viewed as unplanned work. On project A, the client asked for a number of variations during the course of the contract. MC explained that the consequences of managing variations in the changing conditions of the project were considerable. With bargaining strength on their side, MC used cost increases as a tactic to deter the client from going ahead with variations.

	At T1, MC *"Take the list of variations and split them into those that have no consequence and those that have significant consequences and are distraction. I'll take that to the meeting with 'A client' this afternoon" "Will tell them we need to take on a additional design manager if we do that variation" "The money we would make is not worth the distraction" "We will scare them off with the budget"* (26) (3 July 14)

Quotations 21: Commercially rational decisions and variations

Once subcontractors' contracts have been let and the negotiating power shifts from the buyer to the supplier. If things start to go wrong after this, MC will go to significant steps to help subcontractors who are struggling. As costs rise because things have started to go wrong contractors will negotiate significant deals on costs. The case study provided data on the ways in which costs are handled more flexibly, through informal practices that are not found in textbooks, when the possibility of delays emerge. The groundwork subcontractor on project A was delayed, seemingly struggling to cope with the work. MC went to significant lengths to help.

	At T1, MC on Project A the groundwork subcontractor fell behind programme early on in the project. The site team spent time considering different ways they could help to stop the subcontractor falling further behind. MC saw gaps in the groundworker's resources and asked to look at the subcontractor's plans. "*A Groundwork's' supervision on site is unacceptable. They need a non-working supervisor on a job this size" "I need a written action plan from them on how they will manage the job."* (22) When the groundworker failed to share their plans the MC decided to try to help by providing additional resources, *" I spoke to 'A groundwork' He said he's bitten off more than he can chew. There's x who used to work for x…we could employ him…another option is to ask 'A concrete frame subcontractor' to do the groundwork but they are stretched…I'd rather help' (22)* But alongside the offer of help MC gave the subcontractor and early warning that they would be prepared to take contractual action *"get a letter of concern to 'A groundworker'…what was the difference between him and the next quote" " There as little in it… three close tenders." "Two choices…coach him along or take a chunk of the work off him...he's good on flat site jobs…this one is harder"* (23)

Quotations 22: Main contractors need for flexibility from subcontractors when progress veers from plan

The ground worker did not deliver to the plan and started to delay the work packages that followed on. Needing to minimise the knock-on effect of the ground worker's delay on the rest of the plan, MC looked for significant changes elsewhere. They took decisions about their own temporary works, such as introducing shrink-wrapping of the building to make it watertight earlier. They also took decisions that changed subcontract packaging, such as increasing off-site manufacturing.

	At T1, MC on Project A there was some consideration of moving some activities off site to pull back time. *" How much off site is 'M&E Contractor A' using? Explore the opportunity to use pre-insulated ducting"* (22) *"Can they spray paint the MDF bulkheads off-site"* (27) On Project A, different solutions for the brick panels was considered in detail including unbundling and off site manufacturing *"Options for the brick slip panels. We buy the bricks and the insulation. Use 'A Brickwork subcontractors' factory to put the panel together…We need a design and a sample panel…It depends on 'A Brickwork subcontractor' having a bespoke rig. We could set up a yard near the site… do we know what 'A Brickwork subcontractor's' expectation of a margin is*?" *"He wont say" "I'll call him and ask I can ring-fence his profit?"* (22) *"The price for hiring factory down the road for manufacturing [the brick slip panels] and storing them is £x. By buying the materials, the brick slips, louvres and insulation ourselves, we've taken £x off his price."* (23)

	The main contractor looked for ways to pull back time by planning temporary works differently *"Wrapping the building in temporary shrink wrap.. £x…but we can install the windows in from the inside. 'A M&E subcontractor' will have a section of the building earlier. We will have higher demand to get materials in and out of the building…set up one way in one way out...not sure we had a really robust plan in the beginning…its become a really big issue now" "we are being clear with "A subcontractor' there's no pre-loading of materials"* (26)

Quotations 23: Main contractor's need for flexibility on construction methods and plans II

The case study provided a further example of non-textbook practices when delays were realised and caused financial impact. MC switched from hard bargaining on small items to more flexible negotiations on big items, aiming to do deals on big sums of money.

	At T1, the groundworker failed to accept the help offered, caused significant delays and MC changed tactics, to do deals with the groundworker and the client. *"We need to have conversation with "A groundwork subcontractor' on the claim.. its probably £x…we'd settle for half that"* (28) (5 September 14) *"See if we can do a deal [with the client]. Absorb their variations free of charge if they give us an extension" "If we know that, we will then know how hard to go for the groundwork and the concrete frame subcontractors"* (30) (3 December 14)

Quotations 24: Deals on big sums of money

4.5.3 Cashflow

Cashflow is important to all contractors. To advance their cashflow, MC overvalued claims for stage payments to the client and rigorously pursued the client for payment on time. They did not pass the benefit of overvalue to their subcontractors, but they were concerned to pay their subcontractors on time. Subcontractors felt that generally their work was undervalued in stage payments and received late. Subcontractors at tier 2 explained how they might overvalue claims for stage payment and pass the benefit on to their subcontractors. The subcontractor at tier 3 of SCA emphasised the importance of cashflow to them, suggesting that paying money due earlier, by not deducting retentions, would help their business.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCA, SCA1 explained how their cashflow suffered from undervalue or late payment by MC *"…if we demonstrate that we've done an element of work, they still won't value it properly, or they'll pay us late." (15)* At T2 in SCA, SCA1 explained they sometimes used overvalue to help their subcontractors in lower tiers *"we have.. in the past, supported business during the contracts...where if you're providing materials… we'll pay them early" (41)* At T3 in SCA, SCA2 explained how cashflow could be helped by relaxing requirements for retentions. *I was talking to a couple of main contractors; some of them now are considering not holding retentions on subcontractors. Which could make an awful lot of difference. (41)*	At T1, MC explained they liked to advance their cashflow from the client by "overvalue" in stage payments *"We like to have overvalue in our orders. So we get paid more than we pay out every month and that generates a surplus for our business." MC (40)* *"We are behind on the year end cashflow. We will get the M&E kit into the basement so we can claim it"* (28) *"the client is being lenient with what he signs off*" (30) MC also liked to keep their cashflow to plan by chasing the client to ensure the never received late payment *"Chase the payment from the client. Find the cashiers name"* (22) (5 February 14) *"We are chasing payment from the client…the previous issue was an undervalue"* (24) (4 June 14)

	Although MC didn't pass the benefit of overvalue on to their subcontractors, they were concerned that they didn't make late payments to their subcontractors *"[Our head office] has slipped performance on late payment of our subcontractors…all on different invoice terms. We have got a new system. Don't post anything to me. Email it. "* (22) However when things started to go wrong, MC used the tactic of "setting off" future predicted costs that would fall due in claims against payment *"We are not paying "A Ground worker'"* (25) Where potential claim costs emerged, senior managers in MC took a pragmatic view across projects *"I'll balance what we give them on other jobs so we don't break them"* (22) *"'A subcontractor' owes us money [on another project]. Ask them if they can do work on x on this project"* (23)

Quotations 25: The significance of cashflow through the supply chain

4.6 Cost handling at final account

There are two sources of information about final costs: contractual payments and each firm's internal accounting systems. Participants accepted final accounts as a calculation of payment due. Each firm knew their own outturn costs and profit margins on projects. But they did not claim to know the outturn costs of tasks to compare with their estimates. At the end of the project participants recognised that firms across the supply chain each hold their own version of outturn costs. Participants saw project costing as a process in which the relationship between cost information for component measured items and work carried is tenuous. They saw contracting a process in firms in the supply chain win or lose across projects at each other's expense.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCB, SCB1 explained that they were unwilling to share their cost information. They saw requests from a buyer for more cost information as a sign of low trust. *"what does it matter to the main contractors what we make on a job, all that they need to know is that they're going to get the job done to the standard that we give, for the cost that we say." (10)* *At T2, SCC, SCC1 "every month. the cost analysis on every project that's finished…all the costs have come in and we compare that with the with what was the original and most of the time we actually make more margin at the end than what we anticipated ... if it's ridiculously more than we thought we would make, we will bring the estimators into that loop and just say, look, yes great we have made extra money but on another job we could have lost the order. " (11)* *At T2 in SCB, SCB1 Everyone's always out for their own individual gain." (10)*	At T1, MC explained that at the end of a project every firm has their own version of costs in their private cost model *"You know when it's costs less but that doesn't signify improvement because you don't know whether everyone else in that supply chain made a loss on that job." MC (40)* *"Some contractors will make double the margin they expected to make and other contractors, they'll make half the margin they expect to make. You can guarantee only one of them is going to bang your door." MC (40)*

Quotations 26: The final account as commercial decision

Data on resources consumed by activities on site was rarely collected. Participants knew that actual work done on site is largely unobservable. SCA1 explained that in one instance, work had been observed on site and compared to their firm's standard productivity rates in their estimating database. The productivity observed on site was faster than the rate they were using as their firm's standard rate for estimating costs in projects. But the information on this difference was treated as a way to build in contingencies on future projects. The relationship between productivity rates used in estimates and actual work done on site was obscured. In SCB, SCB1 said that they do not need to know an accurate output rate as they pass the risk on to SCB2. When the risk of poor productivity is passed on in this way the outturn productivity on site remains largely unknown.

"There are industry standard resource and productivity rates for activities but we create our own. We reviewed our labour productivity four years ago with our site operatives. We identified efficiencies, but then we didn't change our productivity rates because we were in a rising market and all costs were going up." SCA1 (15)	

Quotations 27: Feedback from site treated as commercial information

4.7 Improvement interventions

4.7.1 Opportunities

This Section shows that contractors see improvement in site operations as desirable throughout the supply chain. It also explains where contractors think opportunities for improvement in site operations lie. Participants thought that contractors take their own accumulated experience between projects but saw little learning between contractors from project to project. Participants from MC in workshop 1 held a range of views on the magnitude of the potential savings that could be made if they could improve site operations and sustain that improvement across projects over time. Their estimate of the order of the opportunity for savings ranged from 5% to 0.5%. They reached a consensus of 2% to 3%. Participants viewed this percentage as significant. Four categories that emerged from the data are used to present the findings in this section: early contractor involvement, earlier planning, innovation in materials, plant and equipment, and money.

4.7.2 Early contractor involvement

In workshop 2 MC explained that they saw the greatest scope for improving site operations in the client's procurement choice on the selection method of main contractors. MC explained that as the market was currently picking up they were able to choose projects where the client procured the main contractor by negotiation rather than competition. MC explained that in a negotiated contract, during the negotiation they are also deciding how they will do the job. So the negotiation is about both the plan and the costs and allowed for greater integrity between the forecast of work to be done and the commercial offer.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCA, SCA1 "if you truly engage with each other, then you're going to get efficiency in that process, because you're going to say, well, no, this is the best way that we think we can do it." T2 (41) *At T2 in SCA, SCA1 "you'd work through with the design team from stage D, E, in the old RIBA stages, up to F, developing the design and developing the costs alongside it. All declared all open with the clients. I say open: we'd have quotes to back it up and we'd have take-offs to back it up, and then we'd put our mark-up on it. And the idea of that is that you build up a good, solid coordinated design together. And that works for us, we like those" (9)* *At T2 in SCC, SCC1 "All these specialist subcontractors they know their game better than the main contractor, but they don't feed of that."* (11) AT T4 in SCA, SCA3 though they "*have value to add in the design and planning stage but nobody is prepared to pay for it."* (41)	*At T1, MC "We can sit round the table and negotiate and bring our M&E partner into the mix of this, and we all truly negotiate that project, the right program, the right price. We can bring in all of these good thinking ideas that we've been lacking over the last four or five years" T1 (41)*

Quotations 28: Earlier contractor involvement

4.7.3 Collaborative planning

All parties thought that earlier, collaborative planning could play a large part in reducing disruption of subcontractor's work on site. They thought that joint planning at an earlier stage increased their level of communication with other firms and increased their control over their work. Once on site all subcontractors thought that their work could be simplified by isolating their tasks from other trades.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCA, SCA1 had experience of working on projects where they were more involved than usual in sequencing *"Getting round the table and really discussing sequencing with your key supply chain, really looking at the project, getting into the design. We built rooms in our mind, drew them and built the programme around that. Then we built the bigger programme." "we suffered problems,… but those problems would have been horrific, and would have, you know, for everyone involved would have been a lot worse." (41)* In SCB, SCB1 had experience of working on shop fit out projects though very detailed day to day planning of tasks *"we do x stores and they're all lean builds so, within six weeks, they're completely fitted out and, prior to going on site…, we go to about three or four design meetings…to sit down together and put down how long you're going to be working for in each area so…as soon as a wall's built and boarded on one side the M&E will then move in. As soon as the M&Es gone out, we'll board the second side. As soon as we've boarded the second side, they'll come and skim or tape it, as soon as they've skimmed and taped it, the painters will come in and then the joinery will go on. So it's all, it's literally, everyone just follows each other round."*	At T1, MC put resources into planning parts of the work in detail commissioning *"On mechanical systems if we don't explicitly tell them how we want to commission a building, as in that floor, that floor, they wont design for it to be commissioned that way. Commissioning set out to commission legs of pipework. So if you don't design how you want to commission it, early days, you wont be able to commission it that way…. So I think commissioning process is probably more troublesome than the install in itself… I'm introducing a commissioning manager…" (43)* At T1, on site MC used design reviews during the project to identify the tasks to be done and plan them in detail *"we have the design review so we know explicitly what tasks we've got left…we put the focus on the management on those tasks so they don't disrupt us…"(43)*

Quotations 29: Collaborative planning: meeting subcontractors' desire for certainty in the day-to-day plan I

In Workshop 2the main theme that came up in participants' views of site improvement was planning. Developing a robust was seen to be a key to the main contractor. The subcontractor at tier 2 saw task level method statements as standardised safety statements. The electrician at tier 4 corroborated and said that they disregarded planning at a detailed task level that they received in method statements. They said that they did not value method statements because they are generic statements do not reflect either what they are faced with on site, or the flexibility they use to respond to a day-to-day conditions on site. Subcontractors' own, higher-level daily task briefings were thought to be more useful by the subcontractor at tier 2, but the electrician at tier 4 said their day always changes and they always do something different from the daily task briefing.

At T4 in SCA "the method statement that I sign...well, they have barely any level of detail about the specific job." T4 (41)	At T1 MC recognised the limitations of task level but saw opportunity for improving them *"we tend to focus method statements on controlling health and safety risks. We talked about quality method statements to give our guys information on what to manage. This bit is tricky, check this bit" (42)*

Quotations 30: Collaborative planning: meeting subcontractors' desire for certainty in the day-to-day plan II

The participants identified that, in practice, repeat projects have provided their most successful examples of achieving improvements in site operations across projects. They put that down to the people, not the technology. They also though that repeat projects achieved of greater degree of commercial integrity than one off projects.

Subcontractors had no experience of repeat projects. The move to repeat projects had not reached subcontractors, and secondary competitive tendering remained the norm on projects that were repeat contracts for MC.	The main contractor explained that they had achieved significant cost savings on repeat school product they delivered in project B. *At T1, MC "the first one took us eighty five weeks...and it cost eight million quid. But the last one took us fifty six weeks and it cost seven million quid and…but we did six in the meantime" (40)* *At T1, MC "we had the supply chain constant at every job so they turned up knowing that the making do was very negligible and it wasn't technologically driven, it was people driven because we always used [company A] on partitions. There was always also that implicit threat because the damages were so hard. But there was peer pressure and we used to have workshops and it was all very people focussed" (40)*

Quotations 31: Keeping to plan: main contractor's long road to certainty in the day-to-day plan

4.7.4 Innovation in materials, plant and equipment

Participants thought that the big improvements in productivity in site operations have come from technological improvements in small, hand held tools.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCA, SCA1 *"because there's been advances in technology and things now, you get a lot more stuff that's easier to fit than it used to be, you get cartridge fixings, and you get snap joints, instead of having to put three screws together, some of our rates, we've proposed, should come down." (15)* At T2 in SCB, SCB1 *"we can't be more efficient if we can't afford new tools and machinery such as a plaster spraying machine" (14)* AT T2 in SCA, SCA1 *"if things go wrong, it's normally down to labour overspend, sometimes prelims but predominantly labour… we try and do as much offsite pre-fabrication as we can…. (15)*	

Quotations 32: Innovation in materials, plant and equipment

4.7.5 Money

Participants knew what good site operations on a well-run site looks like when they see it and cited money as a driving factor in good or bad site operations. All participants linked better project delivery with making money.

Lower Tiers of the Supply Chain	Main Contractor
At T2 in SCC, SCC1 *"now the client is going to have to pay a little bit more going forward and hopefully we will all benefit from that, we will all be able to deliver a better job and make a little bit more money, well hopefully." (11)* At T2 in SCB, SCB1 *"The perception of value for money will impact on relationships. Its human to want to make more money, lets earn enough and reduce the hassle" (14)*	At T1, MC saw money as the driver of site operations *"you can go on to a site and within twenty minutes of walking round you know whether that site is running as it should do…everyone is starting at the optimum time and the process is running correctly…everybody is making the margin they should be making" MC (40)*

At T4 in SCA, SCA3 *"we're all going to be one big team, and that's what's going to make it most efficient, but when the market drops, it's competition. So this team that you've got together for one build, will be at each other's throats tendering for the next jobs. So you're not really a team." W2 T4 (41)* *At T3 in SCA "because we get delays in the install and the delays in commissioning, you're fighting a losing battle by spending more money to try and keep up." (41)*	*"They want to turn a good product and they want to make a margin they expected… they can get very quickly discontented but what's the driver for that? He's probably already not making any money out of it" MC (40)* *"I think the supply chain do bring benefits. But I just think it's hidden by where the market's going at the moment." MC (40)*

Quotations 33: The fundamental importance of money to good site operations

4.8 Analysis and summary of findings

4.8.1 Introduction

This Section is divided into two subsections: costs and work done. The first Subsection summarises the case study material on costing practices. The findings show that, because subcontractors themselves subcontract work, there is little distinction between the costing practices of the main contractor and subcontractors. The findings illustrate the creation and loss of cost information across a project supply chain. This reveals a *disconnection* between cost information held in contractors' private cost models and costs to the client. This is not a problem for delivery, as each firm has made commercially rational decision based in their appetite for risk. However it is a problem for the main contractor for costing improvements, because adjustments to costs do not accommodate changes in any real way after the main contractor has made a decision on their tender sum. Changes in any part of the project have a wider, knock-on effect that is difficult to identify and cost.

The second Subsection summarises the case study findings on work done in the supply chain. Contractors across the supply chain saw a link between better programming and costs incurred. But the findings showed a distinction between the main contractor and subcontractors in the degree of flexibility they desired to achieve better programming. The main contractor, managing considerable uncertainty, desired and used significant flexibility in both work planning and work methods. In contrast subcontractors desired certainty in both work plans and work methods.

4.8.2 Costs

The findings concur with the formal methods for cost handling during estimating and tendering set out in literature Section 2.2.1. However the case study revealed the detailed components used in the build up of costs. There were found to be known by everyone involved and considered the norm, but little found in textbooks.

In terms of the formal methods of costing, once a contractor has decided to submit a tender, their costing process has four parts as described in literature (Section 2.2.1) and expanded in the findings. Estimators build up costs on the use of internal resources (Section 4.2.2); estimators or buyers build up costs from quotations from subcontractors and suppliers (Section 4.2.3); commercial managers and directors make strategic tendering decisions (Section 4.2.4); then once a contractor has won the work, their site team has the job of building to the budget (Section 4.5.2). The methods of costing are generally replicated through the supply chain. There are exceptions when experience-based estimating only is used (Section 2.2.2 in literature and Section 4.2.2 in findings).

When cost information is created about the estimated resources that will be consumed in a project there is considerable need for judgement. Forecasts of quantities of materials and plant are the most certain pieces of cost information created in an estimate, but the costs of materials and plant can be volatile and even subcontractors in the lowest tiers of the supply chain see materials and plant as an opportunity to make money through by buying more cheaply (Quotations 3). Forecasts of quantities of labour created are historically-determined norms. Project specific risks of achieving productivity rates on site are, in some trades, transferred down the supply chain (Quotations 2). The estimated rates of pay for labour created are exposed to changes from market forces, especially in the lower tiers of a supply chain (Quotations 1). At the bottom of the supply chain it is more likely that no information is created on the resources that will be used in a project (Quotations 4). Cost information that is created in quotations does not show the constituent resources and firms see quotations as an opportunity to make money through by buying more cheaply. The extent of subcontracting and hence the proportion of cost information based on quotations is highest in the top tiers of the supply chain (Quotations 5). In some specialist trades this exposes the limited nature of competition in construction (Quotations 6). Cost information created on estimated contingencies for risk and allowances for profit are based on experience and judgement (Quotations 7) because even tenders based on detailed designs are based on incomplete information.

The cost information created within firms is presented in the clients' cost model, usually a bill of quantities. Subcontractors did not trust clients' cost models as providing an accurate description of work. Subcontractors said they withhold specific information about omissions in a client's cost model for fear of losing a job. This appears in textbooks on commercial practice as an occasional practice (Section 2.2.2) but was found to be the norm (Quotations 9) and also known and accepted by clients. Likewise the practice of frontloading clients' cost models appears in literature on commercial practice as an occasional practice (Section 2.2.2) but was also found to be the norm across the supply chain (Quotations 10).

Contractors viewed their decision about costs at contract as commercially rational decisions at a project level, but inadequate for reflecting commercially rational decisions about the costs of subsequent client changes though either value engineering (Quotations 11) or variations (quotations 21). Participants described a dynamic world as a construction project unfolds on site. One in which formal contract provisions for adjustments to costs through value engineering and variations do not accommodate these changes in any real way. This is because changes in any part of the project have a wider, knock-on effect that is difficult to identify and therefore cost.

Findings on cost handling during site operations revealed that although the practice of secondary competitive tendering appears in some textbooks on commercial construction practice (Section 2.2.2) this happens systematically in practice throughout the supply chain. Contractors at all levels of the supply chain force cost reductions onto lower tiers. The only exception is SCB2, the labour-only subcontractor at the end of supply chain B, who only has costing routines around the use of their own resources and their own strategic tendering decisions, and no suppliers to pass cost reductions or risk on to. Subcontractors at all tiers of the supply chain therefore knowingly "never give their best price first' and everyone involved knows this (Quotations 12). This process can result in higher prices to the buyer when demand is rising (Quotations 13). But when prices are not rising due to demand in the market the purpose is usually cost reduction though either hard bargaining (Quotations 12), reducing quantities or specifications (Quotations 15), or sometimes soft bargaining when relationships need to be preserved (quotations 14 and 16). To avoid claims the main contractor negotiated on big sums of money (Quotations 24).

Participants described a negotiable world in which bargaining on costs is part and parcel of projects. Participants repeatedly described project cost handling as "game playing". Participants thought that the level of bargaining on costs was able to accommodate the normal level of disruption experienced in site operations within projects. Participants thought that over time the industry accommodates mistakes and the changes in the market across projects. But they saw that this contrasts with the formal, fixed, deterministic cost model of the bill of quantities. Participants willingly used the bill of quantities for payment and for agreeing a final account based on adjustments allowed for in the contract. But participants controlled their firm's costs, not against the bill of quantities, but against the breakdown held within their firm on the use of their own resources, quotations negotiated and contingencies on the project. This leaves the balance to contribute to the firm's general overheads and profit.

Cashflow was naturally important to all contractors. All contractors were trying to make a living out of doing work, not out of manipulating cashflow, but all contractors made efforts to push cashflow in their favour within good practice, and recognised the use of cashflow as a soft negotiating tool (Quotations 25).

Drawing on information from across the findings, the creation and flow of cost information within a project and across a subcontract supply chain is illustrated in Figure 7 below. The illustration uses the example of supply chain B (SCB) from the findings, the subcontract supply chain for the suspended ceilings package of work on a project. *Costs a contract* are built up through the creation of cost information through the supply chain in a competitive tendering process based on resources (R), quotations (Q) and mark-up (M) in each firm. The resulting *costs at contract* are expressed in a *bill of quantities* that establishes the fixed price to the client based on unit rates of measured items. When a main contractor is awarded a project, a phase of *secondary tendering* begins. The main contractor restarts the creation of cost information and each firm in turn carries out a secondary tendering process with their subcontractor and suppliers. As costs are re-negotiated through this process, a new set of resources (R), quotations (Q) and mark-up (M) are established in each firm, from the main contractor downwards. As *actual costs* are incurred, a third set of costs on resources (R), quotations (Q) and mark-up (M) are established in each firm's private cost model. Subcontractors evaluate their actual costs against the budgets set in the secondary tendering process, and the mark-up achieved is their balancing figure. The main contractor evaluates their actual costs in a *cost value reconciliation* (CVC) against the budget in the *final account*

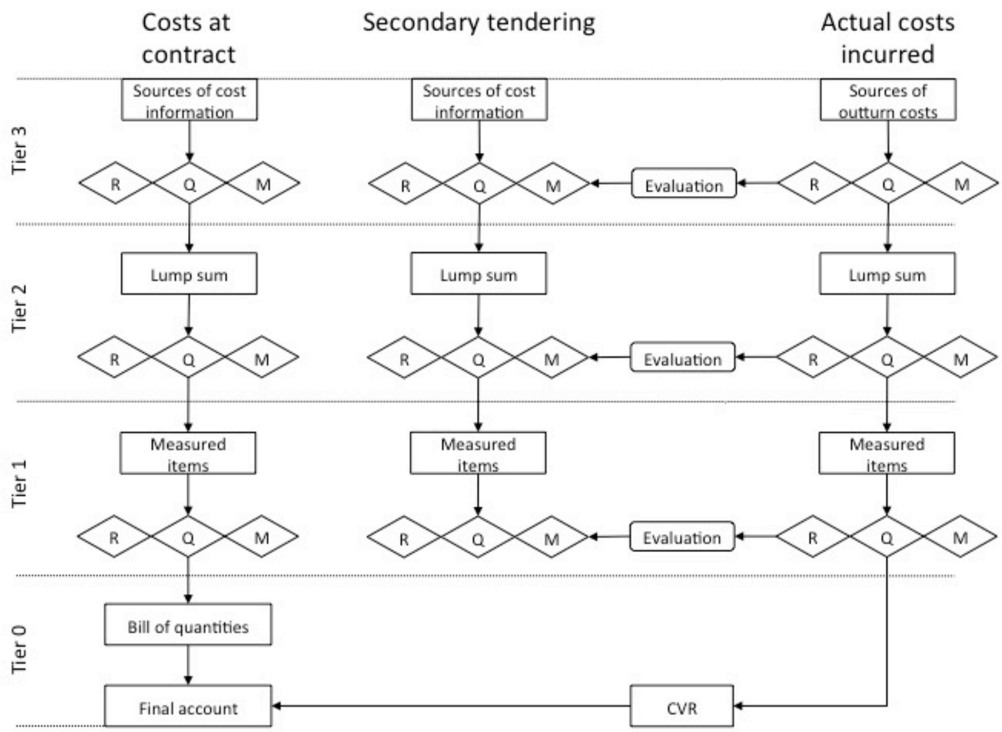

Figure 7: The creation of cost information on resources (R), quotations (Q) and mark-up (M),

In this creation and flow of cost information and the practices that operate the creation and flow of cost information, what is striking is that the formal cost models between the client (tier 0) and the main contractor (tier 1), costs at contract and final account, are disconnected from the rest of the cost information in the supply chain. The greatest disconnection is illustrated by the shading in the Figure 8 below. The actual costs incurred by tier 3, shaded resources (R), quotations (Q) and mark-up (M) have three levels of separation from the actual cost to the client, the shade costs in the final account.

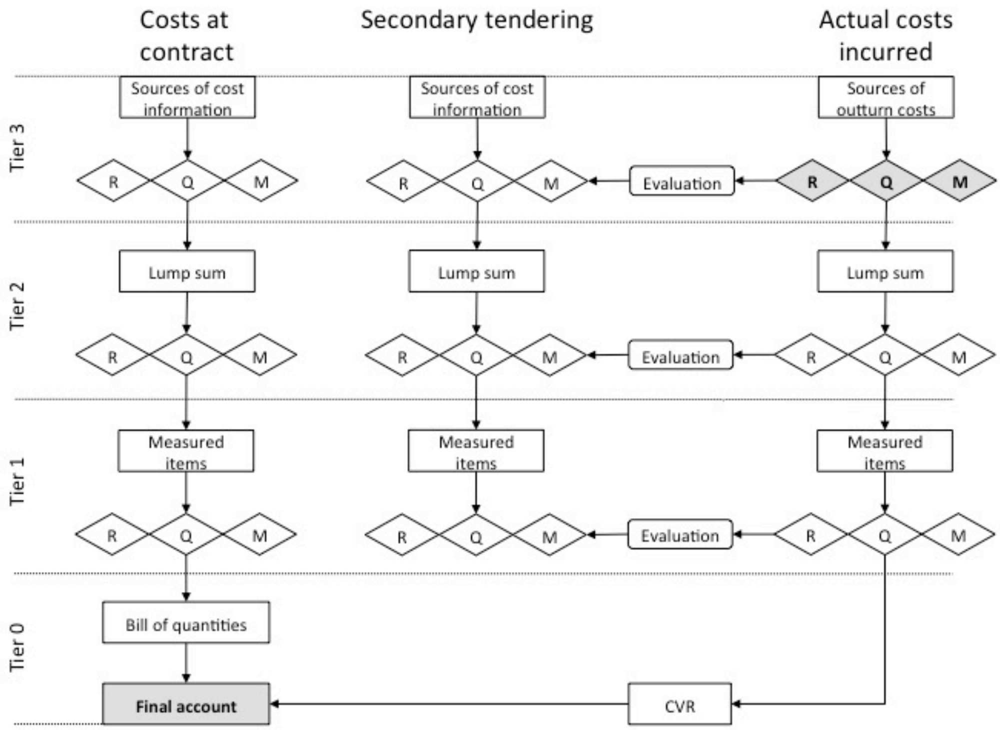

Figure 8: The disconnection of costs across a construction subcontract supply chain

The practice of making commercially rational decisions about costs at contract and committing to these as situations change is not unique to the construction industry. But the extent of change across a construction project supply chain between the costs at contract and costs at final account is unique. Change from the extent of the uncertainties from design risk, construction risk, market fluctuations and client variations are recognised in literature (Sections 2.2.1 and 2.2.2). But the extent of change from renegotiation across the supply chain illustrated above is unacknowledged.

Participants said that these costing practices work for pricing and payment because each firm makes what they view as a commercially rational decision for them and then controls their costs against the budget in their private cost models. Budgets are able to accommodate a normal level of uncertainty as projects unfold. But controlling costs depends on the ability to renegotiate deals to a significant extent. Any improvements on a project are taken as increased profit for the individual firm and the lowest tier in each subcontract supply chain bears most of the risk and most of the impact.

Different attitudes to risk are part of the commercially rational decisions made in the costing practices described above. Different tiers of the supply chain and different trades showed different attitudes towards risk when they were coming to their decision about what is commercially rational for them. The main contractor showed the strongest appetite for risk in relation to design completeness and cost certainty. They viewed incomplete design as the norm and, in a low demand market, waited to “lock in deals on cost” as close as possible to the start of each work package. The mechanical and electrical services subcontractor took a much more cautious approach to design risk. They were not prepared to provide a cost until a set level of detail of design was available (and they had control of the design of their work package). The internal wall and ceiling subcontractor also took a cautious approach to construction risk, passing the risk of realising assumptions on labour productivity to their subcontractors through lump sum pricing.

4.8.3 Work done

This thesis did not set out to explore construction planning. But the importance of the link between construction planning and costs was emphasised by participants across the case study (Quotations 33) and data on construction planning and work methods was collected from observation of site meetings. As the link between construction planning and costs emerged as an issue, workshops 2 and 3 were set up to explore what improvement in supply chain operation deep into the supply chain would like.

The formal agreement between the client and main contractor in relation to construction programme at contract is limited to project start and completion dates. The contract does not assume that a disaggregated project programme can be fixed at tender stage. During the course of the construction period the main contractor maintained flexibility in their decisions about work packaging and construction methods (Quotations 17). This contrasted with subcontractors’ desire to have certainty in both long-term and short-term plans (Quotations 18 and 19). Subcontractors explained how they start on site on their planned start dates to show they are trustworthy, but often find the physical conditions on site are not as expected (Quotations 18). Subcontractors said changes to daily plans were part and parcel of all projects. They thought weekly or daily plans were inaccurate and desired much more certainty (Quotations 20). When project A was delayed early on in the groundwork package the main contractor made significant efforts to manage the situation using soft bargaining to try to preserve their relationship with the groundwork subcontractor (Quotations 20). As delays materialised the main contractor made significant changes to work packaging and work methods, for example a decision to make the building watertight by temporarily shrink-wrapping of the façade (Quotations 23).

Subcontractors expressed a desire for more collaborative planning; illustrating the stress those subcontractors experienced and wanted to change. The main contractor wanted to maintain flexibility in planning. However they were in the process of reducing their planning timescale to daily planning of work during the mechanical and electrical services commissioning period. They saw commissioning a key area for daily planning because it has a high degree of uncertainty arising from interdependence between trades, is on critical path, and is at the end of a project when the main contractors' programme contingences have been used up.

All contractors expressed a desire to work on jobs in which their firm makes, not loses money. This was thought to be the biggest source of stress that all contractors experienced and wanted to change (Quotations 33).

CHAPTER 5

DISCUSSION

5.1 Introduction

This thesis set out to investigate the main contractor and their supply chain in order to find out how their cost information links to and motivates improvement efforts in the supply chain. The empirical research found problems in the type of cost information created and indeed its distortion away from a close link to work done. Part 1 of the Discussion theorises these problems to explore the reasons why importing current cost information into BIM will not provide information that supports and motivates improvement. Part 2 of the Discussion develops a new systems ontology of costing for development in BIM.

Part 1 of the Discussion draws on Beynon-Davies (2011) concepts of *signs* from information theory in order to understand how, in information terms, current costing methods link to the organisation(s) and project(s) they are used in. The findings from Chapter 4 are confronted with Beynon-Davies (2011) ideas of f*orma*, *informa* and *performa* to explain the nature of the current representations of cost that are created and used by contractors in projects. The analysis categorises contractors' current cost information as a mixture of direct measures, standard rates, judgement, bargaining and intentional errors and enrols the word *distortion* to describe how current cost information in blurred from being a good representation of work done. The discussion introduces Kaplan and Cooper's (1988) term *surrogate numbers* from management accounting to acknowledge the limitations in representations of costs.

The discussion then links the findings on costing methods from Chapter 4 to the organisation(s) and project(s) they appear in using Winch's (2010) tectonic approach as one way to describe the construction system. It is argued that the feedback loops, thus learning, in the current costing practices contains *acknowledged* practices, and that this perpetuates the status quo. This section calls estimating methods and processes and their feedback loop of acknowledged practices the *system of costing* and concludes that, in the current system of costing, parties share an agreed meaning for the cost information created: a meaning of establishing a price, making payments and controlling costs. But it is argued from the Findings in Chapter 4, that efforts to push the purpose of cost information to rewarding improvements throws the problem of the surrogate nature of cost information into relief. The system of costing breaks down because not all cost information is trusted and agreed as good information with meaning for improvement. The section thus establishes that surrogates may be good for one purpose but poor for other purposes. This means that a costing solution to motivate improvement will not be found through working on the detail of the parts.

Part 2 of the discussion takes up the exploration of what a good cost surrogate may look like in information terms for the different purpose of rewarding improvement in the supply chain. The discussion considers how others have used the terms *hard* and *soft* in theory as a way to explore how different representations handle the systems they appear in. The discussion draws on literature by Rosenhead (1989), who critiques the problem of a *hard systems approach*; its thirst for data to work on positivist problems of optimisation. The discussion argues that efforts towards addressing improvement aims through measuring greater detail are limited by the level of detail that can be known and handled. The section then draws on literature by Rosenhead (1989), who proposes a *soft systems approach;* its search for data to work on social constructivist problems of collaboratively discussing problems and solutions. The discussion argues that efforts towards addressing improvement aims through problem structuring may use less detail, but data that better reflects what is happening in the world.

Participants said that it is difficult to identify and cost changes in any part of a project once they have made their commercially rational decision about the work they will do as a whole. So it is argued that the search for new surrogates and their associated methods of costing that could incentivise improvement throughout the supply chain needs to represent the system. Criteria for a good surrogate are proposed of measurable surrogates that can lead to management action, and are meaningful for improvements deep into the supply chain because they represent the system. Dependencies are identified as a good surrogate to show how the supply chain works together. The discussion explores where BIM technology can potentially help to model different dependencies for the challenging task of costing improvements deep into the supply chain, using a *systems ontology of costing*. Improvement requires as change to the norm. The discussion considers how the norm might be changed and that changed rewarded through money, thus in the long term changing the system of costing itself from the current acknowledged practices that perpetuate the practice of buying more cheaply.

Part 1

5.2. Problems in the representation of costs

5.2.1 Cost information as surrogate numbers

This Section uses the work of Beynon-Davies' (2011) (set out in Section 2.8.1) who takes a information-theoretic approach to better understand problems in today's world and the value of computer modelling in tackling those problems. His approach reflects the concern of this thesis to understand the link between contractors' cost information and contractors' problems in organisations and projects.

This section uses Beynon-Davies' (2011) concept of *signs* to examine how cost information is created and used in organisations and projects. Beynon-Davies (2011) conceives a sign as something of significance or meaningful in the system it sits in. He sees the fixed *physical form*, or *representation*, of a sign as the top of a four-rung semiotics ladder between the social and physical worlds. The rungs of the ladder encompass the *purpose*, *meaning*, *structure* and finally *physical form* of a sign (Section 2.8.1 Figure 3). He makes a distinction between three forms of inter-related action: *formative action, informative action* and *performative action* through which signs are created and used. Pierce's semiotic tetrahedron was also illustrated in literature (Section 2.8.1, Figure 2) as a device to understand signs through the entities represented and the idea that they generate in an interpreter. In both these conceptions the unifying idea is the conception of information (signs) as data plus meaning. In this discussion the terms information and signs are used interchangeably to express the idea that data harvested from the world has to be interpreted and this interpretation is socially constructed.

This Section uses the example of subcontract supply chain B (SCB) in a bidding situation for a work package for suspended ceilings. The intention across SCB is to carry out work and make payments for work done at agreed prices. The signs to be used for the purpose of payment are created in the fixed cost commitments that contractors enter into at different stages of a construction project. The cost commitments through a project are illustrated in Figure 9 below. *Costs at tender* are created first. Then, when a main contractor's tender is successful, and any adjustments have been negotiated, *costs at contract* are established as the basis for future payments. As the construction progresses on site *costs at stage payments* are created, usually monthly. When work is complete and adjustments have been negotiated that are allowed for in the contract, *costs at final account* are established.

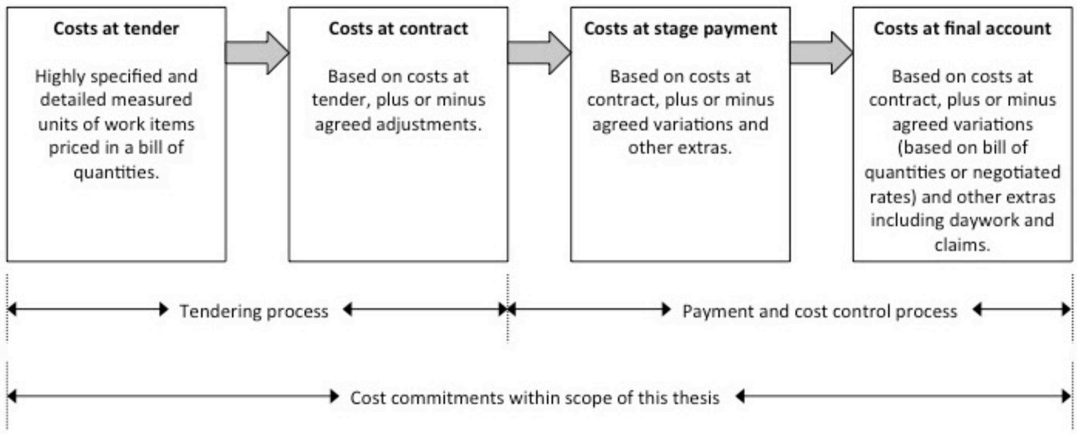

Figure 9: Cost commitments represented through the supply chain

The costs at contract are particularly significant signs in a construction project. As outlined in Section 2.4.3, Gosling *et al*. (2015) stress the importance of the contract point in supply chain terminology as the *decoupling point* (Hoekestra and Romme, 1992), the point at which a client's order is set in a unique design and cost before construction begins, decoupling design and cost from the construction process on site. Winch (2010) also stresses the importance of the contract point but using terminology from transaction cost economics, the *fundamental transformation point (*Williamson, 1985). This is the stage at which there is a reversal in bargaining power from the client to the contractor. The findings in Section 4.8.2 similarly recognise that at this point contractors commit to project costs that contain forecasts and, apart from adjustments to costs allowed for in a contract, the contract point is significant because of the fact that the budget does not alter from this point, despite the fact that new decisions are taken and uncertainty continues to decreases as the building is progressively realised.

The creation and flow of cost information through SCB in a tendering situation is illustrated in Figure 10. The labour-only firm of suspended ceiling fixers (SCB2*)* in the lowest tier of the subcontract supply chain (tier 3) creates estimates of the use of their own resources (E) and makes strategic tendering decisions (S). They pass cost information up the supply chain in a quotation (Q) for their work. A suspended ceilings subcontractor (SCB1) in next tier of the chain (tier 2) receives the quotation from SCB2. The quotation becomes part of SCB1's cost information. SCB1 in turn creates estimates of the use of their own resources (E) and take strategic tendering decisions (S). This repeats up the supply chain to a main contractor (MC) in the next tier (tier 1). A client is at the top of the chain (tier 0).

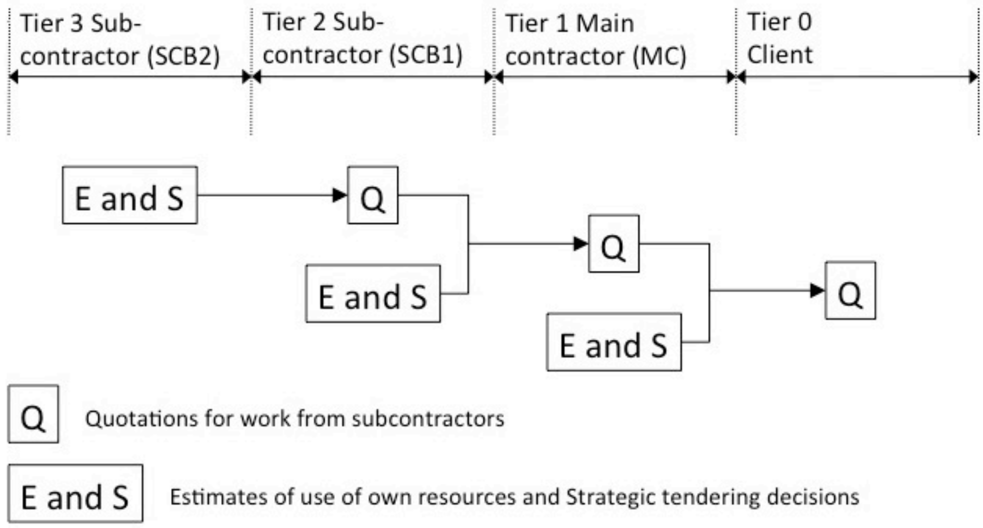

Figure 10: The creation and flow of cost information through the supply chain for a subcontract work package

SCB2 (the labour-only suspended ceilings fixer at tier 3) is asked by SCB1 to bid for the labour involved in putting up ceilings in defined rooms for fixed price lump sum(s) under a *sequential spot contracting* arrangement (Section 2.2.2). In order to provide a quotation to SCB1 under this price basis SBC2 goes through cycles of forma, informa and performa in creating and using cost information in their firm. They create forma in their ideas about the area of ceiling they can put up in a day based on historical information, the particular design features of the ceilings in a particular project that will affect their productivity, the rate of pay for skilled ceiling fixers that the market is currently paying, and the loyalty that they give to and receive from SCB1 in terms of a long term relationship and prompt payment. This forma becomes informa when they discuss it within their firm. This informa becomes performa when they decide on their negotiating position for the project. SCB1 also goes though multiple loops of forma, informa and performa as they come to their negotiating position on a fixed price lump sum. SCB1 explained that, depending on the market, their negotiating position with SCB2 ranges from a fixed amount that the market will bear when demand is low, to an open question about what SCB2 will do the job for when demand is high. In the negotiations both parties know (informa) that SCB2 will take all the risk of delivery under the lump sum pricing arrangement. SCB2 will realise a higher hourly rate of pay if they work more quickly than the rate of productivity they assume in their bid. On the other hand if they work more slowly, they will come out with a lower hourly rate of pay. The lump sum price for labour agreed with SCB2 is expressed in a quotation and the quotation becomes an element of forma for SCB1 in their bid.

SCB1 prepares a bid for putting up ceilings for a fixed price represented as unit rates for measured work items (such as a cost per square metre of a specific quantity and type of suspended ceiling). The measured work items are set out in a bill of quantities in accordance with the detailed conventions for measuring work. Section 2.2.1 described the bill of quantities as taking the form of a *Product Breakdown Structure* (PBS): measured items of work that are attached to finished products (or objects) in a design model. Literature presented in Section 2.2.1 also established that there are detailed conventions for estimating costs. Figure 11 illustrates the cost information created by SCB1 in this process. SCB1 disassembles measured items of work into activities and the resources the activities will consume (labour, material, plant, overhead, contingencies and profit) calculating quantities of resources using labour productivity, material waste, and plant utilisation rates. This includes distributing the lump sum for labour negotiated with SCB2 across measured items of work using the hourly pay and productivity rates negotiated. Thus the activity based cost information in the lump sum quotation received from SCB2 is abstracted away from its origin, the lump sum, by SCB1 as they create their product-based cost information. SCB1 then reassembles all the activity costs into the composite costs for products (measured work items) listed in the cost model. As set out in Section 2.2.1, Winch (2010) notes that estimators come up against problems of integrating their activity based cost information with measured items of products in cost models. He notes that contractors create activity-orientated *Work Breakdown Structures* (WBSs) and trade-orientated *Organisational Breakdown Structures* (OBS) to help with estimating, and then funnel this information into the object-orientated PBS of the cost model. This view is supported by the findings in Section 4.2.4.

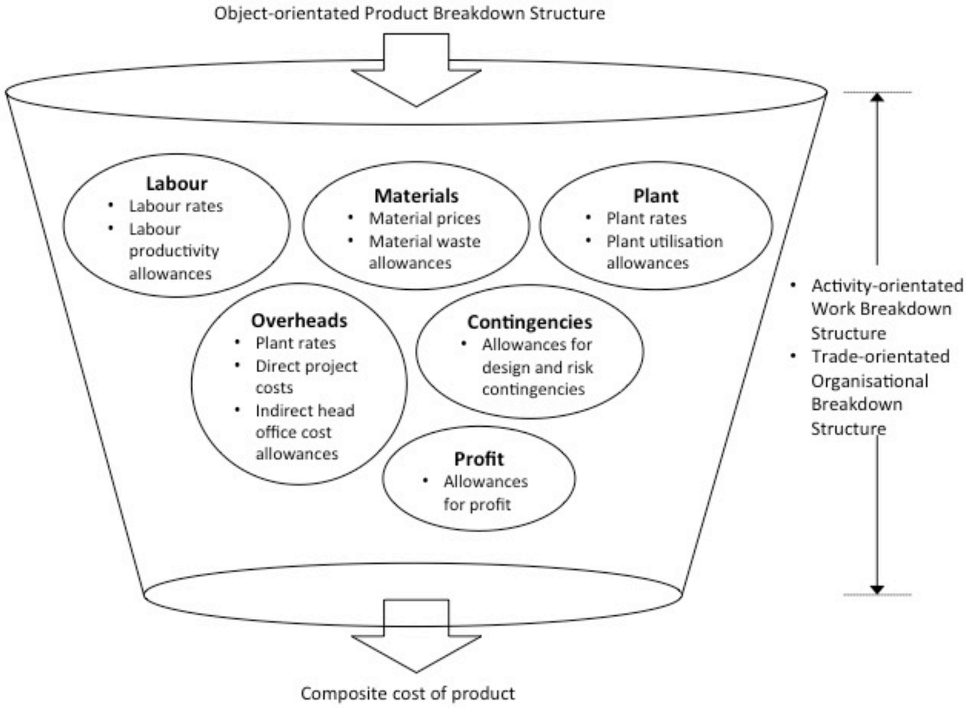

Figure 11: Records of cost created within organisations and passed on as composite costs

Findings in Section 4.5 also show that a bottom-up approach, building up costs from the lowest tier of a supply chain to the client's cost model, is followed sequentially in the initial round of competitive tendering. However commonly, once a main contractor is awarded a project at an agreed price with the client based on initial quotations, the main contractor discards the initial quotations and carries out a secondary tendering process nearer the start of each work package on site. All subcontractors commonly do likewise with their own subcontractors and suppliers. Thus further cycles of forma, informa and performa occur in methods of costing within and between firms.

The signs that represent cost commitments across the supply chain are created through the methods of costing described above and all involve cycles of formative, informative and performative action. The different types of information used within the methods of costing are categorised in Figure 12. Figure 12 uses the term "signs" to mean data plus meaning in accordance with Beynon-Davies' (2011) theoretical use of the term. The first category is Dean's (1993) term *direct measures* of "the cost basis of the firm's resources" (Section 2.5.3). Dean's (1993) term "analogies" is adapted into the term *standard measures* to express the historically determined norms for consumption of resources. The traditional category of quotations (Section 2.2.1) is adapted into the term *bargaining* to more specifically reflect the treatment of quotations as one of commercial buying behaviour rather than straightforward comparative prices. Dean's (1993) terms *expert opinion* and *best guesses* are adapted into the term *judgements* to reflect cost records that are correlated to the market or other parts of the construction system. Lastly a category of *intentional errors* reflects practices that knowingly corrupt a cost model from a good representation of work the cost of work to be done in any specific item of measured work. Figure 12 uses the term *distortion* to describe the degree of distance between forecasts of physical work required, and the signs created. The level of distortion is shown to rise progressively, from its lowest level in firm at the bottom of a supply chain to its highest level in the clients' cost model.

Types of information created across a subcontract supply chain (From primary data)			Type of signs	Distortion within signs
Labour-only sub contractor's private cost model Tier 3	Subcontractor's private cost model Tier 2	Main contractor's private cost model Tier 1	Across the supply chain	
• Labour cost	• Material cost • Plant cost • Direct project overhead cost • Trade discounts	• Direct project overhead costs	**Direct measures** of cost of internal resources correlated to the market	Low: an environment of ***sureness*** created by *direct measures* of cost
• Labour productivity • Back of the envelope estimating	• Material waste • Plant utility • Cost allocation for project overheads. • Cost allocation for the indirect overheads of a firm • Back of the envelope estimating	• Cost allocation for project overheads • Cost allocation for the indirect overheads of a firm	**Standard measures** From industry-wide or organisation specific estimating databases of historical use of internal resources	Low to medium: an environment of ***uniformity*** created by comparisons to - determined norms and allowances for context
	• Driving cost reductions on Quotations received • Secondary discounts • Going back to market to negotiate		**Bargaining** correlated to the market or other parts of the construction system	Medium to high: an environment of ***non-cooperation*** *created by lowest price commercial buying behaviour*
	• Cost inflation • Qualifications • Planning for variations • Contingencies • Profit		**Judgements** correlated to the market or other parts of the construction system	Medium: an environment of ***chance*** created 'best guess'
	• Frontloading • Late payments • Underbidding • Planning for claims • Cover pricing • Dutch auctions		**Intentional errors** correlated to parts of the construction system	High: An environment of ***distrust*** created by acknowledged non-collaborative practices

Figure 12: Signs created and their classification by type and level of distortion

Figure 12 shows that some of the signs that represent cost commitments are relatively faithful to forecasts of work that will be done. For example the specifications of products, their quantities and the geometry of their design are the simplest representations to make and provide direct measures of the materials required. But even where bills of quantities provide a large amount of information there are gaps in design information. The activities that contractors will go through (such as sequencing tasks, allocating resources, putting up ceiling grids and laying ceiling tiles) in changing conditions on site are much more uncertain and harder to represent. So there are bigger gaps in technical information at this stage about work programming and work methods. As well as gaps in technical information the signs in the cost model are removed from a good representation of the physical work done by the commercial decisions that contractors make. The influence of commercial decisions on the signs will also change after the contract point, when contactors engage in a second round of competitive tendering in changing markets that create shifting power between buyers and suppliers.

Taking each type of sign in Figure 12 in turn, costs of a firm's own resources are perhaps the closest representations of cost made to work that will be done, but are highly market dependent. The cost of labour for example depends on the availability of skilled labour. The costs created by lowest tier subcontractors are potentially closest to true input costs because the greatest proportion of their costs falls in this category. Material quantities are good representations but material costs are negotiable throughout the supply chain. They are based on the list prices from suppliers, and contractors across the supply chain hope to negotiate better prices and credit terms for repeat business. Plant input costs are either direct measures of cost where a contractor owns the plant or forecasts of cost for hired plant based on list prices. Like materials, costs of plant vary in the market. Project overheads, such as the labour costs of a site supervisor and plant costs for site cabins are also examples of direct measures of forecast costs of a firm's own internal resources. Direct measures comprise the surest information on which to forecast costs, thus introduce an atmosphere that this Section calls *sureness*.

The use of a firm's own resources are highly project dependent. The productivity and skill of labour for example are assumed to be fixed, but in practice will vary between projects. The utilisation and performance of plant and equipment are assumed fixed. But in practice innovations in materials, components, plant and equipment can differ between projects and may be slow to be costed. Section 4.2.2 found that the industry-wide or an organisation's own standard rates for labour productivity, material waste and plant utilisation are based on historically-determined norms from site, but the context of any particular project lowers the relationship of this type of cost information created to the actual work done. The standard rates, amended by best guesses for project-specific factors and uncertainties, introduce an atmosphere that this Section calls *uniformity*.

Quotations received are influenced by bargaining, negotiating lowest costs deep into the supply chain. Examples from literature section 2.2.2 and the findings from primary data section 4.5.1 showed that negotiations include bargaining for discounts on prices and better credit terms, driving cost reductions on quotations received with the threat of going to competitors, and actually going to competitors for new quotations. Section 4.2.3 shows that over 80% of the main contractor's costs falls into this category, as well as around 70% of SCA1's cost, and 60 % of SCB1's cost. The bargaining across the supply chain is therefore significant because of its extent and introduces an atmosphere that this Section calls *non-cooperation*.

Strategic tendering decisions examples (Section 4.2.4) are readily acknowledged as commercial decisions and create an atmosphere of *chance*. Other practices also create an atmosphere of chance. Experience-based estimating (Section 2.2.2) bypasses the creation of information about the use of resources and introduces acknowledged guesswork. Judgements on cost inflation, planning for variations, and qualifications introduce further degrees of acknowledged guesswork and increase the atmosphere of chance.

Acknowledged practices of intentional errors across a cost model (from findings in Section 4.2.3) include frontloading. Other categories of commercial practice come from literature (Section 2.2.2). These systematic practices create an atmosphere of non-cooperation so sub-contractors price for acknowledged non-collaborative practices such as disruption and late payment, by adding contingencies for poor coordination due to the atmosphere of *distrust*.

This analysis reveals that apart from direct measurement of quantities, contractor costing sits in the social world of standard rates, bargaining, judgements and intentional errors. Contractors put uncertainty costs in to their cost models to handle this. In Beynon-Davies' (2011) terms the signs represented in the resulting cost model point in two directions through their interaction with forma, informa and performa in the methods of costing. One direction is to the physical world of work to be done linked to technical design and construction information, and another direction is to the social world of negotiation of design, work programming, work methods and commercial exchange in construction projects. The signs in the cost model are thus *distorted* from a good representation of work to be done. The bill of quantities thus becomes a list of assertions about work to be done and payments due.

Representation of cost is not just a problem in construction. Across commerce in general how the information world of costing handles this social world of uncertainties and commercial practices is also not transparent. In management accounting literature Van Der Merwe (2007a) notes that management accounting has for many years sought new cost perspectives that better link costs with causes. He argues that causality should be the overriding modelling principle in cost modelling. But agrees with Johnson and Kaplan (1987) who had earlier observed that management accounting had become uninterested in direct measures of activities in the firm, relying instead on what they call *surrogate* financial numbers, that reduce the instrumental value of cost information in providing management with a tool to better manage a business (Ahrens and Chapman, 2007). Johnson and Kaplan (1987) also used the term surrogate to draw attention to the disconnection between the representation of cost and physical work. They said that cost information had become “uninterested in representing actual work done.” This was also recognised by Dean (1995) working on costing in the space industry who also used the term surrogates in a wider sense to establish a wider conversation about the broader range of alternative surrogates available.

Surrogate numbers in cost information are the norm, even in manufacturing, as uncertainties and errors are inherent in even the most detailed estimating methods and commercial pricing strategies influence product cost models away from a good representation of work done. In construction, where uncertainties are greater, even the detailed and specialised formal project cost models adopted in the UK do not represent actual work done well. The term surrogate is therefore important as it acknowledges that the representations of costs created cannot be complete, ideal representations of physical work done to create a finished object. The output, the contract sum, is made up of surrogates. The surrogates are established and connected to the task of payments by their meaning of establishing a price. The construction industry has worked with the surrogates described over a sustained period of time, despite the atmosphere of uniformity, non-cooperation, chance and distrust within the signs that are used in project costing.

5.2.2 The system of costing in construction

The *system of costing* that handles the surrogate nature of cost information in construction can be described using the concept of the feedback loop from systems thinking as one way of conceiving how methods and processes carry the significance of the system they sit in. Ackoff (1979) sees the feedback loop as an adaptive control system, a system that compares outturn with prediction and proposes corrective action. The feedback loop is therefore central to learning and hence improvement. Figure 13 illustrates a feedback loop for a generic costing routine.

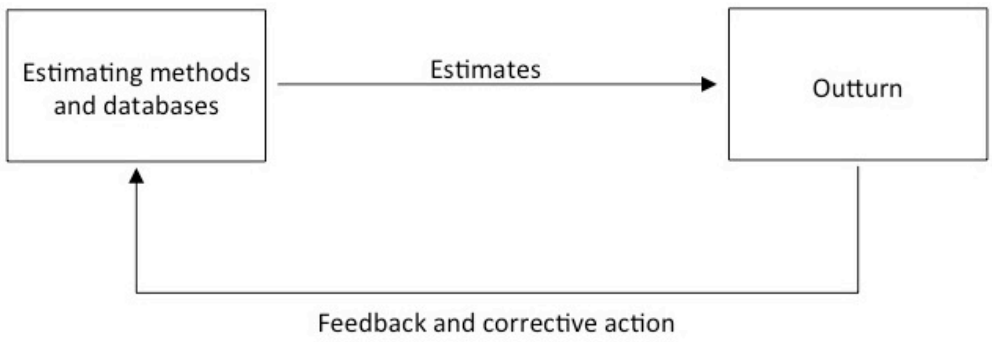

Figure 13: The feedback loop in a system of costing

Multiple feedback loops occur in all systems. In the system of costing in construction multiple feedback loops exist throughout a construction project and deep into the supply chain. Using the concept of distortion (see Figure 12 and the discussion in 5.2.1) the feedback loops in the system of costing are described as loops of *acknowledged practices*. Figure 14 illustrates how the acknowledged practices form the feedback to costing methods and processes to the next project, and become constant from project to project, thus form the system of costing,

Figure 14: The feedback loop in the current system of costing in construction

Estimating databases and methods are part of the system of costing, which itself is part of the system of construction. The estimating methods and databases are based on *signs* that contain a mixture of sureness, uniformity, chance, non-cooperation and distrust. The final account is only one version of outturn costs within the system of costing as illustrated in figure 14. The acknowledged practices include aspects of practice identified from the primary data (section 4.7) such as non-cooperation experienced on site, differences between trades identified from the primary data (Section 4.2) such as lump sum sequential spot contracting or attitudes to risk and such as lowest price competitive tendering across the supply chain and secondary competitive tendering for subcontractors (Section 4.5). The acknowledged practices in the feedback loop arise from practices across all three levels of the system of construction as conceived by Winch's (2010) (as described in Section 2.7.1): a system of ever changing conditions at the three levels of processes, governance and institutional. From the site operative working with concrete in the process level, to the government policy officer working with procurement ideas at the governance level and the market responding to the wider environment at the institutional level.

The feedback loop of acknowledged practices in the current system of costing creates stability, which maintains the status quo. The people who establish prices, make payments and control costs respond to the current signs in the cost model by operating on the basis that the cost model contains *agreed* data. In this way they make the cost model appear as if it works as a deterministic, mechanically simple system in which there is one unified purpose between parties and known, quantified feedback. There are advantages to everyone for this to be so. It allows routine costing activities that are quite concrete and closed to continue, and money to flow through projects.

But what really happens is that the methods and processes of costing adapt in order to accommodate the uncertainty in the system. At a project level, adaptations are made that cannot be accommodated by the formal costing routines, so they are dealt with through informal practices. The primary data shows that people working on the costing routines know that sometimes people drive a hard line on costs, usually from a top down approach, in which cost commitments are non-negotiable in hard bargaining (Sections 4.5.1 and 4.5.2). At other times people make deals on costs to preserve relationships and factors that affect costs such as credit, warranties, insurances or quality of work are used as reasons to adjust prices in soft bargaining (Sections 4.5.1 and 4.5.2). But neither of these commercial practices is seeking to discover information that may result in improvement.

Detailed bills of quantities that are calculated to two decimal points seemingly take a reductionist view that the detail is correct and add ups to a larger model of the system because “the parts make the whole”. But part of the acknowledged practices in the feedback loop is that everyone knows that the detail is not correct. At an industry level adaptations are made between projects that cannot be accommodated within projects, but are dealt with in the informal system (Section 4.5.1). The findings (Section 4.8.2) show that everyone knows that firms win and lose on different projects and any improvements are hidden in the system, taken as profit within firms. Knowledge of what the current system of costing means is part and parcel of the skills of the people who are running the system. The system may be used at times for practices like hard bargaining and this forms a significant part of the stress for people in construction (Section 4.8.3). But most of the time costs are used to ensure money flows through projects in a way that that keeps companies liquid, in a collectively acknowledged way in which people understand the problem of money flow. However it is difficult to operate this system to everyone’s benefit. People higher up the supply chain may want to know that fair costs are being paid, but they pursue subcontractors for increasing cost reductions because that is part of the system.

This presents a problem in using the current cost surrogates for the purpose of improvement. The primary data (Sections 4.3, 4.4 and 4.5) shows that current cost information is not generally agreed on for the more uncertain and open activities of negotiating deep in to the supply chain on changes that result in improvements. Like Nicolini et al. (2000) (Section 2.2.3) this Section argues that when the industry moves away from short-term market-based exchanges to more relational exchanges, it takes the same problem of the surrogate nature of cost information with it. Pushing the purpose of cost information to establishing improvements in more relational exchanges is problematic. There is a lack of agreed data for costing improvements in the supply chain operations. The agreements on cost break down, for not all cost data is trusted and agreed as good information for improvement purposes. The next Section will go on to consider current views on tackling improvement in the supply chain and their associated surrogates for cost information.

5.2.3 Current improvement interventions and their associated methods of costing in construction

In order to understand how new and different cost surrogates can better motivate improvement, this thesis enrols the concepts of *hard* and *soft* to describe improvement interventions in organisations and projects, and their relationship to information.

The field of Operations Research (OR) (Section 2.7.1) has taken both hard and soft approaches to interventions that seek to bring about improvements. A hard OR approach is one of improvement through setting unitary goals and optimising processes. This approach is underpinned by an epistemology of positivism. It attempts to engineer a situation to take the uncertainty out of the system. This approach requires hard, measurable information, which is specific and deterministic. It aims to get full data about the system. However there may be a limit to the availability of data and / or the ability to interpret more and more data. Hard measurements are important because they deliver trust. However trust is compromised if there are problems of data availability or analysis. A soft OR (Rosenhead, 1989) approach contrasts with a hard approach. It starts from a situation that some people regard as problematical and worthy of serious attention aimed at improvement. Finding an optimal solution is not important; coordinating people around an imperfect world is important. This approach is underpinned by an epistemology of social constructivism. It accepts the uncertainty in the system and attempts to acknowledge and better understand the uncertainty. Soft OR recognises that some factors cannot be measured and need to be treated differently. Soft OR sees value in information that is non-deterministic and thus allows for learning. There may be less data, but that data may be more transparent what it represents. In this soft approach data distortion and data unavailability are acknowledged, increasing trust.

In construction, the industry has been criticised over time for poor performance and high costs on the basis of high profile projects (See Section 1.1). Though not all agree that the construction industry is a poor performer, it is generally agreed that improvement, including cost reduction is desirable. But a guiding set of interventions to deliver improvement in construction are far from established, uptake of interventions promoted as best practice is slow, and where improvement is reportedly delivered in demonstration projects evidence is anecdotal and the improvement is not agreed on as good by everyone in the supply chain.

Supply Chain Management is a broad category of interventions that could potentially deliver change agreed on as good by everyone in the supply chain. Section 2.4 detailed supply chain management interventions in manufacturing and their adoption in construction. Many views on importing supply chain management into construction conclude that one or more barriers exist due to the adversarial nature of relationships, fragmentation of the supply base, an inability to innovate, and an attachment to competitive bidding. However attempts to import supply chain management into construction have been made. Supply chain management interventions adopted by construction can be classified into *consolidation* between firms, *process improvements* and *procurement interventions*.

Section 2.4.3 shows that there are a few examples of consolidation of the supply-base in construction industry in certain trades. Moves to modular design and off-site manufacturing have also resulted in a smaller supply base in some trades. Not all agree that significant consolidation of the supply base into fewer, bigger firms is advantageous because the cyclical market for construction is seen to favour the *dynamic capabilities* that come from a larger number of smaller firms.

Section 2.4.3 reports on efforts to adopt process improvement through *lean thinking* in the production phase of construction projects, termed lean construction. Lean construction tends towards a hard systems approach, which takes the view that it is possible to model ideal tasks and activities for site operations and ask the contractor and subcontractors work towards them. This approach attempts to remove the uncertainties in the system. This does not address the contextual problem that construction tasks are carried out in changing conditions. Construction projects are people-paced environments. This contrasts with the machine-paced environments of manufacturing where the dominant costs in the system are inflexible and fixed. In a construction project, the dominant costs in the system are labour costs, which are flexible and negotiable in an ever-changing environment.

Given the continued fragmentation of the supply base, construction has tried new methods of co-ordination and control through procurement that sets up different relationships between firms, usually for a single project, occasionally two of more projects. Procurement options were covered in literature Section 2.2.3. The range of procurement initiatives cover consortia, partnering, alliances, frameworks, early contractor involvement; clustering also known as building down barriers. These approaches accept the uncertainties in the system and adopt a soft system approach that attempts to change the culture and behaviour in the system.

Solid evidence of agreed cost reduction for clients from improvement efforts such as lean, partnering and clustering is sparse, even from promoters. There is very little literature about how people who are asked to achieve improvement respond to cost information. However there are examples of authors who have found efforts towards pushing the purpose of contractors' cost information to accounting for improvements to be problematic. The Tavistock Institute (1966) identified cost handling as a fundamental barrier to improvement. They took the view that the cost information during design, at the contract and at the final account "cannot, without making many assumptions, be related to one another nor validated one against another". They said that "as long as the different parts of the process [of construction] and its costs are so divided, with independence and even mistrust between parties, it would seem impossible to get a more rational system for costing the whole".

More recently the introduction of incentive contracts in demonstration projects has required more from cost information than traditional contracts. The most strident voice that holds the view that incentive contracts throw into relief the prevailing problem in cost information is perhaps Nicolini *et al*. (2000) who said "the lack of most basic knowledge on the supply side regarding costs and the cost drivers means that target costing approach is not viable in the current state of the industry". Nicolini *et al*. (2000) also found that contractors responded to cost information presented by the client's quantity surveyor in a pain / gain share contract with scepticism, because there were no feedback mechanisms from outturn costs or differing contexts of the previous projects behind the cost information presented. But nevertheless, the cost information was still viewed as effective enough for all parties to use it in the one off situation of an exemplar project. Winch (2010) acknowledged the view of Nicolini *et al*. (2000). But saw the solution in the fee model for designers, not in construction cost information.

Research into improving cost information in construction has been motivated by the advent of BIM (Section 2.6.2), and has worked towards increasing the detail in the hard data available about individual parts. Tsai (1998) pursues more accurate *costs of quality* in estimating so that cost information can lead decision-making. But a large proportion of the new cost information required to achieve this relies on judgement, not direct measurement. Foruges *et al.* (2012) and Staub-French *et al*. (2003) pursue more accurate costs in estimating by identifying new attributable *features of the product* in the design. O'Brien and Fischer (2000) pursue new measures for intra-firm costs. They looked at *capacity costs* to more accurately account for fixed expenses incurred by construction firms across their portfolio of projects. Other authors such Peleskei *et al*. (2015) pursue Monte Carlo simulation approaches to more accurately costing risk contingencies. Smith *et al*. (2000) explore stochastic calculations for the performance of excavators in earthworks. This is of benefit in civil engineering projects where a high proportion of costs are incurred in earthworks and the current historically determined norms do not reflect the large variation in conditions between projects. But the assumption that evermore ideal or perfect models can be created and the industry can work towards ideal or perfect models has a limit. Modelling that better links costs to activities is of advantage in accurately pricing projects. Probabilistic modelling that tames uncertainties is also of advantage in that it can price projects more accurately. But efforts that seek completely accurate information for pricing purposes are unattainable.

Outturn costs at the end of projects, as represented in final accounts, are a potential source of feedback, hence learning, to costing methods and processes. But cost models in final accounts are a poor match to realised, as-built costs. The primary data section 4.8.2 shows that the realities of construction are that everyone working on the costing routines knows that different companies hold different outturn costs within their firm and contractors continually win or lose in relation to costs on different projects. So the final account does not represent as-built costs and every firm holds a different version of outturn costs. This also presents a problem for the operation of Open Book Accounting (Section 1.2) in construction because the system of costing includes different versions of costs in different firms. Sacks *et al*. (2010) and Sunil *et al*. (2015) in lean construction see opportunities for new information on outturn costs to be collected from site feedback (Section 2.6.2). The primary data (Section 4.3.4) and literature (Section 2.2.2) found that feedback mechanisms from work done on site to estimating databases are hard to find. It is particularly difficult to observe construction activity on a project and no two projects are the same. An example from the primary data (Section 4.3.4) shows that SCA1 collected hard feedback on out-turn productivity rates for a particular activity, but the data was not deemed to be relevant for updating their estimating database because the economic cycle eclipsed the relevance of this feedback from site. Ross and Williams (2013) similarly pointed to the same problem (Section 2.2.2).

The system of costing contributes to the current situation where there is no universal agreement deep into the supply chain on cost reductions from different types of improvement effort. Nor is there universal agreement deep into the supply chain on why agreement has not been forthcoming. Clients may believe they have realised cost savings on projects. But this may be short-term and cannot be agreed on when improvements are not readily attached to cost.

5.2.4 New surrogates for costs in commerce

Section 2.5 set out literature from management accounting in the field of supply chain management that has explored some alternative cost surrogates to support inter-firm decisions. The literature review set out the detail of these alternatives and Table 9 summarises the purpose, core cost surrogates, and emphasis of five different cost management tools: Activity Based Costing, Lean Accounting and Throughput Accounting, Strategic Cost Management and Target Costing

Cost management tool	Main purpose	Core surrogates for cost	Emphasis
Activity Based Costing (Cooper and Kaplan 1998)	Analysing profitability of specific products	Assigns indirect overhead costs more accurately to specific products	To provide more accurate estimates for pricing decisions for individual products
Lean Accounting or Value Stream Costing (Womack and Jones, 1996)	Aggregation of direct costs by value stream.	Records weekly outturn costs of operations	Changes in the overall outturn profitability of a firm based from removing waste
Throughput Accounting contributes to Theory of Constraints (Goldratt, 1990)	Whole system profit optimisation	Records sales price minus outturn costs of materials. Some authors record sales price minus outturn costs all variable inputs	Changes in specific product outturn profitability from removing constraints
Value Engineering and Target Costing supported by open book accounting (Ansari *et al.*, 1997)	Analysis of a product design and production process related to customer needs	Rules for assigning estimated input costs, (direct costs and overhead costs) absorbed by products and adding a profit margin. A cost-plus basis to establish a target. Followed by open book accounting for records of outturn costs.	Design stage improvement plans for cost reduction in product and process design at the same time as increasing function and quality. To bridge the gap between target costs and outturn costs.
Strategic Cost Management (Porter, 1985)	Assessing competitive advantage	Integrates cost information on outturn costs from across firms. Assigns outturn costs and target costs to each firm	Design stage improvements to assist invest to save and make or buy decisions across firms

Table 9: Surrogate measures for costs associated with improvement interventions in commerce

These interventions lean towards the hard approaches of measuring more detail. Target Costing, Lean Accounting and Throughput Accounting all involve collection of outturn costs. The more controllable environment of manufacturing lends itself to interventions that take a hard approach to cost measurement. But even in manufacturing environments these accounting interventions are far from universal. This lack of agreement on the benefits of supply chain costing techniques in manufacturing and the nature of construction supply chains as a short-term, project supply chains formed to deliver a one off asset, both raise the question of the value of importing ideas of supply chain costing from manufacturing where long term supply chains are formed to deliver repeat products.

The construction industry is wedded to a specific system of surrogate cost information and has learned to make the surrogates work for short term, project based tendering and payment purposes, rooted in a belief that the surrogates work for getting the best price possible. Surrogates may be good for one purpose but poor for other purposes. When a different purpose of longer-term, industry-wide improvement is taken, the current surrogates do not work well. Alternative surrogates that better serve the purpose of improvements in organisations and projects could be established. There is no simple intervention. Interventions are needed that are more holistic and therefore work for more people. If rewards were tied more to the system of operation of the supply chain, main contractors and subcontractors would have an incentive to change.

Part 2

5.3 New representations of cost

5.3.1 Redefining the problem

The current *system of costing* works for the problem of establishing payments to individual firms delivering packages of work, but does not provide information that is agreed on by all for costing improvement across the supply chain. This Section considers a new costing ontology that could change the system of costing through acknowledging the different problem of establishing improvements though the supply chain.

The search for new improvement interventions and associated costing methods that can account for improvements (identify change, measure it and put a cost to it) is not new. Some approaches to improvement have attempted to engineer situations to take the uncertainty out of the system. They, and their associated methods of costing, have worked on accuracy and detail. These approaches have tackled, but not resolved, the problem of representing improvement in a way that can be costed and rewarded. This approach is partly the *lean* model for improvement (Section 2.4.2). This is a hard systems approach in which optimising the parts (making small changes close the symptoms) results in the whole working better.

But approaches to improvement designed to work in hard systems are difficult in construction, as construction projects are soft systems in which sociological aspects are of key importance alongside technical aspects. Amongst authors who take such a socio-technical view of construction (Section 2.7.1), Winch (2010) describes the construction system as a dynamic system of *information flow* on three interacting levels. Dubois and Gadde (2002) similarly observed the industry to be a *loosely coupled system* that operates through negotiation. The Tavistock Institute (1966) characterised the construction industry as *a system of interdependence and uncertainty*. They identified the importance of uncertainty because they saw uncertainties throughout the construction process; including doubts about information, faulty information and limited attempts to plan. They identified interdependence as the second important characteristic because they saw that any decision taken set in train a chain of consequences that could change the decision, thus decision and actions depend on one another. This concept of interdependence and its management provides an opportunity for taking forward the measurement of improvement.

The loose-coupled system of construction presents problems that are more complex than those in hard, tight-coupled systems, which is in part the manufacturing model. In construction, efforts that seek completely accurate information are unattainable. There are limits to the level of detail that people can measure and manage, as many aspects of site operations are unobservable or unacknowledged. In fact interventions and their associated methods of costing that work on accuracy (such as activity based costing, lean accounting, and throughput accounting) can be poorer at representing problems, as greater detail in one area can involve greater exclusion of what the problem actually is, and because optimising a part might cause greater problems in the whole.

The system of construction also presents problems that are too complex for single, simple interventions to solve. A different approach to improvement to the *lean* model, are approaches that seek to acknowledge and tolerate the uncertainty in the system, and advocate culture change throughout the system. This approach is partly the *partnering* model for improvement (Section 2.4.3). But no simple intervention will provide a solution and approaches to improvement that accept uncertainty and attempt to change the culture in the system have not tried to tackle the problem of representing improvement in a way that it can be costed and rewarded.

One participant described how improvement initiatives in construction need to take account of a bigger picture.

"When you get involved in the value engineering process, you start off with the job that's been well considered, but then we embark upon this period when we undo all that work and we pick at all the edges of it. So that the coordinated piece of design now has got different assumptions." MC (30)

This Section therefore *redefines* the problem of improvement and accounting for improvement in construction project supply chains, from the pursuit of ever-greater detail in cost models to new cost models that are simpler but purposefully designed to motivate improvement deep into the supply chain.

5.3.2 Addressing common interests

Participants described the potential for improvement through joint planning, in which multiple people across a supply chain are involved in defining problems and finding holistic solutions around common interests.

"Getting round the table and really discussing sequencing with your key supply chain, really looking at the project, getting into the design. We built rooms in our mind, drew them and built the programme around that. Then we built the bigger programme…we suffered problems, but those problems… for everyone involved would have been a lot worse." T1 (39)

This example shows an approach to improvement that establishes common interests, explores problems collectively in a way that recognises that different people hold different views, and leads to more holistic solutions that work for more people. It also sees dependencies as key. This is a soft systems approach to improvement. Construction projects lend themselves to analysis and decision-making using Soft Systems Methodology (SSM) (Section 2.7.1). SSM makes soft systems ideas - ideas that are concerned with the interactions between parts of the whole and emergent properties of the whole - fundamental to finding improvement solutions in construction. SSM makes six major assumptions in its method for identifying improvement solutions (i) there is an ever changing flux of interacting events and ideas (ii) different meanings are attributed to events by different people (iii) because of this system ideas are appropriate, a concept of the whole and its emergent properties (iv) individuals are trying to take purposeful action in accordance with their worldview (v) it is therefore appropriate to create models of human activity systems (as a device to explore the real world) and map them on to real world action (vi) learning about real problems takes place by comparing real world action to the model.

Such soft system approaches thus seek to better understand situations, develop an approximate ideal, then manage the situation towards this approximate ideal and finally feedback information to make better predictions in planning for the future. This in turn brings about system change. But the link between improvement solutions generated through soft system approaches and information requirements that support soft system approaches so that they can represent the change brought about, and put a cost to that change, needs careful consideration.

There is a tension between SSM and its information requirements, as information systems can only deal in hard information. Rosenhead (1989) (Section 2.7.1) suggests that using SSM as a front-end to a more traditional, hard information systems design potentially offers an opportunity to bridge the gap between soft and hard worlds. SSM is used to structure a debate about activities and processes. The method then takes the position that once new activities and processes are agreed on, the information requirements to carry out those activities can be defined. However Beynon-Davies (2011) is cautious about the achievements of soft system approaches in practice in considering information requirements fully. He recognises SSM as a systems model, and sees SSM as a device that promotes change through redesign of organisations, or parts of organisations, in dynamic situations. However he argues that definition of the information requirements that can represent the change brought about through SSM has been poor. He said that SSM "has little consideration for signs, and as a result communication and representation are seen within the design method as if to magically emerge from the consideration of the proper ordering of activities or processes". Thus a much richer information model is required,

5.3.3 Information requirements of soft system approaches to improvement

Information requirements will clearly not magically appear just by using soft system methods. Information Technology (IT) is the enabler of change in that is the provider of information, but IT can only deliver hard information. The problem of using soft systems thinking effectively is therefore a problem of how to bridge the gap between the soft world of organisations and the hard world of Information Technology. This Section takes the example of construction cost information to make this transparent.

Returning to the idea that IT provides a means for communication through signs, shown as representations. All representations are hard information in the modelled world of IT, but representations also contain the significance of the soft world of reality. This Section argues that the gaps between the soft world of organisations and the hard world of IT can be bridged by making the softness in representations more transparent though the concept of signs. Figure 15 draws on Beynon-Davies' (2010) concept of information-use through cycles of *formative, informative* and *performative acts* to illustrate that the system of costing includes significance from the soft world of reality. This is illustrated through the examples of two signs of work to be done and their costs represented by a lump sum cost for a product and a composite cost of a product in a measured item of work. The forma, informa and performa attached to these signs were described in Part 1 of this Discussion through the example of supply chain B. IT can only model forma, hard information, in methods of costing. But the significance of the soft world of reality arises in the signs from informa and performa. The illustration puts a greater significance on informa and performa over forma, even though forma is the only the representation that can be made in IT.

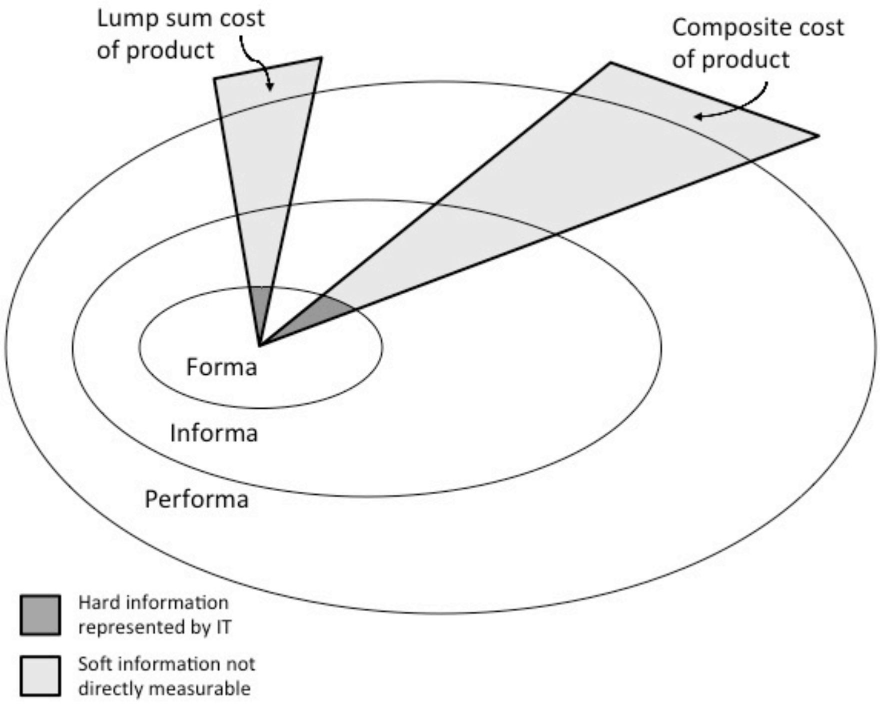

Figure 15: The make up of signs for work to be done and its cost

As said before, all representations are hard information, in the sense that they are fixed in forma. However meaning for improvement arises from the softness attached in a sign. The informa and performa, the softness, needs to be acknowledged in order to show the limitations of the forma. If the limitations of the forma are made transparent there is opportunity for increased data credibility. This Section takes this approach of increasing the transparency of the way in which cost information can only be presented as forma in IT, but in fact contains softness.

5.3.4 Dependencies as an information requirement for improvement

What is needed is information requirements that can identify and put a cost to improvements for the supply chain. This section thus proposes new surrogates that can better represent the system, prompts discussion about change and measurements that can be used to cost change.

The Findings (4.8.3) reported on what improvement that reaches deep into the supply chain would look like. They showed that better project programming was important to all parties, but important in different ways. Subcontractors expressed a desire for more collaborative and detailed planning throughout a project; they wanted to reduce uncertainty. The main contractor wanted to maintain flexibility in planning; they accepted and managed uncertainties through projects. During workshop 3 the main contractor explained their current ideas on improving their project planning practices. They explained that they were in the process of reducing their planning timescale to daily planning for activities concerned with the commissioning of the mechanical and electrical services. These activities occur at the end of a project. At this point, there is a concentration of activities and the interests of the main contractor and their subcontractors converge onto short-term daily planning. Daily planning becomes of the interest to the main contractor at this point because they have reached the end of a project and used up the contingencies in their plan. This section develops information requirements that identify what it calls *hotspots* of activities that would benefit from increased collaboration through joint planning at earlier points in projects to bring about improvements across the supply chain.

What is needed is an approach to improvement in construction project supply chains that better understand situations, and generates requirements for information that has attributes that make better sense of the realities a situation. This requires surrogates that are hard and measurable, but in which their softness is not hidden.

This Section defines four criteria for good surrogates:

- Meaningful: a meaningful surrogate is given when every representing symbol (or entity) is linked with one corresponding concept.

- Measurable: a measurable surrogate is given when a representing symbol is available, it is linked to a known dimension of reality,

- Manageable: a manageable surrogate is given when a representing symbol is linked to the actors who are involved and can take action.

New surrogates that meet the criteria of being meaningful for improvement that is agreed on through the supply chain must represent the construction system, that is be concerned with the interactions between parts of the whole. Interactions can be represented by *dependencies* and interdependencies between entities in a system. Participants knew this when they said that the current system works on knowing people. If you know someone you can get things done (Section 4.5.2). IT brings the potential to make cooperation between everyone in the system more visible. Dependencies are suggested as a new surrogate that reflects the whole system. The process of identifying entities and their dependencies starts with defining what is included in the system, and therefore what to exclude. Then defining what the entities are and what the dependencies and interdependencies between them are. This is not a simple task.

5.3.5 Dependencies in BIM

Technology can give opportunities to measure and work with a new surrogates of dependencies to account for improvement deep into the supply chain. It needs to be acknowledged that all representations in Information Technology (IT) are only the forma but contain the softness, the informa and performa, in the sign. It also needs to be acknowledged that IT biases discussion towards hard information, information associated with the assumption that the world can be perfectly represented and made perfect. In costing, the quantity surveyor has traditionally done a job of providing seemingly hard information against a product breakdown structure. But as revealed in Part 1 of this discussion cost information in fact contains a degree of softness and users make cost information work for pricing, payment and cost control within a particular band of assumptions. Literature presented that describes the ambitions of BIM (Section 2.6.1) sees its successes in design models (made up of objects linked by coordinates) that are used for visualisation and simulations, including immersive virtual reality simulations and decision support analyses, such as design clash detection or analysis of regulatory requirements. Delivery of design management in BIM is more advanced than delivery of construction management in BIM. Construction planning is slower to move into BIM but as contractors' work planning information moves into BIM, physical work represented as tasks with durations and dependencies is represented in planning models. This provides new representations of the construction process and the resources of labour, plant and materials can be linked to the planning model.

The adoption of cost management in BIM (Section 2.6.2) has focused on automation of current practices of quantity take-off, linking the measurement of quantities to the design model. These routines are the same as those already carried out on spread sheets and in costing software. Thus automation of the measurement of quantities assumes the problems of costing are already clear and well defined. Section 2.6.2 presented some research (Foruges *et al*., 2012; Sacks *et al*, 2010; Sunil *et al*., 2015 and Lawrence *et al*., 2015) into taking more complete or complicated measurements from the design model and automation of the new measurements for subsequent cost estimation. Some authors (Eastman *et al*, 2011; Monteiro and Martins, 2013) see automation of cost estimating in BIM as problematic because of the level of interpretation and judgement used in creating cost estimates. But the lack of real competition in construction and the existence of a system of costing that, more or less, works for firms across projects, results in a lack of pressure for systemic improvement. Thus there has been no incentive to search for new solutions. Cost management in BIM to date has involved itself in minor changes to existing sub-optimal costing processes, rather than been developed as a tool to enable systemic improvement.

There is potential for technology to help create new knowledge about the operation of the supply chain that has meaning for improvement and can be fed back into either managing the current situation or planning the future. But to date all disciplines in BIM have been criticised for delivering technological but not organisational change towards greater collaboration (Section 2.6). This requires a new surrogate for improvement, and an associated method of costing, that can reward improvements deep into the supply chain, contain softness and represent the system.

Although BIM offers opportunities to increase the creation, storage and transmission of hard information on costs in a digital form, and to automate this, technology offers greater opportunities when it is used to deal with the softness too, through its ability to show information on the whole and the parts. This extends the reach of model-based analysis: either by manipulating hard data faster and more extensively, or by taking more complex measurements (measurements from different places), compounding them and analysing them collaboratively. This can be seen as using IT to *informate* (Zuboff, 1988), which is to acquire and create new knowledge in a process of continuous feedback from interaction between the technology and its users. This Thesis acknowledges that the computable world cannot deal directly with soft issues, but argues that it can create new surrogates that can represent the system to help deal with non-computable things through analysing them collaboratively. Informating cost management in BIM involves hard information on costs with a soft approach to its analysis. The goal of informating cost information in BIM is one of creating feedback into more rational practices for identifying improvement in the whole, measuring change and putting a cost to the change.

Previous work (Tavistock Institute, 1966) and this research identified dependencies as good surrogates for the purpose of improvement that are meaningful, measurable, manageable and represent system. Dependencies between the objects that make up the finished building lie in the design focused BIM model of the building (product). Dependencies can be extracted from design models with parametric information in BIM, from objects that know what they are and how they interact. Other dependencies lie in associated BIM models that can be linked the design model and to each other. Project planning in BIM can link the design model to construction activities, resources, time and space. Project scheduling software can extend to 4D planning with associated applications that allow visualisation and decision support. Feedback about changing situations on site can be collected through Site BIM. Site BIM can provide feedback from site via GPS and photography. To date Site BIM has ben used to monitor progress and quality of work. Another link for the design model is a geographical link to GIS information.

There are as many dependencies in construction projects as there are products, people and rules. Table 10 provides examples of dependencies, showing how dependences interact with work to be done. This Thesis takes an approach of managing dependencies, not necessarily reducing them. This Thesis provides a route to managing dependencies through *informating* construction projects from early in a tender to final account: acquiring and creating new knowledge on dependencies in a process of continuous feedback from interaction between the technology (BIM) and its users.

Model	**Dependencies**
Design model	Intersections between different products from (such as bulkheads between walls and ceilings)
Planning models	Dependencies between different trades in sequencing (such as plaster boarding and electrical first and second fix)
Organisation models	Dependencies between different firms (such as drawings or other information requirements, or plant to move materials around)
Regulations, codes and the market	Dependencies between institutions and projects (such as planning approvals for materials, requirements for equipment and their permits or availability of labour)

Table 10: Examples of knowledge on dependencies in BIM

5.3.6 A systems ontology of costing

Dependencies need to be placed in the system of construction. Ontologies (Section 2.8.1) are a way of representing the world. This Thesis argues that what is needed is a new information ontology, that represents the costing of the system of construction delivery. This will be called a *systems ontology of costing*, rather than a structured model of costing. Staub-French *et al.* (2003) have developed on an ontology linked to design features in a design model (Section 2.6.2) and developed this in BIM. They identified design features based on estimators' views on design features that were previously unmeasured but important for costing, such as features that define where work will be done in open areas or restricted areas. Staub-French's *et al.* (2003) representation of design features includes connections (dependencies) between objects from geometry. This ontology of design features is important to the measurement of dependencies. But this Thesis goes further to identify the dependencies from additional models that between them can approximate a representation of the system of construction throughout the construction process. New measurements can be undertaken of a situation and of change in the situation in a way that better represent the whole system, not a work package The measurement of change in the whole, and the ability to cost the change, is more meaningful than measurements that work on accuracy through detail.

Figure 16, below suggests a systems ontology of cost information that takes information from a range of models in order to provide a new surrogate of dependencies from across models that between them better represent the system of a construction project, not the parts. The ontology provides a means of representing the world of a construction project at and between the three *system levels* related to Winch's (2010) construction system (institutional, governance, and process). The ontology divides processes into construction and design processes. The ontology then identifies potential sources of new forma, in the form of dependencies, which can be measured from across BIM models: from national regulations to work breakdown structures. The ontology makes the representations explicitly *meaningful* for supply chain improvement. The ontology identifies *measurable* quantities highlighting dependencies to provide information across the supply chain (encompassing dependencies that arise from regulations, organisations, activities and component design). The ontology recognises that looking any lower, such as at the task level, would involve records that are too detailed to collect, too late to do anything about on a one-off project and too specific to individual subcontractors. Finally the ontology identifies spatial mapping and planning of hotspots of activity from the dependencies to identify problems that are *manageable*, therefore bring about change that can be measured and costed.

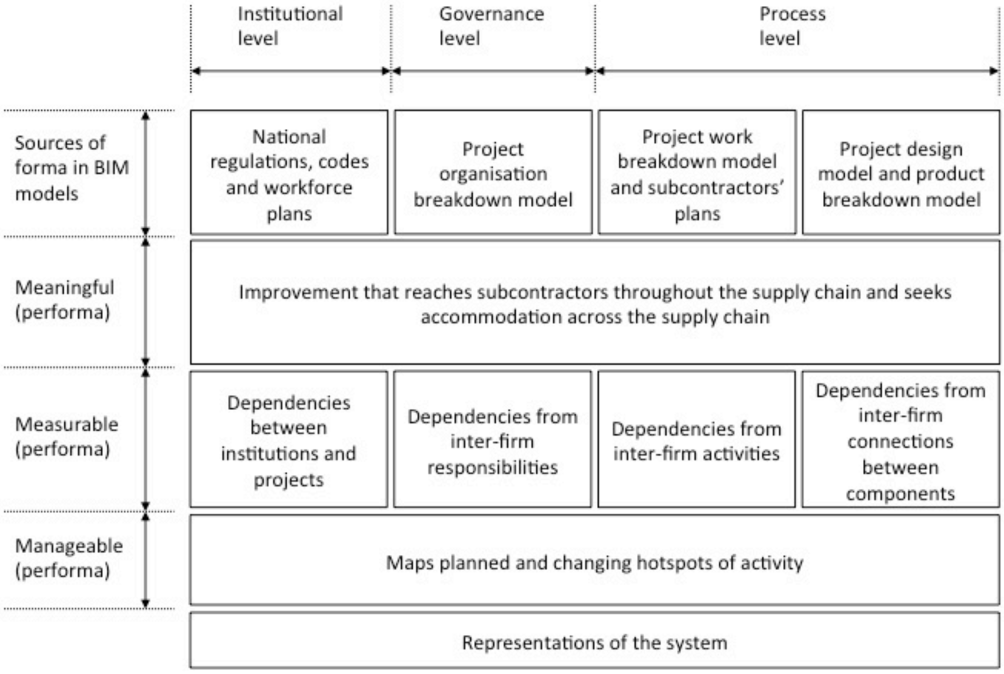

Figure 16: Schematic diagram for a systems ontology of costing

This systems ontology for costing seeks to represent costs in a way that forma (surrogates in BIM) are used in way that they are transparent as signs, in that the forma contains the significance of the informa and performa that influences change that brings about improvement. The systems ontology facilitates this through making dependencies visible with the intention of managing dependencies for the overall benefit of the supply chain. Collaborative problem identification and solution building from soft systems methodology can achieve this, based on discussions using new surrogates of dependencies. This takes a bottom-up approach, thus it recognises that real improvement takes place when subcontractors at the bottom of the supply chain can work better on site, with the main contractor accommodating change in the system across subcontractors. This establishes improvement that has meaning for the overall supply chain. This requires that dependencies can be measured in BIM, used effectively to identify hotspots as tools for discussion about change and the measurement of agreed improvement. This identifies change that can be acknowledged costed and rewarded at an earlier stage to gain benefits when the market holds greatest sway. This needs to develop in time, as dependencies are not fully planned at tender and change as uncertainties reduce during the course of a project.

The process level offers the greatest potential scope for dependencies from the work breakdown model and subcontractor's plans. However before rushing to take new measurements from work planning models, the nature of the surrogates in planning models needs to be understood. Just as cost models contain a high degree of distortion (as described in Part 1 of this Discussion) planners rely on intuition to estimate durations of work. Winch (2010) argues that Critical Path Method, Critical Chain Method and Critical Space Analysis based on sequential task dependencies are viable to help improvements on site. Dependencies and interdependences in site operations arise from the level of detail that it is viable for the designer to model and the main contractor to schedule. This approach relies on understanding the nature of project planning through its forma, informa and performa, in the same way that this thesis has understood the nature of costing. It also relies on a better understanding of the tensions identified in the findings Section 4.8.3 between the main contractors' desire for flexibility and subcontractors desire for certainty in construction planning. Only then can project schedules be used to better understand and learn from the soft system of project scheduling. This thesis contends that this task needs to be done before working on better attaching costs to the plan.

This Section started from the desire to find representations of cost that have a transparent purpose of improving site operations. Dependencies are a surrogate for uncertainty arsing for interactions and can be visualised. Dependencies visualised through IT and the identification of hotspots could enable contractors and subcontractors to be better informated. Everyone would know more about what was really happening. This would contrast with the current approach of hiding what is really happening through the use of IT for automation. To exploit the potential of technology in BIM, this Section has considered how *new surrogates of* dependencies that better represent physical work carried by the supply chain by better representing the system, might improve cost information. To achieve this, this Section accepts the uncertainties in contracting and concentrates on managing dependencies and interdependencies under conditions of uncertainty. This Section has therefore proposed a new systems ontology for costing that motivates improvement by changing the system, not just part of it.

5.3.7 Technology that changes the system

To exploit this potential of technology in BIM, Part 2 of the Discussion has considered how new surrogates of dependencies, that better represent physical work carried out by the supply chain by better representing the whole and better reflecting the softness of what is really happening on site. Dependencies can provide the basis for cost information that is a good surrogate for identifying and rewarding for improvements. The surrogates are envisaged as being used within a new system of costing that has a purpose of motivating improvement in site operations through cost reward. For a new system of costing to be taken up people have to see either the fairness in it for the whole or the way they can use it for their own advantage. It also needs to be developmental to allow the system to change.

This Section has taken an approach that looks across BIM models for measurements of dependencies that can help make situations in the whole supply chain more visible. Then hotspots can be used to prioritise areas that will benefit from managing uncertainly more collectively and actively. This may be able to encompass feedback about work progress that can be used to manage site operations in real time situations and make future predictions to create work methods that are more efficient, thus introduce learning, and change the system.
More active collection of data and management of data, linked to cost, could provide the mechanism for fair reward as well as improvement benefits for the supply chain. Costs provide an incentive to try to improve, rather than using the contractual method of buying cheaper.

The difficulty in obtaining suitable measurements is formidable. The measurement of improved teamwork and the like cannot be measured by piecemeal calculation of individual incidents. The field of measurement must be the complete construction system, rather than an individual feature of its design or production But the rewards of a system of costing in which it is possible to measure the effects of change aims to lead to a lessening of resistance to change.

CHAPTER 6

CONCLUSION

6.1 Summary of thesis

This Thesis has developed a preliminary systems ontology for the identification, measurement and costing of improvement through the use of BIM.

Chapter 1 presented the research rationale. This comes from the challenge to the construction industry to improve its work processes and reduce costs at a time when new technologies are driving growth in the complexity of projects. This is a problem for all industries. But collaboration is more problematic in construction where main contractors subcontract most of the work, to mainly small or medium sized, local firms, who work together in short-term, project-based relationships. So solutions to improvement require working collectively. BIM is promoted as a solution to obtain greater efficiencies through information processing in technology and organisational collaboration. The link between IT and organisations is fundamental to achieving this. Organisations are fundamentally affected by money; every firm in a supply chain has strong obligations to their own financial requirements, separate to their obligations to projects. Whilst formal cost models prescribe how costs should be presented to the client for pricing, payment and cost control, the actual process of how contractors and subcontractors create and use cost information is not clearly articulated in literature on costing and largely absent in literature on improvement.

Chapter 2 presented literature on contractors' methods of costing that prescribe how formal project cost models should be presented and how contractors should build up costs for work from the constituent resources of labour, materials, plant and overheads plus profit. Literature on the influence of commercial pricing decisions that recognises a wider set of forces acting on the formal cost models was also presented. The emergence of new financial incentives for improvement, through Target Costing and Supply Chain Cost Management, was set out with the arguments of a few authors who have found that a lack of basic knowledge on costs on the supply side and an adherence to competitive tendering on the demand side of the industry are barriers to improvement. Improvement concerns, in construction in particular and in commerce in general, were presented with associated developments in intra-firm and inter-firm management accounting. The Chapter moved on to the arrival of BIM in construction and cost modelling in BIM. Finally literature was presented that looked upwards to systems thinking and associated hard and soft views of systems, along with literature from information theory that specifically seeks to link IT to the organisations it is used in.

Chapter 3 presented the research methodology. The research was carried out through a partnership with a main contractor who sponsored the studentship for this research. The primary research took a *critical realist* methodological stance to understand current contractor costing in its social context, grounded in practice to uncover the actual processes of how the main contractor and subcontractors create and use cost information through projects. A case study of a supply chain was assembled from the primary research. The primary research involved semi-structured interviews, workshops, observation of site meetings and in-depth reviews of documents from a main contractor and five subcontractors to investigate current approaches to the creation and use of contractors' cost information. This provided insight into how cost information is created and flows from forecasts of work to be carried out, to costs to the client.

Chapter 4 presented the research findings. The findings showed that cost information that flows through the supply works as agreed costs for establishing a price. Current costing practices were described that showed that contractors and subcontractors view agreed costs as commercially rational decisions, in which all parties accept the uncertainty inherent in what will be required to fulfil their part of the bargain and all pursue their subcontractors and suppliers for cost reductions. The findings show the *disconnection* between the formal cost model shared with the client and the informal practices in the negotiable world of costing in the supply chain. Cost information that is tied to physical work carried out in the supply chain, which would be useful for evaluating and rewarding improvements, is either not created, or is obscured or lost when cost information passes between firms in the supply chain. It was found that cost information that is agreed on for pricing and budgeting, is not agreed on for assessing and rewarding change and hence improvement. The findings also showed that project planning also involved much negotiation in which planning and re-planning of work and construction methods was undertaken during the delivery of projects. Thus moves to automate planning processes in BIM may produce non-viable results and cannot be justified for the assessment of improvement.

Chapter 5 presented the discussion. Part 1 of the Discussion used the information-use model of Beynon-Davies (2011), involving the concept of *signs* to encompass the *forma, informa* and *performa* that interact with cost information. Through the detailed analysis of the cycles of formative, informative and performative action in creating cost information, the Discussion identified the *distortion* in cost information, the practices that remove cost information away from a good representation of work to be done. Thus *surrogate* numbers are created that become fixed reference points in formal cost models, but are disconnected from the informal routines of cost handling as established in the Findings. The ideas presented so far were brought together in a description of the current *system of costing* that includes its acknowledged practices. Part 1 of the discussion argued that new surrogates need to be found, enabled by BIM, and agreed for effective representation of improvements. Part 2 of the discussion proposed a new *systems ontology of costing* for the specific purpose of improvement across the supply chain. The proposed ontology in turn, through a developmental introduction, changes the system of costing from a system based on buying more cheaply to a system based on identifying and fairly rewarding collaborative improvement that works for the supply chain as a whole. The Discussion took the position that new surrogates need to be measurable, manageable and meaningful for representing the system. The systems ontology of costing proposed is based on measurement of dependencies to achieve this. The Discussion argued that the measurement of dependencies from a wide range of BIM models can provide a measurement of the whole, not just the work package parts, and allows hotspots of dependencies to be identified. This information can then be used for collaborative discussion and decision-making about improvements deep into the supply chain following soft systems methods. Change can then be managed, represented and costed for fair reward across the supply chain and through projects from tender to final account.

6.2 Reflections on research achievements of objectives

This research aimed to develop a framework of costing that supports more efficient supply chain practices through the use of BIM. In order to achieve this aim the following objectives were set:

<u>Objective 1: Determine how current approaches to supply chain costing affect supply chain operation and overall construction costs in a project.</u>

In order to achieve this objective the research accessed commercially sensitive information on the detailed costing methods and practices of a main contractor and six firms across three subcontract supply chains. This established comprehensive accounts of current approaches to supply chain costing from interviews, document review and workshops. The findings revealed the *surrogate* nature of costs created in their representation of work to be done, and the *disconnection* between the surrogate numbers held in contractors' private cost models and the surrogate numbers held as fixed reference points in the formal cost model presented to clients. The findings on current approaches to costing were also confronted by literature from information theory in the Discussion. This provided a new analysis in the Discussion, of the nature of the data *distortion* that cost models are built on. The analysis of current approaches of costing revealed that the practice of forcing cost reductions onto the lowest tiers of the supply chain fundamentally affects collaboration across the supply chain, whilst reducing overall costs. The client thinks they are getting a cheaper building, but reductions in cost that could arise from greater collaboration remain unknown.

<u>Objective 2: Determine how different approaches to costing of supply chain operation can be used to deliver efficiency and cost savings in projects.</u>

In order to achieve this objective the research presented literature that encompassed the fields of supply chain management, construction improvement, management accounting, systems thinking, and information theory. Each of these fields are vast in themselves. There is much more to the work in each of these fields than is presented across this thesis. However it was necessary to cover this ground broadly, as to leave any of these fields out of the consideration of the research aim would give an incomplete consideration of the problem. The ideas presented in each field have been chosen as a way to analyse “cost as information” from improvement in supply chains in construction projects.

Objective 3: Examine costing through the lens of information theory to identify different, more useful costs of supply chain operation throughout projects

In order to achieve this objective the research presented literature from information theory to establish new foundations for the development of cost modelling. It was established that automation of the current system of costing will not produce new cost information. New criteria arising from information theory have been developed for an information model of costs that are measurable, manageable and meaningful across the supply chain.

Objective 4: Develop a schematic information model of costing that represents the whole system of costing in the supply chain to inform the development of information approaches such as BIM

A schematic information model of costing has been created. The model takes the form of a systems ontology of costing that makes improvement by everyone across the supply chain more visible. This research argues that the systems ontology of costing can assist thinking about the development and testing of models of costing in BIM.

6.3 Research contributions

This research has revealed new elements of the current situation. Firstly the importance of the question it is trying to answer. Money is a driver of the industry and of collaboration. One participant illustrated the importance of money in construction.

“You can go on to a site and within twenty minutes of walking round you know whether that site is running as it should do…everyone is starting at the optimum time and the process is running correctly…everybody is making the margin they should be making” MC (30)

It became clear during the course of the research that good site operation goes hand in hand with fair cost recovery. Therefore tackling costing is fundamental to any programme of change. Any programme of process change will only work deep into the supply chain, if it considers costs linked to the supply chain as a whole. The industry is making progress towards easing cashflow in the supply chain by tackling the bad practices of late payment of money due and non-payment of retention money. But the ability to measure the effects of change in work done and reward it financially remains elusive. The position taken by this thesis, that work on linking the cost modelling and work done in a way that represents the system and can be agreed by all as improvement, is not being suggested elsewhere.

The research has revealed the importance of seeing “cost as information” in order to understand the limitation of current cost information and directions for new types of cost information. Beynon-Davies (2011) highlighted the advantage of a clear conception of systems and their associated information requirements. The concepts of forma, informa and performa in information have been used to unpick the bases that current cost information is created from and how it is used. This illustrated the *distortion* in the current cost information created from a good representation of work be done, thus losing its meaning for direct measures of and improvement in work done. It described how distortion arises from the use of standard measures, bargaining, judgements and intentional errors in cost modelling. It also illustrated the *disconnection* between formal project cost models and informal cost models held within firms, in a way that has not been done before, and in a way that shows why it is difficult for firms to pool current cost information. Both the distortion and disconnection of cost information arise from the negotiation inherent in the current system of costing, thus the meaning of cost information resides in its performa.

Efforts that pursue greater detail in costing have not investigated the level below the representations of cost they have to work on, or the system of costing that the representations are used. This thesis showed that the problem of change is not one of gathering more data, because the data created is distorted and disconnected in the current system of costing. Change needs to be evolutionary as the current system of costing is so ubiquitous. Announcing a change will not make it happen. Change needs to progress in a way that allows people to learn to trust the information in the system. The *systems ontology of costing* proposed involves the creation of data that can be pooled across the supply chain, and data that better represents work done, because it better represents the system of construction. The systems ontology is based on the measurement of dependencies through BIM. Dependencies are chosen because, when taken from across a range of models in

BIM, they provide a representation about the reality of work done. This involves the measurement of dependencies from early in the tender stage to the final account.

Lastly, this research contributes substantially to different fields of literature. It contributes to literature on standard project costing and the commercial management of construction projects as it describes current practices of contractor costing deep into the supply chain. It also contributes to literature on management accounting by looking at how developments in management accounting relate to construction project costing. It further contributes to literature in information theory as it applies Beynon-Davies' (2011) preliminary framework of formative, informative and performative acts at a concrete level to current practice in construction project costing. Finally it contributes to literature on cost modelling in BIM, calling for a pause in automation of cost modelling in BIM, and a consideration the information requirements, viewing 'cost as information', alongside improvement efforts.

6.4 Limitations of research

The research does not include the view of members of the construction team other that contractors and subcontractors. Clients, designers and the client's quantity surveyors would have a particular view of how contractors' commercial interests play out in projects. The case study approach to establishing current methods of costing and system of costing is limited to one main contractor and seven subcontractors. But each said that what they described is usual on all projects. The research has relied heavily on Beynon-Davies' (2011) work. His framework of forma, informa and performa is not simple and not easy to work with. It is also just one view, although it is consistent with the view of others that information arises from data plus meaning. Evidence for the suggested way forward, a systems ontology of costing, is based on one case study, but supported by argument. But information theory contributes and defines the idea of ontologies as the basis of a good data model. Finally the research is limited by the fact that the issue of main contractors' construction planning was not researched in detail. This is because its importance to a new method of costing for the purpose of rewarding improvements was not established until the late stages of the research. These limitations are addressed under future work (Section 6.5)

6.5 Future work

This research has suggested one approach. The approach is theoretical, but needs a comprehensive evaluation and critical analysis of planning to be brought together with this evaluation and analysis of costing. An analysis and evaluation of construction planning would provide data for specifying the nature of future measurements of dependencies that would better link costs and work done. The measurements would reflect a much wider reach of interests for the purpose of reflecting improvement in work done than the measured items currently harvested from BIM models. Dependencies can be made visible early on in a tender and though the project delivery, thus taking account of the continuously changing conditions of construction projects on work done. This would address the current disconnection between costs and work done through connection to the whole system, not parts of the system. Then a theoretical model can be set up and tested in practice.

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APPENDICES

A1

Research Partnership

A1.1

Collaboration Agreement

Academic Collaboration Agreement
Company funded PhD studentship

The Development of Contractor Costing in BIM

MC has awarded a PhD studentship bursary attached as Annex 1 to the Birmingham School of the Built Environment, Birmingham City University. The Collaborators are Professor David Boyd and Dr Niraj Thurairajah at the University and participants at MC. The Collaborators will co-operate to undertake the supervision and the project for mutual benefit.

The bursary will be administered and the student managed by Birmingham City University. The Project start date is February 2013 for a period of 36 months, contingent on the appointment of a suitable candidate.

MC will provide access to appropriate company information, processes, staff, project sites etc. and to relevant supply chains. MC will identify an individual to work with the student and the University as part of the supervisory team and to facilitate access. Although the project will have joint academic and business aims, the academic will take precedence to ensure appropriate and timely progress to a PhD. The student will be employed by the university but can undertake work for MC, relevant to the PhD study, but the request for this will be through the supervisory team.

The project will produce journal and conference papers, articles etc as well as a PhD thesis. External publications will be submitted for review by MC prior to publication; however, consent for publication will not be unreasonably withheld.

Whilst on company premises the student will adhere to MC's policies, particularly relating to health and safety, as if they were a company employee. Appropriate briefings will be provided.

The student's progress will be reviewed formally every 6 months by the supervisory team. The student and supervisors will provide a written and verbal report to MC every 12 months detailing achievements and developing directions.

The project's research ethics will be reviewed by the University. The project may require and generate confidential information. This will not be communicated outside the collaborators and the supervisors without prior permission from MC and any specific individuals involved.

All intellectual property and knowledge generated in the course of the Project ("Arising IP") shall belong to the Collaborator(s) generating the same. Each Collaborator hereby grants to the other Collaborators a licence to use its arising IP only for the Project and associated teaching and research purposes. All outputs of the Project will be available for internal teaching and research purposes by each or all of the Collaborators and in on-line research archives.

Any disagreements during the course of the project will be discussed openly by the collaborators with a view to finding amicable solutions. The project will not be terminated without 6 month's notice.

A2

Data Samples

A2.1

Interview guide

Research into Contractor Costing in BIM

Subcontractor interviews – commercial and managerial employees
Interview Guide

SEMI-STRUCTURED INTERVIEWS

Timing	Key Questions	Notes
	Abigail Robson from Birmingham City University Research in partnership with Main Contractor (MC) looking at how contractor costing can be enhanced across the supply chain, enabled by BIM Thank you for agreeing to be interviewed The conversation should last half an hour to an hour Outline research aims (see accompanying sheet) I'm trying to find out: How costing is done by contractors and subcontractors Gather views of different people working in subcontractor companies (commercial managers, QS's and site managers). All opinions are valid. Most companies are already using or developing BIM on projects but this work is a longer term, in depth piece I research about systems development, potentially changing that we do. As a large subcontractor you're a sophisticated subcontractor who inputs into design, manufacturing, production on site and maintenance. I will treat all information that you give in confidence. MC will not be able to associate your name or details with your responses. Although some MC staff may know that your company have taken part in this research. Permission to record this interview? I'll use the recording for analysis purposes only (the recording will not be passed to MC) I may include quotes from your comments in reports, although not in a way that would allow you to be identified. If at any point you would like a response not to be recorded just let me know and I'll stop recording. I'll be using the answers that you and other interviewees give in written reports, journal and conference papers and my thesis, which will be finalized in early 2016. The information you give will only be used for this research project.	Welcome; objectives of research; researchers role; 'rules ' of the interview

	Your currant position and qualifications? **How long have you worked in this company?** **How long have you worked in the construction industry?**	Introduction about the interviewee

	Who's involved in putting the PRICE together for a tender during the procurement phase and how does the company go about it?
	
	• Extent of downstream subcontracted packages?
	• Extent of directly employed labour, materials and plant priced from first principles?
	• Overheads and profit?
	• Extent of collaborative programming at this stage?
	
	Would you share one of your build-ups with me?
	
	Once you've been notified that you've won a tender, are package prices renegotiated before placing an order?
	• Buying gains? OR
	• Integration / production gains?
	
	Does a BQ provide you with a useful cost model for the business process of managing costs to achieve the greatest value and economy?
	• Your package prices? OR
	• Your direct costs
	
	As a project progresses or at the end of a project, do you record and use actual COSTS (wins and losses) to assist decision-making?
	
	Final **price paid** for packages? OR
	Your direct **production costs**
	• **Activity-based costs** (an intricate allocation of costs) to capture the true costs? Is this worthwhile for decision-making? Or are all activities meaningfully allocated to objects?
	• Does the company record any **transaction costs** (an assessment of the costs required to in control work between companies)
	  • Building in buffers / waiting
	  • Waste
	  • Adapting processes
	  • Adapting / redoing work
	  • Renegotiating costs to get a better deal
	  • Dealing with people / technology
	
	Are you costing what you need to manage?
		To find out what cost information is held and in what format?
		
		To find out how methods of costing reach through the supply chain

	What are the key relationships for your company and how do they affect collaboration? • Design manager? • Main contractor's programmer and site manager? • Preceding trades? • Following trades? What could the **main contractor** do to manage your work more effectively? • Ask for more information? • Provide missing information? Design underdeveloped? • Late information? • Late changes? • Critical delays? How does your **company** incentivize value and economy across its upstream supply chain? Have you ever worked on a project where there is a **third party** whose incentive is to achieve total profit maximization? • Does anyone record and share the aggregate financial wins and losses across the supply chain? • Is there information that would benefit everyone? • Does anyone have an overall model of the wider system? • Does the client have the most to gain in doing this? • Could BIM model wider interactions? If you could see more, could you control more? **Do you think that the financial performance of your company affects its conduct?** • Restrictive practices versus innovations	To find out about organizational behaviour and organisational decision – making in relation to supply chain management

A2.2

Interview Transcript (example)

INTERVIEW TRANSCRIPT (EXAMPLE)

I: Okay, so this is about finding out – the first of the aims and objectives really – finding out what current approaches to costing are. So I wondered if you could tell me perhaps who is involved in putting the price together at tender from [SCA1]'s point of view, during the procurement phase, and how the company goes about it.

R: Okay so we have – it's probably changed over the recent years – but we now have what we call a preconstruction or a pre-contract team. Which we never really used to have; they were an estimating department. Essentially it's the same thing, but it has a bid manager and a preconstruction manager, or pre-contract manager as we're now calling it, we're just going through with the change. Their responsibility will be to…not only are they looking as business development – so the business development manager feeds into that as well: he'll be out in the marketplaces talking to people, getting the inside knowledge that we can and trying to look at opportunities. For example if there was an opportunity coming up with a university we might try and support, go and make contact with them to start with, maybe sponsor some students, that sort of stuff. So we're always looking at that with regards to business development.

And then as a bid comes to fruition and a tender comes in, or a request you're interested in tendering – they often come as an expression, at least to start with, so, are you interested? And you might do a prequalification document, which would be a short synopsis of why you're interested and a bit of detail about the business, who we are and what we can do. Obviously from our point of view we've got quite a big name, we're well known, so we most of the time get on to a tender list by doing a prequalification, unless there is somebody in the business that you're prequalifying to that has had a bad experience with [SCA1]. Because it's amazing how long they last: 'I worked with [SCA1] 20 years ago and I don't like them, so they're not going to tender this job.'

I: That's an interesting one isn't it?

R: It is, yeah. It does stand, you still hear of it now. So we would prequalify hopefully, and if we prequalify then we proceed to the tender pack. That comes in varying ways. Most common would be from a main contractor who's already been engaged.

I: Yeah.

R: Actually I'm saying that, it's not necessarily now: a lot of what we see now is the overall bid coming out and then we would align ourselves with a main contractor.

I: So you would approach the main contractor?

R: Or they'll approach us, which you call a back-to-back bid. So, for BCU here [MC] tendered the project, and on phase one we went back-to-back with [MC]. So they named us in their documentation, their bid, and then we did a combined bid for the university to say, look, you're taking on [MC] but also [SCA1], and we come as a package.

I: Were there any others named back-to-back, do you know, or was it [SCA1] because of the importance?

R: What often happens is that there's a bit of a scenario there where each of the builders would be looking to who they're going to name. So we might get asked by two builders or three builders to go back-to-back with them. Again, potentially because of our name and because of our reputation, we sometimes find ourselves in that situation. And then at other times we just end up saying we're just going to bid everybody because we'd rather have a competitive bid in the market. If you will want to name us then that's fine, but we're not going to just go back-to-back with you, because we end up in a position there where if the main contractor loses the project because they've done a bad bid, we might have done the best M&E bid out of everybody, but the main contractor's bid is two million over, and that's it: we've lost the job because of it. So there's this whole backing the wrong horse or backing the right horse, which is awkward, but a lot of large contracts require you to tender that way, so...

Just strip that back a little bit, sorry: when a bid would come in we have our own internal bid/no bid process. So that's a big three, four hour meeting, standard set of questions, such as 'Have we worked with this client before?' 'Yes.' 'Have we had good jobs with them?' 'Yes.' That's good: ticks, ticks. 'Do we like the client?' 'Yes.' 'Do we like the client?' 'No, actually he was really hard work, didn't pay us.' All those sorts of questions, all the sensible questions to ask yourself. 'Is it worth us investing in this bid?' Because on these large projects they can be time consuming, they can be costly.

There's a bid at the moment – I was talking in the office to the preconstruction manager – we had anticipated that we were going to have spent £100,000 just to bid it. Large contracts, really large contracts, quite attractive, but can we afford it at the moment? Does it really fit in the business plan? Actually if we've got this job and we've got this job then we're going to be stretching ourselves a little bit with that, so we might choose not to. So there's that whole bid/no bid process. Lots of other things are assessed: you know, do we have the right resource, do we have the right people to deliver it, are we going to provide the client with a good project or are we going to be…we've currently got a £40,000,000 workload, and we're full, so actually we're going to be taking it on and not be able to deliver. So there's a whole process that we go through.

If we're happy that we do want to bid it then all those discussions take place as to whether we're going to back certain people or whether we're just going to price the market, so.

The other way it sometimes happens is that the main contractor will have already been appointed by the main client, and then the main contractor will be coming out to four or five M&E contractors. Best price not particularly attractive to us, because we don't normally see ours…although we are…actually we are competitive, but we sometimes think that we're not going to be quite as competitive as a smaller contractor who's perhaps not going to do everything perfect. We like to think that we do. They might cut a few corners, but might assume that they're going to get some...we're getting into some details then. So for example a lighting manufacturer might have been named in the bid, [Inaudible 00:06:26] approved, we've gone in on the lighting manufacturer, but somebody else might go in on lower cost lighting assuming that they're going to get it agreed. May or may not get it agreed, may force the client to agree because of the equal or approved – well, why can't we use it? So if we're going in bid [inaudible 00:06:43] we sometimes think we might not be the most competitive, which can obviously be an issue if we're going into an open competitive market. So again those are contracts where we might sometimes say we're not interested: we're going to be one of five at least, sometimes they're going out to more. So in the past few years with the recession people have just been looking at the lowest price.

I: Can I ask, do you know, if a main contractor comes to you at tender stage, and then they are awarded the contract, do they come back to you and try to renegotiate?

R: Yeah.

I: Yeah. Is that standard practice?

R: It's a…it's not unexpected. I wouldn't say it's a standard practice, and it depends on how…what often happens is that we would put a bid in, say it was £10,000,000, and we'd say that's our best offer. The main contractor would win the work but it wasn't necessarily with a named M&E contractor, it was just that they've used our price. And then they might come back and say 'Right guys we've got the job now, we had to knock £2,000,000 off this entire project to get this job: you need to come along with us, and you need to make some savings and knock some money off otherwise we're going to go elsewhere.' So yeah, that does happen.

I: And would that be through…are they trying to get a buying gain, or are you looking at process improvements and what might be called value engineering?

R: In all honesty it's a buying gain. It might be badged up as something else but realistically that's what it is. The question is then asked, did they or didn't they really knock that £2,000,000 off? Or are they just trying to get some better margin on our package? I don't think that's quite as common now but it's always expected, we do anticipate that happening. And then we have to decide how strong we're going to be and how confident we are in our position, in saying okay if that's what you want then you'll have to go elsewhere then. Or do we – which we often do, and certainly did in the past, because of the market as it was, and we were like everybody else trying to chase work – knock some more money off to get going, and get the job over the line. But things are picking up at the moment now so I think a lot of people now are being more selective, and can afford to be more selective, because some people have gone bust, there are less people in the marketplace, and there's an opportunity to be a bit more selective about your work.

I: It's changing isn't it?

R: It is changing definitely, yeah.

I: Quite a lot of people are saying that.

R: And you can say well actually, if you're going to behave like that, then we've got this other option and opportunity over here, which might not have looked as lucrative to start with, but now you're telling me that, then fine. If that's how you're going to behave we'll go for this one. So we can afford to be a bit more selective now, which is nice: to be back in a marketplace where you can be…I mean if you looked at our accounts over the past few years it's been some economic margins to keep people employed really, so.

I: Yeah. And in this situation you're a subcontractor.

R: Yes.

I: But you've got subcontractors down then line as well?

R: We do, yes.

I: Do you know, ish, what proportion of your work…are you doing direct costs, materials, and then a proportion of subcontractors?

R: Yes, so generally we'd buy all the electrical materials ourselves. So lighting, power, containment, cables, all that: we'll buy all that ourselves through our own supply chain arrangements with lighting companies or wholesalers, like Edmundsons or [Newin Ayres 00:10:23], people like that. And again it's been influenced by the downturn; we carried 200 plus direct employees – electricians and pipefitters – and when the downturn came we had to make redundancies. So now it's picking back up again we're in a position where we've got less guys, so then we are looking at, and we do sometimes, subcontract the labour element: we might employ a company just to come on board and do the electrical labour on a project. As we are over there actually.

Now that might change over the coming years. If the market picks up and we get steadier again then we would probably increase our direct labour force again. That's how we'd prefer to deliver a project, because you've got much better control over the quality, and the people, and who's doing what, et cetera. But you can appreciate that when it turned down, and suddenly you've got 200 guys and you've only got work for 100, you just can't carry them. If they're directly on your books you can't do anything about it, whereas if you're sticking at a lower level and supplementing that with subcontractors to deal with the peaks you can afford to go through a leaner time and not pay people to sit at home, for example, which is obviously a loss of revenue.

I: Do you have specialists that you always use subcontractors for as well?

R: Yeah, that's sort of general electrical, and then fire alarm and security systems – we've at times done it ourselves but generally we would go to a specialist subcontractor for fire alarm systems and security systems, access control – and that would be a sublet subcontract package to the likes of for example an ADT or a Protech or somebody like that, we would use them and, they're a supply chain partner of ours that we would use regularly. They would tender the project with us – I'm jumping around a little bit now – during the tender process they would have anything between three weeks, which is not a lot of time, to five, six weeks, seven weeks to actually…we'd go out to our market and put together the bid. We might go to three fire alarm companies, and at that point then we'd choose the best or the most competitive, or the one who's got what we assess as the right price to use in our bid for the final submission as [SCA1].

But then on the mechanical side we would always subcontract ductwork: that's a supply and install package, the ventilation ductwork. Pipework, again that varies: we carry our own direct labour but we would also often subcontract pipework systems, and we would we might subcontract materials and labour for that as well because there's an element of risk with delivery issues. We can say right, we'll buy all the pipework, because we think we can make a bit of money buying it, we'll supply that for you, but if we're not getting the materials onsite in time then we would be buying a subcontractor for delays and costs for…so often we would package it all up and say you're going to supply it all, keep yourself supplied: and then we would oversee that and manage that and make sure it's being done properly. So yeah, we have a large supply chain. I don't know as a percentage really what we do. I could probably find that out for you.

I: I might come back to you for that at some point.

R: Yeah, just drop me a few questions off the back of it and I'll find out what that is, I'll tell you what that is as a business. That varies from South to North actually as well.

I: Oh, are you in two…?

R: So we're, well, for various reasons…

I: You said you were going through a restructure.

R: No, we're not as a business, just some of the internal reporting mechanisms and the way we do stuff, we're just…

I: Right, so South and North.

R: It's perhaps not linked to this but the recession has hit everybody hard and focused everybody back in on cost certainty, and being more focused on cost certainty, so it's just made people look again at the controls that we have. So there's a bit of a restructure going on with the controls, how we look after things, how we report internally, and avoiding the fact that we're reporting we're going to make a profit on a project and suddenly there's a big overrun and we've lost loads of money. So there's a restructure of that sort of stuff at the moment.

But traditionally, London…we started in Leeds and traditionally directly delivered. So the Northern region has mostly direct delivery with less subcontracts. Ductwork would always be subcontract, and the specialist security and fire systems, but the electrical lighting, the power, and the pipework are all direct delivery. That reduces a bit as you get to the Midlands, and then in London it's pretty much all subcontract, we don't carry much of a labour force at all. That's just traditionally the market in London. In the Midlands now we end up employing subcontractors: so the subcontracted electrical labour that comes on board is often some of the guys that we made redundant in the past, so we know we're getting a good quality labour force, but it's a different approach. So it does vary across the country really.

I: Yeah. And do you know if your estimators work on from first principles? So labour material, plant, and profit. It might be quite interesting at some point knowing a bit more about that? I don't whether that's something – again I could put this on an email – whether those build ups could be shared with me, or an example?

R: Yeah, just to briefly tell you: again, tenders come out in different guises, so you might get a project where you've been asked to just declare overhead and profit and margin, and the way that the client is going to engage you is in what they call a two stage process. There's less of that at the moment. But where you'd come on with a GMP – a gross maximum figure – and declare your overhead and profit, and then you'd work through with the design team from stage D, E, in the old RIBA stages, up to F, developing the design and developing the costs alongside it. All declared all open with the clients. I say open: we'd have quotes to back it up and we'd have take-offs to back it up, and then we'd put our mark-up on it. And the idea of that is that you build up a good, solid coordinated design together. And that works for us, we like those, because we've got almost a guaranteed margin that we can work up.

There's less of that at the moment but that works better with the bid approach, getting us on board earlier and working it up together as a team, an open and honest approach to everything. There's trust, obviously, that gets thrown into all of this. But then what's been more recent has simply been a stage E type design, which is a quantified level of drawings, where we'd literally sit there and we'd count off the lights, we'd count off the power, we count it all off and then we tender against that, and that would be our price. And it would be on a design and build project, so we'd build it up from materials, and we'd have per light fitting – we'd have half an hour or twenty minutes or whatever it is – so we'd build it up literally to that much detail, and then we'd sit in a meeting and we'd talk about the marketplace, how it is at the moment. We would scope that, we'd look at it and say okay, we've got a lighting quote…I mean, we always talk about prime cost and getting to your prime cost at tender, and that means getting the best price off everybody at tender: that's essentially what you're going to place the job at. And then mark that up properly with a margin for overheads, to cover our overheads, and to make a profit, which is what we are all here to do. With some prelims, management charges that we'd put on top as well, et cetera.

The problem is that, we'd love to, but we don't ever seem to be able to get to that prime cost at tender, because it's done in four weeks sometimes. We might get three bits back that are all at different levels and not necessarily get the time to analyse those properly, and you take a view. So you take a view on it and you say okay, so when we get this detail worked up and we get the design worked up more to a stage F, we go back out to those guys and we say, 'Right, this is your fixed product that I want to buy from you now. I've got the job now. What's your best price?' And often you can see a slight reduction in their prices. So we try and anticipate that at tender. We build up the price and then we say right okay, we probably knock another five percent off.

I: As the design gets firmed up?

R: As the design gets firmed up, and when we go back to them and the job's won and they're being a bit more focused on it, and they're having time to look at it, and they're having time to look at…for example on the air handling units, where they can make a few savings on components or whatever. When we get to that stage we think we can knock another five percent off the air handling unit price, so we'd take that off, and that would be what we call our prime cost at tender, and then we'd mark that up. What then happens – and what's happened for the past couple of years – is that we might mark it up a couple of percent, or three, four, five percent, which is not enough for us to make a margin, so then we have to make further gains out of the supply chain. So then when we go back to it we are, we have to, because otherwise we would be at a loss. You know, we have to breaking ten percent to be actually making a profit. So we'd be back at the supply chain then and we'd be looking at reengineering, perhaps trying to design a few things down, reengineering systems, so that the client is getting the same deal of rubble but in a slightly more efficient way for us, or more cost-effective way for us. Client gets what he wants, he gets his output, and we've managed to make some gains to get us back up to a profitable place. Which is a bit ridiculous really – the whole process – but it is how it works.

I: Yeah. It anticipated my next question actually, which was good: we've gone right in the same order. You're describing, once you've won the tender, that you've got to renegotiate the package with your subcontractors before placing an order with them.

R: Yes we do.

I: But you've described doing that on the basis of production gains and innovations?

R: Innovations, yes, production gains: a simple thing might be that the original ductwork drawings show the duct coming into this room and it came right to the middle of the room here, and was supplying air under the floor, when actually we only need to just poke it into the room. So we might save a metre of ductwork. If you do that on 100 rooms then you've saved 100 metres and suddenly you see some savings come out the package.

I: Do you ever see main contractors go through the same process with you? Or are they usually just coming back for buying gains?

R: They might…okay so I said it was buying gains but that's how…they might come back to us and say 'We've got to make another £200,000. Go away and do it.' Then we'd have a bit more time then you see, because we've tendered this job in four weeks, so we've got some more time, so we say let's get the design drawings out now, let's have another look at these. We think we can scope this a little bit, we think we can make some savings on the ductwork. Actually we're looking at how it's sized originally from the consultant and we think we could let the velocities increase a little bit in the ductwork and actually reduce the size of the ductwork a little bit, as well. So we think there are some savings in there that won't affect anybody, and it will allow us to get to those costs that they need us to, so yeah, if we've got the time we would look at that in that sort of detail. But often it's just the main contractor looking to make some gains. It's just how you badge it up really.

I: So you're sitting in your office looking at your drawings to make gains. Have you had much experience of them at that stage saying let's look at it with you, your preceding trades, your following trades, and us as a main contractor?

R: Yeah definitely, they're better and better at that now. Different contractors are different as well. Willmott's are pretty good, they're quite joined up in partnering approach, but then there are others that just want your lowest price, that don't really care how you do it, don't care how you get there, just need to knock another £500,000 off type thing, so. That's a big figure: not that sort of figure, but you know what I mean.

But yeah, no we certainly go to reengineering workshops and the like with the main contractor, and others trades, and how can we do this more efficiently.

I: So there is an area of cooperation?

R: No there is, definitely, yeah, and people recognise that more and more now, that you need to do it that way as opposed to just trying to ask somebody to lop some money off. But I don't think it's…I wouldn't say it's necessarily the norm to do it that way, but it does happen.

I: Yeah. So that's useful. Now this next question is kind of the one that I think I'm probably going to have to…I probably can't actually ask it like this. I'm going to ask you like that.

R: Okay, go on then.

I: The nub of the question is: are bills of quantities providing you with a useful cost model for the business decisions that you've got to make? So whatever the situation you want to do the job with the greatest value and the greatest economy. Do bills of quantities help you in decision making? And I guess it might be worth looking at it as in your direct work, and then your subcontractors.

R: Okay so, having…

I: So you've got the costs of objects and metres, cubes of concrete, do you…I guess the question is, is the bill of quantities a working document?

R: In our business?

I: Yeah.

R: Yes. Okay so I see what you're asking now.

I: I told you the question was wrong.

R: No, I've got it. So we use a product called Estimation, which you may or may not have come across, but that's updated every couple of weeks with the latest rates for conduit, trunking – so if steel work has gone up in the world then the rate for trunking might have gone up from a pound a metre to a pound and two pence a metre – so when we're tendering we would always be using the latest figures that we can buy that equipment for.

I: As a business?

R: As a business, yes. But that would be generally around about the base materials such as containment, metal containment, plastic containment, dado trunkings, the sockets and switches, accessories, so we'd have a rate for that type of switch and socket in the bills. So yeah we would build it up from that. But then a lot of chunks of the work are in subcontract, so that's where we'd go out to the market and we'd get prices from two or three subcontractors. We go through different stages of getting solid bills of them that we can check from project to project. So, fire alarm: we know roughly how much we pay for fire alarm, for a square metre, we know roughly how much a device costs, but it does vary from project to project, and it varies from subcontractor to subcontractor. So we might go out to the market one month and get the best price from Protech and we might go out the next month and get the best price from ADT and we might go the next month and get it from somebody else, because their internal businesses are changing, their margins are…they're looking at it now, 'Actually we need some work so we're going to drop our margin a little bit and accept that we're not going to make as much money on a project.'

So it's a bit hard to get defined bills off the subcontractors, until we get into contract, and then we'll get a schedule of rates out of them: which is schedule of rates based on what they've won the job for. So if they've just won £1,000,000 worth of pipework, that's how much a metre of pipework costs; if they'd won it at 1.2 million, it would obviously be a bit more expensive. If that makes sense.

I: Yeah. And do you hold back your bills of quantities from a main contractor, similarly?

R: Yeah, as stupid as it sounds. We tend to have an aversion to giving what we call a schedule of rates for the contract. Bills of quantities we would never supply – that's the stuff that we would use to price a job – but we would supply is a schedule of rates, which is…in a luxury day where we've managed to mark a job up 50 percent, which would never happen, but if we had, and we'd marked that socket up 50 percent, then they would have that rate. So if they bought them, if there was a variation for an extra ten sockets, we would be selling them at the price that we sold the job at. But on the same note if we'd only marked it up a couple of percent then we'd be selling them at that rate, so there'd be a schedule of rates based on what we sold the project at. So if we've sold it for £1,000,000 and it's got 100 sockets in it then it would be that price for the socket, but we would never declare what we actually buy it for. That's kind of the protected stuff.

I: So you give a schedule of rates rather than a document that adds up to the final contract sum?

R: The schedule of rates would add up to the final contract sum.

I: Oh, it would?

R: Yeah, but it wouldn't show you our overheads and mark-ups that we've put on the product. It wouldn't show you that we've knocked five percent off and then put ten on, for example, it would just show you the final figure as a rate against each item. And that's based on so that if there are any variations or change or cost change on the project then that would be used as the base to measure that change. But yeah the information as to actually how much we buy it for, that wouldn't get declared. That's kind of the sensitive stuff I guess if you like. It sounds like I'm protecting it because we make loads of money, but…

I: It's the opposite actually.

R: You don't need to worry about that. If you've had a building built in the last five years you've had a deal, you've had a bargain, because nobody's made money.

I: [BCU 00:29:04] haven't done badly, have they?

R: You've built buildings at the right time.

I: Yeah, yeah, just like Grand Designs it's accident rather than, you know, it's luck isn't it.

R: Yeah, it is when you enter the market. If you had gone to the market and built these buildings over five years ago they'd have probably cost you more, even with inflation or whatever they'd have probably cost you more.

I: And next year.

R: And in the coming years they'll probably cost you more than you've got – certainly phase one and phase two – because people are getting back to the stage where they're saying let's mark this up properly and actually make some money for the business. We had losses of, last year…we had a couple of real problem jobs, and if we hadn't had had those we'd have made £500,000 profit on £500,000,000 worth of turnover.

I: Hardly worth getting out of bed isn't it?

R: It's ridiculous. Especially when you listen to the margins of supermarkets and things like that, what they make, it's shocking really. And the risk that we carry is massive. We had a couple of substantial problems last year that cost us 6 million so we ended up coming into a 6 million loss for the business. So yeah, it's high risk, but the margins were just not there previously, but they are starting to come back in and we can afford to put them in now and still be competitive. Because everyone's doing the same. All the main contractors now, and the main subcontractors, have gone this can't go on, we can't continue to do this, we're all fighting each other, causing ourselves problems, and then we're trying to understand why we've lost money: because we've taken the work on at sub-economic rates. Can't deliver it. You can't deliver a quality project at that low a price.

I: And have you got a sense whether demand is increasing or people are leaving the business, or a bit of both?

R: We're pretty good at retention actually. I did a training course yesterday delivered on preconstruction, there were only ten [SCA1] guys and I don't think anybody was less than 13 years' service. There was a 23, there was a 40. So yeah, we have got good retention, but there are opportunities now though, you're getting the phone calls again now: 'Would you be interested in coming and having a look at this?' I had one a couple of weeks ago for a project manager role for another M&E contractor, and the wage was relatively attractive actually as well. For me phase two over there is 15 million give or take services, this was for a £6,000,000 job, so a smaller job, less stress, less strain, and it was more money than I'm on.

I: Yes, that's a real example of the market picking up.

R: It is picking up, definitely. Certainly in the Midlands as well, noticeably in the Midlands compared to the North, the North is still struggling more. And strangely for us, London; but that's our business model not so much the market down there, because that's not really changed much I don't think. But yeah it certainly is picking up, from what we can see, which is good news for us all really.

I: That is good news. In terms of the costs again – again I'm not sure if this is worded right – when you go through the project, and at the end of the project, does the business record actual costs? Well there are wins and losses to assist decision making, but I'm not thinking of the big wins and losses I'm thinking of an analysis of where those wins and losses came from.

R: Yeah we do some, but not as much as you'd have thought we would.

I: No. That kind of leads on to the other things in terms of your direct production costs. You can use activity based costing, which is quite an intricate allocation of costs, to capture true costs. Do you know if the company has done any of that?

R: Yeah, we have. Under the banner of BLIS: [SCA1] Lean Implementation Strategy, which was essentially best practice. We did a load of videoing and value add and value analysis basically, as we call it. So there's value add, which was actually screwing something to the work phase, non-value add, which is things like putting your steps up to get to the work phase, sorting your drill out, collecting your screws and your nuts and your bolts – so it's not adding specific value but it's essential to the project – and then waste, which was going to the toilet or stopping and smoking a fag, that sort of stuff. So yeah we've done all that, and your value add is really about 38 percent. There's a lot of analysis on that.

I: I'd like to come back on that as well.

R: That sounds inefficient but it's not really, it's the actual…the industry norm is about 40 percent, of actual value add.

I: Because part of it, I also wondered whether that recorded transaction costs? So the costs of controlling work between companies.

R: Explain that a bit more, sorry?

I: So you've got the costs of your guy going in there and being self-contained, would it also have recorded the costs of where the previous trade has run over therefore you're late, things like you having to build in other people increasing your waste?

R: Not enough. This is where we kind of price that value loss in our rates. So when I say it's half an hour for a light fitting, in the nicest project where everything is clear it might take you 15 minutes, on a bad project it might take you 45. So it's in with the rates, but not broken down.

I: Probably not recorded?

R: Not really no, only through that process, but then that's not necessarily…the concern for us with that was let's get it all broken down and then that means we can work out exactly how long it takes, and if you do that then you don't cover off the inevitable inefficiencies of a project.

I: Okay, yes. So you haven't done any analysis of that but you are aware of it?

R: Yeah.

I: And it's in the rates?

R: It's in the rates, really. Our rates include for those inefficiencies, but they don't always cover them. It's a nice thought that a construction project is a factory where…but it's not, it's not that, it's not a car plant where you've got a box of bolts here and it's always the same every time. The efficiency they're up at 70, 80 percent, 90 percent value add, but we're never going to be able to do that, that's not how construction works. With far better planning, detailed planning, and coordination, it can increase, but that then comes into proper joined up planning with the main contractor. People getting things finished when they say they're going to get them finished, no delays, no issues, no getting to site and then something on a drawing works but it doesn't quite work.

BIM is one thing but we've been 3D coordinating for years, for tens of years, so there would be a space in the corridor ceiling, we know how big a duct is, and the pipes, and the containment that we've got to put in there, and we 3D model that – and we've been doing that for a number of years – to make sure that it all fits, and then invert level drawings produced from that that we can install to and be comfortable that everything fits and is all coordinated. Which is what BIM does as well, as part of that element of BIM, but it still doesn't stop the fact that that wall might be a day late in being built. The guys go over there to do something over there and then come back to there, and to analyse a project in that much detail, to actually track it properly, is a monstrous task to do.

I: It is, yeah. This is a rhetorical question but I guess what I'm trying to get to is: are we costing what we need to manage? Those interfaces between different companies, they are a considerable amount of the cost within it, is there anything in there that cost information would help us with decision making? And I wonder whether, just to kind of illustrate that…what I was going to ask you about – we'll come back and do these with David another time – was key relationships for your company, and how affect collaboration, and then what the main contractor could do to help you manage your work more effectively? How your company incentivises your own direct staff and subcontractors, to incentivise value and economy? But then the last question, which might be worth just spending the last five minutes on…

R: Yeah I've talked a lot, sorry.

I: No, thank you. The last question that it leads up to is wondering whether…the question was going to be, have you ever worked on a project where there's a third party whose incentive it is to achieve total profit maximisation?

R: No, no I haven't.

I: That's kind of the concept I'm trying to get to.

R: Well, I say that…where did I… Hospital, I did a project there and that was on a pain gain – I can't think of the contract terminology now – so the main contractor, the subcontractor and the M&E contractor and everybody would go in, and the project aim is £40,000,000, that's what it's been tendered at: if it comes in at 38 million then that two million is shared between the client and the main contractor, and everybody gets an allowance of that. The problem with that is that if it comes in at 42 then it's still our problem.

I: And did you find that altered behaviours, collaboration?

R: It does actually, because everybody works together to get their own. But it has to be so open…it still promotes your own internal gains a bit as well, because it can…and also there's an element of if you spend it all then actually you're going to get 12 percent margin on it because it's an agreed margin, and actually that's pretty good. If I'm making 12 percent on that I'm happy anyway, so the benefit of the reduction is not actually a major benefit.

I: Okay, so there is still a doubt of whether everyone is putting enough in or if anyone is taking too much out?

R: I think so, yeah. I'm not overly experienced in that, but I would say that that's probably the case. But those sort of collaborative pain gain projects and contracts are good, we like working on those. Also again normally they have an associated agreed margin on them which we get paid. Obviously if that took us over the 40 on that project then that would still be a risk and we'd lose out, but the margin has been agreed at a good margin – or the right margin if you like – as opposed to a project where we've got no pain gain but we've taken it on at five percent mark-up because we think we might get some betterment out of the supply chain, but we don't know.

I: Yeah, so that pain gain is overt in this situation whereas it isn't in another.

R: Yeah. We take a risk with those percentages that we knock off, so for example on phase two over there we took a view on the ductwork – we've talked about ductwork a few times – and we knocked a chunk of money off the ductwork because we thought we'd be able to reengineer that, make some money out of it, but we've ended up costing us a large chunk of money more than we included, so it's costing us to install the ductwork over there and we're supplementing the cost for it. But that was a risk we took to win the project on the competitive margin that we did, whereas in that type of contract we'd have just had: the ductwork costs 500,000 and we've got an agreed ten, 12 percent margin on it. So actually we're quite happy with that, which works better than us trying to…on the off chance that we might knock £30,000 off the ductwork – that's great – but we might also lose. There's a lot of risk with the general approach we take but a collaborative approach is far better for us, we much prefer that, and you get a lot more out of the supply chain in that type of approach. If everybody's comfortable they've got a protected margin they will work to reduce things, they will work to it. Whether it's a complete driver, whether it needs another mechanism in there, maybe, I'm not sure. Like I say if you can spend 40 million and make 12 percent on 40 million why try and spend 38 unless there is some real gain out of it?

I: Yeah, and I think it is the costs between companies, potentially there might be some leeway in there for…because everyone's taken out as much inside companies as they possibly can, and will continue to do so.

R: Yeah the intercompany relationships and efficiencies. The key one, the one we get most of, is the main contractor is not completely ready for us in areas and we work around…so they've managed to do most of this floorplan, but they've had an issue with this wall so we can't quite finish there, so we have to go off somewhere else, and then come back, and why haven't they done it? Because there was a bit of a design issue, or something was wrong, or when you got to site actually it didn't quite look like everybody thought it was going to look like, and there's an issue. Something it out of tolerance, some bloke had three days off because he was sick, you know, whatever it might be. And it's never simple, it's never that run of cars going along the line. If somebody is off sick there's somebody else to step in his spot: if he's off sick then oh God, it's going to take me three or four days to get somebody back to do that. All those sorts of things make for inefficiencies, along with hundreds of other things, so.

I: Yeah, makes for inefficiencies, but flexibility as well.

R: Yeah, you do have to be flexible, otherwise you wouldn't build the thing.

I: Okay. I think we should probably leave that there for today otherwise you're going to be very dry, aren't you?

R: No, that's alright.

I: But thanks ever so much for that. Is there anything else that you wanted to add at this point?

R: No probably not, no, I'm quite happy with that, the information that we're sharing is quite good, I'm more than happy with that. For me the whole process of BIM, it is potentially an issue for us as a business and also potentially an issue for consultants as well, in that actually involving the M&E contractor earlier in the contract – because traditionally you've got an M&E consultant who does the work up to stage E, and then he hands it over and we pick it up and do F and deliverable – so it's either we come in earlier and work with the job throughout, or they come in and deliver it all. And then if they're doing all the design then do you really need an M&E contractor? That could just be a main contractor, they could just go and employ the guys to build on those drawings. We like to think we bring a lot to the table so we like to be involved earlier in building it up. So the whole BIM process is great, but then you get the divisive costing issues.

I: That's right.

R: So brilliant bring us in earlier, but how are we going to work up the costs then if we're involved? Are going to do it on an agreed overhead and profit margin, which is good, we like that, but the obvious bell that goes off in the client's head is then is this going to cost us more money than we could actually get it for if we just went out competitively? But is it going to get you a better job? Well, yes it is: it's going to get you a far more coordinated project, with a team that's well involved, and everybody wants it to succeed, than it would.

I: So the question is, can BIM create ways of trusting and sharing whilst trust that everyone is delivering value?

R: Yeah, value is the key. But then you'd pay more for a Sony TV than you would for a Matsui, you know? You accept that if it's in my budget I'm going to get the best I can. So if a client has got a budget, which he often has, if he can get that capped, and he's happy that that's all he's going to spend, then why not get the team all involved, collaborating together, build up the cost to get to that and say right, it's still within cost, that's great.

I: You can have that Mitsubishi, you don't have to go to a…

R: Yeah you can have that top-of-the-range, you don't have to go out to the marketplace and band it around. And actually if you band it around the marketplace you might have got it for half a million pounds cheaper, or a million pounds cheaper, but have you got the best product out of that? Has everything gone well, has it gone smoothly, has everybody been working together? Probably not no, because it's all been fought and everybody is fighting to make an extra couple of quid where they can because they've all taken it on at lower rates and had to do it competitively like that, so. I think if I was a client and I had 40 million to build a project I'd like to do it in a collaborative manner to get the best that I can out of it as opposed to I might get it for 39 million but actually…but obviously the money people see that don't they and that's a million pound…okay we've done it, well done, but in the long term you're going to get the best project, you know, and is it going to cost you 39 and a half in the end? Probably, because of change and the issues that occur on site, because one of your subcontractors is going to go bust because he's got no margin on it, and he's losing money? Maybe: certainly in the market as it is now. I'd like to think that's the right way to do it, and this drives that, so hopefully in the long term this becomes a more collaborative approach with costings as well.

End of transcript

A2.3

Field notes (example)

6.6.14. [redacted] Medical CRM.

2.20pm - D&B basis contract...
perf spec to be satisfied.
[redacted] Architects work to [redacted].

Design dvt cost vs details not provided at contract. eg twice as many brick panels as contract... not shown as changes on building

materials ordered to latest dwgs - effects thermal modelling + planning.... the time to change is past... meeting monday.

levels of PI against original contracts loosened reqmts.

[redacted] facade engineers

warranty tracking

[redacted] Rehau, backfilling to do (groundworks)... extl wks, drainage, tanks, BT infrastructure... not difficult ... not resource hungry... non-critical...

Taking materials out.... doors... gone out to other subbies... joinery package, lab, plant, mats split. [redacted] building products 40% of our work ... Construction Services... might loose saving if goes to a labour only contract.

Richard ... [subbie] is superb ...
worth asking if we can keep him
on the contract ...

WD providing skips & taking everything
away ...
[redacted] will take only his own stuff off site.
(floor tiles).
BG will put a skip here & take away
packaging.

March to June 13 quotes. Quotes up
25% all 3 for feature staircases.
(Architectural metalworks).

feedback to pre-con how much subbies
are uping their price.
Ask for help to procure at this price.

Lag between quotes & orders is great
& a significant period of time.
AH has buying analysis to guide /
use in conversations ... we need
some help ... site staff do 'final
buyes analysis ...

3PM sub-con proc schedule

Take out traffic signal & buy
direct as order with subbie
not yet placed. Benefit? Or,
progress order early ... when up
against WD proc process ... please act
on ....' the only thing outstanding
is the order notice.

3.20 design programme... are we buying on the right dwgs ? Details need checking... not highlighting changes on dwgs...

shouldnt put new stuff on dwgs

or flag it up and it will be.. then...client or us... will be building on a construction issue dwg....

will procure against these dwgs... will pursue you for addl cost...

if we procure stuff we havnt got the money to cover... we will charge [redacted]....

3.30 overall tonnage of reinf... [redacted] said scope to reduce tonnage in reinf... in pile caps etc... if its £50K saving we owe them £10K of that...

3-5 weeks behind drawing issue... looking at internals...

Ed right level of resource on site ?... to check drawings + train Scott... pinch point this month... [redacted] not marking up drawings... adding IOWs.. if dont change... well put checker on & charge them...

3.40 window post details... generic only received... not what was requested... get freelancer... share the cost to [redacted]...

scaffold package facade + bwk
may provide their own... WD are
particular about the scaffolders
we use...

bwk, plastering + metalwork - pressure
on price increases... might have a
opp with one metalwork subbie.... to
be within price

How to nullify this? unbundling?
Can't do unbundling on <u>bwk</u>.. part
changed to a more expensive brick...
to match bk slips.... which would be
more expensive to change...
1 price on <u>ptns</u> so far.... rationalised
boarding ∴ expected to go down...

[redacted] are there any new names?

[redacted] [redacted] insulation will offer a full
package ... [redacted] screed doing ptns
again... but screed lower risk
than ptns... MEASOM... might
want the work...
value, past performance

[redacted]: All regular people know who we use...
don't want to have the usual 3/or 4
who know each other... they may
say your just using us as a
price check... Cat A think they
should be guaranteed work...

did a great job at [redacted] around
rooflights... [redacted] makes sense to
leave job with them...

getting design mgt right now is essential to how the job goes... got a plan now...

3.45 ... debate about how far we are behind... I'd say minus 5... First floor slab project ahead... would be 7, but think we can pull it back...

[redacted]: go with minus 5....

3.50 Financial... BWK + £84K... is abbie whole package, lump sum likely to give best price...
plastering + drylining.. hope to reduce plbd wastage... spec change... get subbies involved... [redacted] been told we've got big pressures on this job..
[redacted] will come up with value engineering... so long as our architect will underwrite it...

Ed: can't run away from it. Thats where we are...
AFR... anticipated financial...
without £245 design mgt pot...
ptn + bwk will be a struggle...
optomistic £1M - £1.1M. but gut.. £1.3M...
25% of value still to procure ≈ £6M...
subbie packages £2M... have some room to manouvre on spec...

AH: taking longer on procurement trying to pull back... site mgt time being sucked up by [redacted]...

not paying [redacted] or [redacted]... spend is therefore down... spend profile & programme... not achieving..

4.05 [internal site resources]

4.10 plant:
hiring a Theodolite... levels checks...
Ed ... bad habit hiring plant...
cube testing... Metropolitan cost
huge... [2 people] trained...
to compact/make the cube...
revisit the onbunding.. substantial
costs & risks...

Request from Uni for extra hoarding..
for fundraising... paid for from UoL
marketing budget...

AH: pressure on prelims?... only
overrun...

[redacted] moving to site &
place them upstairs?

4.20 Environmental:
Rehau close to roots

Ed: 10 point plan...

records + photos: daily... helpful
for Tin Bats... showing Tin Bats.
and keeping daily diary...

AOB: trying to find somewhere to
store materials off site...
agreement signed...
what can we store there?...
depends what insurance covers...

A2.1

Workshop transcript (example in extract form)

WORKSHOP TRANSCRIPT (EXAMPLE IN EXTRACT FORM)

TA: There were scheduling problems with regards to...it's what the guys call the wet trades, it's always the painters and the plasterers. And those guys are often working on a price when the other trades aren't. So they'll just come in on Phase 2 here, you know the situation where the boarders would come in and they would board an entire flat wall, because it's quick to do that and get it boardered and plastered, and they'd bugger off and to another flat wall somewhere else, and they'd leave all the edges and all the difficult bits. They'd just get it all closed up, the ceilings would get closed up, nothing like what was on the programme that they were scheduled to do. And of course, all of our containment is behind those walls and ceilings. And so then we have to try and get things cut out, get a hatch cut out. These guys, they won't do it for you, you know. I waited nearly two months to get hatch cut out in one place and needed to wire through. So that's this issue with these jobs on a price, jobs on a day rate business, which, I don't know...

TA: Whether that...I would hate to say to any guy like stop selling jobs on a price, because this is how they make their money. It's certainly an issue with regards to screwing up the whole management of a large job. Without a doubt, I think that's one of our biggest problems.

AR: Would you be aware of that, would you say? If that was going on?

CH: Yes, I think very aware. And that is a sense of reality of what happens on projects. But there are other things behind that, that can make that situation clear, because we are sort of picking on a boarder at there, but there could be some issues where design doesn't show that access hatch there, because I know there was lost access hatches missing off the design. So your level of payment and, you know, you're thinking what's going on, is actually, there could be a number of different scenarios rather than just a boarder going in there and boarding it and you walking...so it's about perceptions as well, you know, which is interesting to hear from my point of view.

DB: Or a lack of transfer of information. That's the opportunity...

ML: A job's design information, that sequencing, design information, sequencing or it also comes back to money physically in point, if a job is going bad and the main contractor hasn't got any money in his job, and he's losing money then they need to throw a couple of guys at it, because for whatever reason, design, whatever, to get you an access hatch, this is my perception, and I don't know if it's true, nobody wants to invest, say right, the right thing for the job is to get an extra couple of guys in, put hatches in and go and do that, just throw...we need to push that in. For whatever the reason is, we didn't plan it properly to start with, you know, whatever was done wrong to start with, that shouldn't have gone wrong.

PB: From a builders point of view, do you sit there down with Baileys or your mechanical contractor and go two-week, four-week, look out in terms of we're in...I know there's a programme which says where you should be, but in reality, if you sit down, say where do we board in, that room, that room, that room, these guys know if they've got to get primary containment beforehand, they've got to be in and out of there in a timescale, rather than, as Tony says, a boarder turns up and goes, right, I can get more out of doing that wall today than I am going to do that bit there.

CH: There's...yes, is the answer to that. Sometimes you get 100 per cent buy in from people, sometimes, you know, that gets slightly diluted. It depends how much you care and how much passion is into doing what you want to do. But there is, you know, there are lots of other factors at play here. And if we're looking at

[Client] too, particularly, there was probably the starting point in all of this is a very poor BIM model that was handed over to Matt. So if you're looking for root causes, where the markets gone wrong, which then Matt's team reviewed it and quite rightly so, said we can't take this on. We've got to develop it again ourselves.

PB: It was a lots of design changes within the first three or four months.

CH: Basically, rip it up and start again from scratch. So there was a lag in information, and it was very much hand to mouth, wasn't it? Which is what we were suffering from as a team. The decision was the right decision that Matthew took to actually just...we could have just run with it and ended up with lots of really bad coordination.

ML: Yes, I agree with that.

CH: Which would have...yes, so I'm just sort of winding back to...

CH: If you wind back to starting points rather than going through the information flows key, without the information flow, you're living from hand to mouth with things, and things are happening, and then rework happens, which is loss of productivity.

DB: So the design was impracticable, the consultant design, and it won't go out from here, we're not taking anybody to court over it.

CH: It's fine. I would say that

ML: That's fine, but then it's a design and built contract, so it's our responsibility.

DB: Right, I see. Because of the nature of the...

ML: We were sold on the fact that that model would be fantastic and we could just do it like that and use that. We couldn't. A big improvement, by the way, this time, if we had it now, off the same consultant, it would probably be close to usable. So yes, there's root work. But there should be time to do that. We should be able to do that. I'm trying to think back, to be honest, I can't remember as well as Chris, but some of the design information wouldn't always have got there straight away, we'll have trouble in our design processes, as with the architect, all that sort of stuff. Not having enough time to design...part of this comes back to the contractor being involved in the consultant stage and, you know, you don't need to let the consultant take it that far. We can come in earlier, and we can design a practical, deliverable job earlier in the stage than they are. But yes, there are changes.

But then there's also then the fact that you're trying to make some money in that process, so you get re-engineering things, so you hold off on decisions, so we might not...I don't know, a section of valves, we might not set the valves straightaway, because we might be negotiating with a couple of valve suppliers and what's the best solution before I change the valve arrangement? So we might go from split talks about them on electricals. So two valves into a new combined valve they're doing on the market because that's the cheapest solution. We're going to go through a texting process to get that approved, gets approved, brilliant, we've made ourselves a few thousand pounds, but it's messed up the BMS control process and their designs, there's a change in that we don't always comprehend. I can see all that, definitely, and why that would affect it. That's because we're changing the designs and still designing too close to the delivery, I think.

TA: And then you throw a few more things into the mix in that, which is what you talked about, you agreed a lump sum, I'm guessing, on your work, whereas boarders are on the measure. So it's all about productivity. Every day they're on site, it's about how much meterage they can put down to make their ends meet at the end of the week.

DB: For cash flow.

TA: That's what they care about. You know, that's their cash flow to pay their mortgages and so on and so forth. And sometimes you have to step back and have an appreciation of that.

ML: Why, though? Why do you let it like that? I'd measure it, I don't get that. I don't get that at all. Because the impact of that, you talk about all the design stuff, the impact of that, we don't issue in that corner.

CH: Yes, the problem that we've got is the levels you were talking about, where to...so we would negotiate with you, we've got a job this come in, it's a blank piece of paper, we'll invite our trusted M&E contractor to come and sit side-by-side to us and negotiate that project. What happens then, it gets diluted. You talked about that layer by layer by layer. So we enter into a lump sum with our dry lining contractor, which is essentially negotiated to a lump sum, and then they go away with their black book of names and sub it all out, and they sub it out, all to make money.

ML: You're not talking them into finishing that wall and finishing things as opposed to meterage, because day-to-day, that's some of our major problems, is things not being properly finished, so they go all the way... they go and to do that, plus the hole where they won't box that column in, because that's not boxed in, we can't finish the dado round it and the lights. And they won't come back to that, because the again the meterage, which is I guess what it's worth me talking about. But we can't finish the dado...

CH: Yes. Just putting it into context, they don't go and do that around the whole job. There is a process, which is a first fix stage which we all know about. The metal, they board it one side, we then as you guys come in, put your containment, put everything that you've got in the wall. In an ideal world, we sign it off together, it gets back boarded, nothing is missed in there, and that's an ideal world.

TA: Yes, that's the theory.

CH: When you're under a lot of pressure time wise, things like the ideal world sometimes get forgotten about. For whatever reason they do, and it creates more problems, to be honest with you. And this is what I'm saying, if you truly believe in what you do, but sometimes that gets diluted by your management chain as well my side. You know, and if all people then dilute it when it suits, when their costs are going up and what's coming in doesn't start in their costs, it then changes people's mentality.

ML: Yes, I agree.

CH: And it's all about driving back to how do you get to unlocking that, which is what you're here today to discuss.

ML: Yes. If you can get to...if you can get the building fully designed properly that's an easy...you know, we all know exactly what we're building, great, if we can get that point, but they're such complex beasts, it's not a car that you're putting the same thing on every time that were talking about. So we can get to that stage in a BIM model, and you've had enough time with the constructors, with the guys who actually put it up, and that's the best way to do that, we're going to do it like that so you get to that stage, that's fantastic, and then it comes down to sequencing, and actually hitting your sequencing and doing your handovers, which do fall apart because if somebody hasn't quite finished something and I can't come in now. I shouldn't come in there now, but I can do loads, but I can't quite do that. So what happens is, we go in, we do loads. By the time we get the end, it's still not done, so we don't finish either.

So then you've got, so using that column as an example, the plasterwork, and the plasterboard is not round that, so we go in there, we do all the dado on there and we stop, because we've only got a bit to do. And we leave, because the plasterboard didn't get done in the meantime either. So then somebody's got to come down back and to the plasterboard. Somebody has to come back and to the dado. And actually then your wiring, and you get to there and you …because we still can't finish because the plasterboard...and that roll-on constantly, and it's all sequencing then. So what we should do, really, is say no, we're not coming in. We are not coming in until that plasterboard is finished. Then it's done, hundred percent...

CH: Absolutely right.

ML: The plasterboarding.

CH: I suppose just putting that to you guys, so how many, at peak, general...genuine operatives we have, fixers, installers, electricians, plasterers, on this new place, what do you imagine the peak would be?

AR: Numbers?. Yes. 500.

CH: Probably a little bit over, but not far from. So you're looking at as it's absolutely, give us about 395 people, that's 395 people, and then how many managers from [MC] do you think were controlling 395 people?

AR: Four. One to 100.

CH: Not far off. Probably about five. But there's a message there.

ML: Sub managers. As in industrial managers.

TA: Yes, there's a message there. That's cost driven.

DB: But also, in a sense...

TA: These processes that we're talking about...

dB: Yes. You can see why they get...

TA: So you've got a building that's circa about 24,000 square, and you've got 390 odd people in there, and it only takes that one person to come and see one of the managers and say, I've got a problem here, it takes an hour and a half of his time to sort it out. He's got this to do, he's got that to do. We talked about health and safety. Health and safety is the absolute number one priority for these guys. And you think about their day job and what it looks like now, and it's fairly hectic. And that is because you're driven to a price, whereas in this, today's market, if we are pricing [Project x] again, we would put in double the amount of managers in there, and we wouldn't be afraid to do that, because if it's not on the right price and the right programme, we don't want that on our books. We simply do not want that on our books.

AR: You've worked through booms and busts. Have you seen an appreciable...is there an appreciable difference to your work day-to-day in a boom or in a bust?

CH: In terms of...?

AR: Does price solve all of these problems?

CH: You mean are things better managed in a boom period?

AR: Yes.

CH: I don't remember the last boom period.

ML: This one's been sort of...

CH: I really can't say, I'm sorry. I'm not sure.

ML: That solves the fact that most of those problems come from the facts we've either not designed it effectively enough and co-ordinated it effectively enough or we've fallen out of sequence and we're not getting back on sequence. Those are the two.

There's a number of things that play. But the money side deals with the fact that we haven't designed it well and we haven't contributed well. So a job that might have made X amounts of percentage only makes this much percentage, but in a boom, that lower percentage is still acceptable. And we've been there, and we look in jobs...I look back at jobs and think, oh, we made a good percentage margin on that, we did really well. But actually, what should it have made? And been more effective at design coordination and sequence.

CH: If you look at using the two billions in comparison, Parkside and the Curzon building, the Parkside building is a good success in terms of design, the design was good, the design was handed over to you well, it certainly didn't have the issues that were going through it. And yes, generally, if you were to take which one up to, Parkside, you know, we didn't make a lot of money out of it, but we made some money out of it, and I'm sure you made a little bit out of it.

ML: We made more than we thought were going to lose. It didn't lose as much as we thought it would.

CH: The Parkside building, it was built during the recession, but it wasn't built in a rising market, and that's where we had the issues with the Curzon building. So we won it at the bottom of the market and tried to construct it in a rising market.

ML: We went in there ready to see their margin, and finished at an increased margin, but that was only because we went and beat you up, and you went and beat him up, and everybody beats everybody up...

CH: That's the net effect.

TA: Yes.

ML: And then certainly didn't do as bad as we thought we were going to do, but we didn't clear overhead on Parkside.

AR: They are. And I think within all this, we are looking at...so you mentioned it earlier, Chris, about information flows. So Tony is doing his task, you're trying to put something in, a riser, but everyone else has got a task to make Tony's task happen. And all of those tasks come within a process. So the process is interrelating it all. So within that information is flowing. So I wonder, perhaps starting with you, Tony, what...is there stuff that you know about your task, your situation kind of day-to-day, in fact you think others should know within the supply chain that would help you to a better job?

TA: Well, access to the area that needs work, work at, is essential, just to do the job. Which means that other trades can't be there in that area just doing their job around it, or trying to install contained it in a wall, that wall has to be there already. But where that information comes from, you're asking...you can't just cut, you generally just have to figure it out for yourself on site. Because there is a schedule board, and you can get to the floor and it's not...

AR: Who's schedule would you see? Would you see [MC’s]

schedule?

TA: I don't know exactly where it comes from...

ML: Depending on how well coordinated we've been, it would be a combined services and build scheduled THB.

PB: Tony's information flow is through two roots, there's the information coming from us saying you've got to get from Point A to Point B, and then there's the physical getting from Point A to Point B.

TA: Yes.

PB: I would imagine some of your productivity is to get to the far end of the building, you can't just walk straight across the floor when someone's putting a screen down three floors across the floor, back down...

TA: And that's the nature of the job. I mean, you can't expect everything, you know, is that there's 300-odd guys on there, and they're all different slightly jobs in slightly different places, so it's the nature of it being in construction that you have to work with that.

DB: You were sort of saying you don't quite know where the information comes from, you know, the time you've got to do this job, presumably you're told something about that?

PB: We'll say to Tony...we need to wire and HU number 6 from the panel. That's where we...

DB: So you specify tasks at that level?

PB: So that would be his task for this day

DB: And Tony has to decide how to do that? So you need information about...?

TA: Based on the other information I get from the builder, yes.

DB: Yes. You know what sort of air handling unit it is beforehand? Would you prepare before, or do you just turn up, have a look to see what sort of wire you need, what sort of...

TA: I get all that information from ABEC, yes, the specification, what's required, for the air handling unit.

ML: So ABEC have been told which HU should buy it in, where the panel's going. The notice on the panel, that's on the cabling, et cetera should all be ordered, if everyone's done their jobs properly, and be on site ready for these guys to install.

PB: We've got to make sure the panel arrives in time so that when Tony goes up there to deliver it, to install it, it's physically there for him to wire.

ML: At that point, there's got to be a wall to put it on, we've got to...it's quite a good example, because there's less, actually left less build sequencing on a roof, because once the roof is ready to go, it's all services related. So it's all comes into sort of our free realm...

TA: There's no painters and plasterers up there. It makes it simple.

ML: It's simpler, but we still have problems, because the panel doesn't get manufactured in time and it's a bit late. I then get my containment, so something happens, you know, there's so many influences, you know, we are buying bits from everywhere. If suddenly the market for contained basket trade, there's a shortage, oh no, we can't get any on site, so we can't finish the containment, so then we can't get the guy who's welding the brackets that's on the roof....

DB: You do quite short ordering of materials?

ML: We can do. For some bits we could do, yes. We wouldn't have stuff just sat around waiting to go. It's brought to site.

DB: Do you order every week, or...?

ML: It depends. Containment, we will bulk order, as a containment, but it's kept with the wholesaler. When I say it's kept with the wholesaler, it suggests that they've got it all on the shelf...

DB: And you just call it down?

ML: Yes. But no, they tend to be somewhere else.

DB: They use it as part of their stock?

ML: They'll cast that off to somebody else. So suddenly you go for your call off and it might not be there. We get a delivery from site and it's missing.

DB: Because on most jobs you purchase the materials?

ML: Okay, yes, sorry. So I'm talking general containment. But then these guys purchase.

DB: I'm just wondering what Tony...?

ML: So we'll do primary containment, but then the BMS company will do their secondary containment as we described it. So we do...

PB: We would know the way the building's phased, we're going to do that HU this week, that one in two weeks' time, and that one in four weeks' time. We would only have the panels built in readiness for being delivered. We wouldn't get them all manufactured and stick them in a warehouse. Tony then says, right, next week I'm doing that one, so I need to order materials X, Y, and Z so that it arrives on a Monday morning or whatever it is, so he's got enough materials to do that work.

DB: So it's about a week ahead planning for this?

TA: It usually is about that, yes.

ML: If we had a programme that was in-depth enough that covered all aspects of that sequencing, then...and we stuck to it and delivered on it, and you're planning to be six months ahead, when it's not...

DB: You could order it to the programme rather than order it on request?

ML: Manufacturing facilities, so you wouldn't...okay, so...

TA: Yes, turn a construction site into a factory.

ML: Yes, it's the dream world, isn't it? It's got all of it attached to it and you can press sequence button and the stuff starts arriving because it's all gone to the manufacturing facility...

DB: And obviously, we aren't there at the moment.

ML: No.

DB: And no one would trust us enough to do that, because you would have nowhere to store all this stuff arriving. And it would get damaged, and all that sort of thing.

PB: The issue is not with deliveries of materials, is it? It's actually getting them physically installed.

ML: Yes, normally.

DB: That's interesting, actually. So materials are sort of okay?

ML: They can be a problem, but...yes, normally the issue is associated with, for us, is the fact that a work face is not available or not available in its 100 per cent...

TA: Yes, that's my comment.

ML: So taking it both from Chris a little bit at the moment, another project we'll working on at the moment, they can't get the block work walls ready. So block work walls are supposed to go up and then we come through with our services, so you look down the corridor, on any of the corridors of the moment or any of the walls, and they're 90 per cent complete. So we can only do 90 per cent of our services. So we go home, we stock, and we have to go, we go somewhere else. So the immediate knock on, on that particular job there's a bit of concrete that they haven't made up, that bit of concrete that they haven't completed is the bit between the riser and the floor boards. So I can contain the riser, I can contain there, but I can't link the two.

TA: I had trouble like that as well today.

ML: No, mine's in Birmingham. But those sorts of sequencing issues are extremely common. And I think generally the M&E, we kind of...I would say this, I know, and I'm ready to be shot down, but I think we know pretty well what we've got to install and how long it takes to install it. I think we are better at that, if we think something is going to take two weeks, we'll do it in two weeks, by hook or by crook. I think the problems come with plaster boarders and bricklayers. I don't know if that's purely because of availability of people and bricklayers are notoriously hard to get hold of, or whatever that is, but we always have a programme that's got three weeks in for a brick wall, and they're still doing it after five weeks. And I don't know what the fundamentals that are, but those are the key issues that we have. And I'm putting that back to you now, Chris.

CH: I think you're working on unknown, if that makes sense. You've got a set of drawings, you've got the corridor, you've got rooms, you know, providing those walls and things are there, you're absolutely right, you've got an unknown quantity of what you can to and how quickly you can do it. When you start dealing with complex groundworks solutions and things like that, you're opening up to find a lot of unknowns, and throw in a bit of bad weather with that, poor performance of a subcontractor, or poor design, and it's very difficult during those stages. And then you've got to put a frame on top of that and then start unlocking these work faces for you. And there's a lot of...yes, we deal with a lot of unknowns, that is probably what I'm getting at, before we get to you guys and we go, ta-dah, there you go.

PB: The boarding and the block work one for me is always in confusion. Because that's pretty known, if you like. And I wonder if we don't think through the sequencing of that enough. And I'll give you another example in a job, and it came from [Client] actually. I talked to the builder about sequence for a room, he says right, okay, what we're going to do, we going to get the plasterboard in, blah blah blah, we'll put the lights up, okay, yeah, brilliant. Then we'll get the chippie in, and I was like, okay, we've got to be careful with the dust after lights. And he says yeah, yeah, that's fine though, it's only a bit of architrave round the door and that, that's fine, we'll do the door. So we'll do the chippie afterwards. I said, okay, right, fine.

So concrete slab with plasterboard walls. I said, well, you know when you plasterboard walls, the slab, what do you do with that? Oh, we'll probably need a bit of a skirt round that to hide it. Okay, I says, but how are you going to do that? Oh, probably a bit of timber. Okay, so at this point now your chippie comes in after all our lights up and all our chilled beams are up, how are you going to get up to that? Oh yeah, we need to do that before, aren't we? And they just hadn't thought through that process, and they never would have. They never would think that through, and it wouldn't get...gets to the plan on site, what of it?

CH: Was that one or two?

PB: Sorry?

CH: Is that on one or two?

PB: No this wasn't...it didn't happen with [Client]. I know, because we caught it early. We picked it up. But on this job they hadn't. So I took that learning to that job and they wouldn't have thought it through until we came to install the lights and they'd go, well, hang on, stop. But with one programme to install the...no, no, no, stop, because we need to do the skirting, and we haven't got the chippie on board yet. So a week, two weeks...

AR: Would the skirting beyond the design, or would it not be in the BIM model?

PB: It may be, I don't know. Sometimes they're not, are they, those sorts of details.

AR: Stuff that wouldn't be there anyway?

CH: Yes, it's called the deflection head that runs round the room, and you've got an option of doing like a timber trim, which we've sort of moved away from on the Curzon building. We've got a much more need to detail and less...so it avoided another trade having to go back up there, so we created the detail without the trim, lessons learned, moving things along. But yes, you're absolutely right, they don't consider...

PB: The contemplation of all of that sequencing, so the right people haven't been in a room together at the start of the job to do that sequencing. So you haven't been sat in a room saying hang on, I can't be doing that work whilst the painter's still painting the doors. But actually, I do need the doors on, because I'm going to have electrical power in there, so I need to be able to lock it, which it needs to be controlled. So nobody sat down and done that sequencing in enough detail, because we're still focused on, you know, securing our packages at the best price because we've all been driven on cost. And nobody has actually sat down doing the most important thing, which is making sure we can build it in good buildable sequence, we don't make too many mistakes. And if you've got a decent sequence, then the odd problem that you come across, you can deal with. But we have so many of them, I think, from what I see, so many issues that it becomes unmanageable, and then the whole job sort of becomes just a case of everybody crack on and see how far you can get it done.

CH: I mean, I've got to leave now, but the one thing...we've talked about unlocking how things could be made better and the way that procurement routes and things like that. Effectively negotiating a better value for all of us. But the problem we're seeing now in the marketplace now, particularly in Birmingham for us, it's because of the activity in Birmingham, the quality and resource levels are dropping significantly. So people are supplementing that...

ML: These sort of problems are only going to get worse, aren't they?

CH: So you're almost like in reflection, we've come out of the bad times, you know, so it's really for me now, if we are going to suffer with resource levels and things like that now going forward, which is a matter of fact, we should start to look to pre-fabricate things off-site.

TA: Resource of labour, skills and...?

CH: Massively, yes. It's only going to get worse.

TA: I couldn't believe it.

ML: I could shock you at the moment.

CH: It's going to be horrendous. It's almost like, you know, when a design now comes with this fancy, lovely design, you switch them off and say, no. Because...

DB: They can't deliver it? No.

CH: Let's think about how you can actually module eyes that.

TA: It's terrible, it's a massive cultural problem, isn't it? We're just all becoming idiots.

AR: Can I ask you, Chris, before you go, we've talked about design and what information is needed in there.

CA: Yes.

AR: What about method statements? Do you use them at all? And could they be used for planning sequencing better?

CA: Yes. Method statements we talked about, there's what we all know on a daily basis, method statements, risk assessments for health and safety, which are, you know, they can be...if they're done properly and thought through, they can be, you know, almost like your task tool to make sure it's carefully thought out. And that's the whole purpose of them. Unfortunately, what has come with it, is you get a minority of people who are doing really well, and they actually come to site, look at what they've got to do, write their method statement and work plan for the guys, and they tell their stakeholder they're going to go up this, that and the other. And then the generic rubbish, which is just to tick a box. But I would say, I mean, method statements from me are about...are really getting round the table and really discussing sequencing with your key supply chain, really looking at the project, getting into the design. Matt talked about it, I mean, we sat round the table for hours. We built rooms in our mind, drew them and built the programme around that. Then we built the bigger programme. The more that you do that, the more chance you have of getting it right. We suffered a lot of...we suffered problems on [Client] too. But I can absolutely assure you that if we done all of that at the beginning, those problems would have been horrific, and would have, you know, for everyone involved would have been a lot worse.

ML: I think even with the amount that we did, which I think was far more than the engagements you get with a lot of main contractors, you still hit problems.

CH: Yes.

ML: And we'd have been in a far worse position.

CH: It would have been, yes. So for me, that...

ML: We still didn't do enough.

CH: That upfront engagement, and we did involve...but this time on Phase 2 we involved all the engineers, didn't we?

ML: Yes.

CH: We brought those in, whereas before on Phase 1, it was more of high-level involvement around the table. But we dropped it down layers to make sure that we actually understood from the guys that were going to...the engineers, what they wanted. And so...

AR: And Tony, would you have and use those method statements?

TA: I've never been involved in drafting a method statement.

TA: Yes, but it doesn't have...the method statement that I sign don't have...well, they have barely any level of detail about specific job emerging there.

ML: The method statements you're talking about there, what we're talking about of the method statement of how we are pretty much going to install some conduits. So were going to screw to the wall using a drill, then this is the equipment that we use. It doesn't say that I need to get in there at this period of time, this is how long it's going to take, or anything like that. It's just. It's a safety statement really.

AR: Linking the method statement and the sequence.

CH: The method statements now, what we use in industry, we've turned that into what we call task briefings So the SSS supervisor, which we are now heavily reliant upon to effectively coordinate the workforce with other workforce with us, they do, and should be doing, good SSS supervisors should be doing task briefings every day and say, this is linking that information flow about the builders screeding that floor so now the route is there. And you're going to do some cabling to ASU number 6 next week. While we can't get the cable in that route, because they're shipping of that, so were actually going to bring in that, so it's avoiding wastage, and that is absolutely critical. And providing they're good, and they understand their role properly...

TA: So what are they for then? Are those briefings supposed to be go somewhere and it will be co-ordinated?

CH: Yes. In the ideal world. Yes.

TA: How it works over there.

CH: This is what I'm saying. This is about what they really should be doing, it's the idea of an SSS supervisor is about being able to coordinate, right? And this is where...

TA: What it's for?

CH: This is where people just put bums on seats to tick a box, and that's where it all falls over. So I'm just painting a picture of, you know, you've got five managers, one with Dixon, 300-odd people on that job, and then there's a layer of SSS supervises that should be delivering messages, bringing messages back up, coordinating the work in the ideal world.

TA: So that's the model.

CH: But you see how it would work, if we doing it properly, though.

DB: Yes, and that would be their role as coordination?

CH: Yes. And funnily enough, if you read an SSS supervisor's role, that is what they have...they don't realise it, but that's what they have an obligation for under the CDM rates.

ML: Two weeks of failure of organising turns into the remainder of the job firefighting.

DB: Yes.

AR: Yes. How are you going to keep on top of it?

ML: Yes, once you sequence, then that's it. If you don't stay on top of it, that's what happens.

PB: So we've used something similar to that on other Bailey's jobs down in Bristol, where admittedly our supervisor first thing in the morning briefs his team. And it works. And that task sheet goes to Bailey's, so they know exactly what we're doing, where we're working, and at the end of the day, get signed off.

CH: If it's put into it at every level, it actually does work. I've seen it work...

ML: If you sequence, and it's fixed and it's working...

CH: But even if your sequences and fits, something goes wrong, that's communication...

ML: Yes, you should be able to alter it and that.

CH: And it's key to making things better, to avoid the confusion. And that link between...and the problem that you have is the cross. Because you guys know, what you generally go on from job to job to job to job, and you know each other, and you know how each other work, but then we put you guys in with some decorator SSS, plasterer SSS, you've never seen him before in your lives, you're sitting next door to him and either you engage with them or you don't, and you're just there just to tick a box for 25 minutes. You don't want to bring anything to the table and say anything, and you just want to walk away and go and do your job and hope that that's it.

PB: That's probably because you see him as the person that's going to stop you doing your job.

CH: Whereas the way it works is the people form a relationship and they start to talk to each other, that's where you find you'll go and find that person on the project and they'll talk to him, and they will unlock problems together very quickly. Because they know how to unlock them. And that's how it works well. The way it doesn't work is all these people just in their own little silos...

DB: And communication, isn't it?

CH: It's communication, and it's being able to do that, and sometimes, you know, put people are putting SSS supervisors in a position that they just...they're doing it because their boss says, I need one of them on that job.

AR: Just one...before you go, Chris, is there any...to think you've got information that you could input into the method statement? Do think there's stuff that people never ask you but you know that could work through that process? Because you're saying...

CH: Yes, I imagine if I was involved in...do you mean if I was involved at the sort of planning and design level then? Yes, without a doubt, yes. Because...

DB: Have you got an example of something that might...

CH: I've really got to... So thank you very much, thanks everyone, nice to meet you all.

AR: Cheers, Chris. I'll be in touch.

DB: Thanks so much, Chris. So I may see you tomorrow, if you...?

CH: Yes, I'll try and get across to that. Excellent.

ML: We'll wait till you've gone, Chris. Don't give him this recording!

CH: David will share it with me tomorrow, so....

AR: Chris has left the room.

PB: I'll record from now onwards.

CH: Right, see you later.

DB: Have you got an example of where, you know, you feel, could I...if I taught these people...?

AR: Because you fill them in, and you know what's missing from them in terms of the method statements. Do you think?

DB: Probably more about this operational organisation, not just the health and safety aspect.

ML: Not to talk for you, but do you think...I think a lot of it comes from the fact that I don't think it's always not been thought about, I think it's all been...a lot of it's been thought about, like the sequencing they were talking about there with Chris.

That had been thought about, but it's fallen apart by the time you're there. And actually, the advice that you would give is that you need to be in there on your own. You can't have these trades around you and feed into all of that sequence, I'll tell you that. But we kind of know that already.

TA: Yes.

PB: But that's doesn't get the job done, does it?

ML: No. Yes, exactly, you're at that point, and that's the way...those are the words that come out, we'll just go and get the job done now. And those in three months' time, we just need to get the job done, handover's tomorrow, we just need to get the job done.

TA: And then your health and safety gets compromised, because of those pressures that come down.

ML: Do you know what? I don't think it did so much over there. Are you thinking of Phase 2? Because it can do. But I didn't think...I didn't feel as though it did.

TA: There was this situation with the masks that I was talking to you about, which was a bit of a farcical situation where at a certain point during the job, we were told that we weren't allowed to drill in any concrete without wearing a specific type of face kit and that's with the particular type of filter. So my boss had to go out and buy all these masks. And we all had to have a toolbox talk...

ML: Training, yes.

TA: Basic bit of training, that was it, certain guys. One guy was only there for one or two days, and he got face kits trains, took a mask, that had been paid for, took it off and disappeared. We never saw him again. And like I said, this was like a fab that lasted about two weeks, threw everyone into more turmoil because you only had so many people face kit trained, so if you wanted a hole drilling, to fit a raw plug, you'd have to call some guy, and if he wasn't busy, he would come down and drill a hole for you. I mean, it was a total farce. And then when everyone realised it was a farce, the whole thing was dropped and guys just came and...

ML: It was never dropped.

TA: Well, you weren't on the job.

ML: It shouldn't have been dropped. That's a bit of...the problem with that one, just a quick summary, is that silicon dust suddenly...

TA: Oh sure. We know the reasons.

ML: As soon as you start hearing that then you have to implement it and you have the meaning immediate remaining process.

TA: No, we know the reasons.

ML: But that shouldn't have been...

TA: Even a massive problem of us to installing...

DB: In a sense, the problem was identified, but the solution...

ML: There was no solution straightaway in that.

DB: …was just...

ML: What can we do? We know about it, [it’s like asbestos 61:46] so we've got to...we can't be seen to be not implementing something, because as soon as we know about it...

TA: Of course not, I know.

ML: It shouldn't have...

TA: I was telling you what happened.

ML: It's got into a farce. You should still be doing it as well.

DB: And that was an issue of materials that wasn't discovered till...?

ML: We were on it during the contracts, regarding silica dust in concrete, drilling concrete, so once that came to light, that that could be a respiratory issue, as an employer, we've got to recommend that people are protected from it.

DB: Yes.

ML: And it certainly wasn't rolled out very effectively.

PB: Clearly there wasn't contact. I can remember talking to the guys about it.

ML: Yes.

TA: You know the big issue for me I think, Chris talked about this resource problem. It's been so difficult getting hold of people who are trustworthy and have the skills to do the job. Like I said at the start, so you employ guys to come in and they don't have...some guys turn up, and they don't even drive, and they'll come with their tools in a carrier bag, and then you've got them from an agency, and they're supposed to have qualifications and they're supposed to have been vetted already, so that brings massive problems with the guys, so quality and then cost as well and all that sort of thing.

AR: So they could be within your own company?

TA: Well, they're not. They wouldn't work direct for our company.

AR: But they're doing the work that B&W are doing, yes. So that's not a...

ML: As far as we are...as far as a BEC are concerned, they are B&W, and it's why we are concerned. We don't really deal with B&W. We deal with a Beck. So when...if a quality issue came up, we need to speak to those guys and say, well, I don't really care what the issue is, it's your issue, you need to sort it. And if you don't, it'll be B&W

PB: Which comes back down to when they would have originally closed that job for us, you would have said only X amount of labour...

ML: I can resource that...

PB: We can resource that internally based on a programme of X.

ML: And that program went like that, and then it went a bit like that, and a bit more like that...

TA: That is literally what...you suddenly find guys and I'm like...

ML: Six for every job.

TA: That's a big cultural problem.

DB: Because he would just go out to an agency to get them, because that's the only thing you can do.

ML: You carry a base of labour, and you can't carry any more, because when your workloads lower, you'd have to pay them anyway. So you carry a base and you supplement it with agency guys or subcontractors that you know, and you bring them in when you need to. That's what we do as a business. We have a base electrical resource, and then when we can't cope, we go out to subcontractors.

TA: Do you have the same sort of problem with quality? Because I think the whole...these agencies don't know anything about them, but I don't know, that industry needs looking at.

DB: Yes.

ML: The job I've gasped just come from, the agency are on site with the project manager because he's not happy with the resource, the quality of the resource has been becoming...exactly the same conversations...

TA: There's a lot of gangsters and sharks going on.

ML: They turn up, and the impact of them turning up, they turn up for a day, decide they don't like the job and don't want to work there, so they sod off, so you've lost two days. They turn up for the day, you decide that they're not what you wanted, through a quality issue, and having to get rid of them. By the time you get somebody else, nobody starts till the Monday, so then you've lost a week. But when you're carrying a workforce of five or six guys as well, that's must impact you massively. It's like 5 per cent, 10 per cent, 15 per cent of your workforce sometimes that might be agency.

TA: Of course, and then that means you need greater supervision as well, because they are dross. That eats into more of your own time supervising.

ML: But you've been forced into that position by the position of the project, because you've not been able to plan properly, because the job has moved. So your start date has moved because we've not given it to you at the right time. Then what we've...

TA: We've been forced into it, a massive pressure.

ML: Yes, you're forced into it, and you're always under pressure, and then, you know, I could keep going back to that, that's inevitably because of the other...the trades, they're not sequenced well enough or they're not on board early enough, or whatever the issues are, they never get done. They never get done in time. Any job, any main contractor you go and work with, they never seem to want to talk too much. I know we were talking about Chris, and he won't mind me tell you anyway, but they don't seem to want to talk about why they put plasterboarders on prices. Why don't they get them to do the lot, and you have to do the lot before you leave the room.

AR: Yes, he's saying they don't do it. And I...

ML: No, they did it, they're responsible, they are the managing contract, and they're the people who...

AR: I mean, they had to stipulate it on, wouldn't it? Because all of the plasterwork that I've spoken to do do that. They say, oh, now...that we then let on a either a metre squared or a price per room.

ML: They do, yes. So nobody wants to do the...

TA: You and us, we are on fixed price contracts.

ML: Yes, we are, yes. So we have two...

TA: What's the difference?

ML: Yes, it's interesting.

ML: I don't see it like that. go...go up onto the first floor and do a bit up there, or finish off.

DB: And it is interesting that those sort of trades to work on a quantity basis. And this is why I think there's a mistake in bills of quantity about it, because oh yes, I've done that quantity of work, whereas yours doesn't. It needs those runs of work, and therefore there is almost a contradiction in the way it's costed.

ML: So the good contracts are where the main contractor understands that, and understands the implications on the M&E impact have, and when the man is asking, we didn't get back to the answer on your question of why do I have to wait two months for an access hatch, whether or not the design was good or bad, and whether it was on the drawing to start with...

DB: It shouldn't take two months.

ML: It shouldn't take two months. If it takes two months, because they haven't got enough money to pay for the plaster borders, because they're already in a delay situation, an argument with plaster borders...

TA: Yes, this is what we come back to doing.

ML: The borders won't do it, taking in, their bosses said, don't take any more instructions of them, just to your contract works. And it's all fallen apart, really, because they were delayed because of the plasterers, because of the blocked layers, because of the ground workers, because of whatever.

TA: There's a guy stood there under it with his [pad saw 67:47] I know the plasterboard as well, because I'm I've been working with them for months. I'm sorry, mate, I can't...I said, I've drawn it out for you on the ceiling. I can't do it, I need an instruction.

ML: I've been told not to cut it. Whereas...so you report that to our manager, our manager talks to the manager over here, and he says, oh yeah, I'll get it done, so he goes to his QS and says, I mean, seriously, Chris, I'm not given any more instructions, we are in dispute on the accounts. So by the time then that's come down to the plasterboard and tease...oh, hang on. All for 20 quid's worth of hatch or 50 quid's worth of hatch.

PB: Mack the Knife.

DB: That's what happens.

ML: And then I get damage costs levied at me, because our subcontractors have damaged plasterboard.

TA: Yes, same thing when they put it...

ML: Why did you block the wall?

TA: And they board over our conduit boxes, or whatever. They start drilling holes through the wall to find it, because these guys are meant to board it, and they're meant to put the whole lot up for us, but because that takes more time, so they don't bother. So we end up drilling a hole...oh, it's not there.

AR: Just to find it?

TA: It's three inches to the right, you know? So then damage costs as well.

ML: You're getting all the M&E side and I'd think there was more to it, but I think this is the majority of it. And the amount of times you get to a situation where you talk about...don't put that sink there, we've got services to finish up over there. I've been told I've got to get it up. Don't get it up, I'll I'm putting it up. I was told this morning if I don't everything put it up, I'm off the job and I'm not going to get paid. So I'm putting the ceiling on. But you're going to have to take it down. I don't care, I've been told to put it up. So the ceiling goes up, and guess what? It has to come down, somebody has to cut some holes in it, or whatever, and you're stood around for God knows how many hours waiting for it, and then you end up sodding...and I don't know what the drivers for some of that are, it's just some of it is the...sorry, going back to the start of that, and that was about the good ones are the main contractors that understand the impact of not getting the M&E complete fit. And they go, okay, I understand that, and actually, I won't put my ceiling up, I'll sacrifice the fact that I've got to pay him the day rate because he's on standing time, he's on a day rate, so he has to stand there for 20 quid whilst you finish your services, and then I'll pay that 20 quid for him to put it up. Because I understand that, because of the impact of that is far greater. But the contractors that don't, and a lot of the build managers, they'll forget that the M&E is part of their package of works, because it is, it's all one build. And they get focused so much on finishing the plasterboard, finishing the ceilings, it doesn't matter if the servicing is not done. I don't know...

TA: You can't see them anyway. They're not there.

ML: I don't get it. Because I've sat in meetings as well where you get the main contract are going, oh well, we'll do them, but the M&E is not finished. Well, we subcontract to you. We are you. If we haven't finished, we haven't finished. It doesn't matter, you can't...you know, I've...it's your problem is much as it is ours. So...anyway, that's...yes, it is. For me, it's all sequencing and sticking to the sequence. But to get that right, you've got to have engaged all parties at the start to ensure that your sequence can work, and can work effectively. So again, good ones are where you sit down, you do your program, and the plaster boarding contractor has already been appointed, so he comes along, and so does the ceiling contractor, so does the BMS contractor, so we get the pipe fitter there, and we get the inductor there, and it's not just Chris and me sat there going, take about two minutes, that will. No, no, no, that's going to take four weeks, guys.

DB: There are jobs where the people to get all the four men together to actually do the planning.

ML: Yes, oh yes, it does happen. It would never get down to you though, that's the problem, because you...

TA: Or even Dave

ML: Or even Dave, no. Because...no, not necessarily, no. Not at that...we're probably sat there thinking, so we know enough about electrical installs and how long that would take in some respects.

TA: When all our guys would say would be in a boiler house saying, why wasn't this...why haven't we consulted the pipefitters before they came in here? And we're trying to get our trunking round there.

AR: Is that about space, Tony?

TA: the Yes, about space and coordination of the layout in some. And we always say, it really would have benefited from somebody planning. Sometimes you do get these little 3-D drawings of where all the pipe works going.

ML: They're starting to do it more and more for the trunking.

DB: Does that help?

TA: It hasn't helped so far. Because they don't tend to go according to the drawing, but maybe it's an early start.

DB: Don't they? And I think there's an interesting point here, because people can create these drawings. If they're not of value...

TA: Yes, who creates?

DB: You know, and that's...

ML: Someone said the exact same thing, everyone did say they make sure it fits spatially, and it was describing it...yes, okay then, they work, it fits, and the model works. But it's not practical...

DB: You can't get it up there?

ML: They built them all, and they're building it slightly differently. So it's as good as the models.

DB: Fascinating, yes.

ML: That's because...well, again, we were like that, and you imagine the guy, the right guy not being involved in the drawing. For the guy drawing is a CAD technician that's, you know...

DB: Yes. Of course, never actually installed anything in his life.

TA: Rarely.

ML: Rarely. Then you get the right guys that really understand how it's built.

DB: And I think these are the sorts of issues that I think maybe we could resolve by getting information to flow better. But it needs to be at the right time. And whether...there's this idea of look ahead, planning, you know, at what point does everybody meet together to plan this job? And at what level? And there's probably a sequence of levels of planning. There is a large-scale level on your...you know, we'll do it in this order, and then, you know, let's look ahead, whether it's one month ahead, so I can start ordering my materials, getting the labour force in. And then there's a week ahead, you know, we’re actually going to...this is what we're going to do. This is how we going to do it. This is how we are going to get the materials there.

PB: I think the 3-D modelling is fine from a coordination point of view. But what tends to happen between us and the likes of [Baileys 73:53], if you take a plant where you've got to read the model, eight inch pipe work going up here, or you might have a bit of two inch trunking there, or flush to install our trunking before they put their eight inch pipe in, is never going to happen. So we tend to wait until they're 80 per cent complete of all the heavy stuff, and then we go in afterwards. But again, Baileys, having the trust in us that yes, we are going to be late, but we are going to get it done on time.

DB: And you've got a way of working around the already installed pipework? Because you've got more flexibility in there?

ML: Not everybody. Just Tony.

TA: And that could be one of the problems that comes from this idea of designing everything completely 1st to the stage where in the future and algorithm could bang out a complete building. You're going to end up turning the construction site into a factory, and the people who are actually responsible for putting the stuff in, they're going to be more and more kind of unskilled, in a way. They're not going to need to have to come up with creative solutions and problem-solving, because it's all meant to have been figured out first. So then you get a sort of unskilled...

ML: Does that not just move there, positioning this in the chain? So your skill and experience there then should be introduced earlier in the algorithm building and the model building.

TA: Well, it's not just me. I mean, anyone who's actually working on the coalface really needs to have a degree in problem solving.

ML: Yes, sorry, yes, but the more you influence earlier, the less problems should occur later on.

TA: Yes, should, yes.

ML: So instead of having the CAD operator, but a lot of that comes to appointments, doesn't it? So we're getting...we've talked about this before, about the current way that we engage the supply chain doesn't think to be because we are not employed until potentially two weeks before you actually start installing. By that time, the planning phase is well and truly...

TA: Over, yes.

ML: Completed and done.

TA: Exactly.

PB: How does BIM...if you want to design and build, and obviously your designers...

ML: Yes, BIM is not overly...

PB: ...first time, whereas if you're not a BIM designer, where it's not designing building work and sending out a spec, and the BIM design then, you will probably have a different way of installing it to what they decide.

ML: Yes. That's why that whole process needs all the right people at the very start. Which is massively difficult, yes.

A3

Author Publications

A3.1

UK Construction Supply Chains Attitudes to BIM

UK Construction Supply Chain Attitudes to BIM

Abigail Robson M.Sc. and David Boyd Ph.D. and Niraj Thurairajah Ph.D.
Birmingham City University
Birmingham, UK

The UK construction industry is facing a challenge to improve productivity. It is argued that this challenge can be met though the adoption of Building Information Modeling (BIM) which would improve efficiency by integrating the sequence of processes and activities encompassing all organizations involved in a construction project. Construction projects operate in an environment that is characterized by fragmentation and uncertainty and the companies that make up the construction supply chain possess dynamic capabilities in order to survive in this operating environment. This research study investigated the nature of the environment that subcontractors in the UK construction supply chains operate in, the aims of BIM solutions and the attitudes of subcontractors in the supply chain of a national UK main contractor to BIM solutions. The study focused on determining the supply chains' views on the key opportunities of BIM and the key challenges involved. The study was performed by surveys carried out with practitioners in subcontracting companies in the supply chain of a national UK main contractor.

Keywords: Building Information Modeling, Supply Chain Management, Dynamic Capabilities.

Introduction

It is almost 20 years since the UK construction industry was called on to improve productivity firstly through a focus on efficiency using improved integration, teamwork and partnerships (Latham, 1994), then through reengineering overall delivery (Egan, 1998) as a remedy to its endemic problems. Since then government, through its client and regulatory role, has further driven the industry to achieve greater efficiency through the uptake of benchmarking (Strategic Forum, 1998). Again, recently the construction industry has been specifically challenged to reduce construction costs for government contracts by 15 – 20% by 2015, from the baseline of 2012 (Cabinet Office, 2011). At a time of rising costs and the continuing financial crisis the cumulative saving required on construction cost is greater than 15 – 20%. Building Information Modeling (BIM) is being proposed as a solution to this, which enhances information sharing and collaboration across multiple firms in construction projects (Succar, 2009). BIM is seen to have the potential to improve productivity through efficiency gains (Cabinet Office, 2011) achieved through new modeling techniques that allow centralization of design information and improved communication through a central hub. The search for opportunities for productivity improvement through BIM is therefore of great concern to the industry.

Literature review

The adoption of BIM in the construction industry is seen as a journey through four levels of 'maturity' from two dimensional design practices at level 0, to fully integrated three dimensional modeling of design, time and cost at level 3 and the UK government requires all public projects to be delivered to level 2 by 2016 (BIS, 2011). Level 2 requires project teams to be working collaboratively in 3D modeling of design. Many subcontractors have design input and the concept of collaboration in design is therefore intertwined with the main contractors' supply chain. In addition, Tier 2 (subcontractor) firms generate 80% of the production costs of UK buildings, therefore for BIM to be successful in reducing costs it needs to involve tier 2 subcontractors.

The technological certainty of BIM camouflages the essential vagueness of BIM's aim to achieve efficiencies through collaboration. BIM is perhaps better understood in the same way that Childerhouse (2003) argued that

Supply Chain Management (SCM) is best understood, namely as a sub-theme within a broader discourse that promotes 'new ways of working' to the construction industry from other sectors. When promoting initiatives from one sector to another, differences in the operating environment between sectors will have an impact. Green *et al* (2005) argued that the construction industry tends to introduce 'new ways of working' from other sectors at project level without any critical appraisal of the impact of the contextual differences (structural characteristics, differing relationships with government and relative degrees of global consolidation) that shape the 'new ways of working' in different sectors.

Understanding the particular context of the construction industry was spearheaded by Lansley (1987) who recognized that construction firms need to be able to respond to changing environments due to the boom and bust, cyclical nature of demand in the construction market and also Cannon and Hillebrant (1990) who recognized that construction firms often develop strategies organically in order to cope with the uncertainty inherent in temporary, short term relationships that result from this ever changing environment. These works remain seminal and the construction industry is still characterized by localized, temporary supply chains producing a one-off product for many clients. The construction supply chain is made up of tier 1 firms (main contractors, also known as general contractors) and tier 2 firms (subcontractors, also known as specialist or trade contractors or manufacturers who have a direct contractual relationship with the main contractor). Tier 2 and tier 3 of the construction supply chain is typified by fragmentation into a large number of small, labor intensive companies and business relationships typified by competition and an adversarial inter-organisational culture.

The achievement of collaboration through BIM faces the same challenges that have faced previous SCM initiatives involving 'new ways of working' that have been imported from other sectors at a project level, with an operational perspective. These include constructability with its focus on designing for assembly (O'Connor *et al.*, 1987); lean production with its focus on identifying value, eliminating waste and the smooth flow of information and activities (Ohno, 1998); agile construction with its focus on increased flexibility and responsiveness in project based work to reduce the risks associated with complexity (Christopher and Towill, 1983); and partnering that advocates greater interdependence between firms (Latham, 1994) however in practice is primarily operational, project based change. In these four initiatives the structure of inter-organizational networks remains unchanged (Green, Fernie *et al.*, 2005). A common argument is that better collaboration is difficult to achieve through these initiatives because the construction sector is so fragmented with low interdependency and short-term relationships between firms.

A few SCM initiatives have taken a strategic perspective in which the structure of inter-organizational networks has been consolidated from previously fragmented supply chain structures. The first of these came in the field of logistics though co-operation between suppliers and contractors for improving the total flow of materials by strategic procurement (Johnston, 1981). This was followed by co-operation in specific supply chains such as elevators (Luhtala *et al.*, 1999). A further strategic initiative that has brought change under the banner of SCM is platform assembly, which focuses on increased modularization and off-site prefabrication to decrease the impact of varying site conditions (Meyer and Lehnerd, 1997). However such strategic SCM initiatives in the construction industry that have emulated the secure, long term supply chain relationships of other industries are relatively isolated examples and Vrijhoef and Koskela (2000) concluded that such initiatives have been minimal and have had only limited impact on the traditional fragmented and adversarial structure of the construction industry. The introduction of BIM into this environment of fragmentation and inter-organizational conflict does not guarantee the desired improvement. BIM therefore needs to be able to work in a climate of fragmentation and inter-organizational conflict.

Others have taken the view that the climate of fragmentation, low interdependency and short-term relationships has resulted in positive benefits for construction companies in their adoption of dynamic practices to cope with uncertainty, which set companies in the construction industry apart from those in other industries, in their degree of flexibility to respond to changes in the environment. Cannon and Hillebrandt (1990) highlighted the fact that the nature of construction companies as labor intensive, rather than capital intensive, means that business planning is a dynamic process of matching resources to projects over time whilst ensuring a positive cash flow. Green *et al*, (2008) concluded that the 'dynamic capabilities' employed by construction companies means that strategic decision-making is a dynamic process. The theory of dynamic capabilities views organizations as set of interdependent routines, which are flexible in order to respond to changing circumstances in accordance with feedback (Nelson and Winter, 1982). Green et al (2008) use Teece *et al.'s* (1997) framework of dynamic capabilities to argue that flexibility, through learning and transformation, is key to success in construction companies. In this light, better collaboration in the supply chain through BIM needs to consider the current reality of the construction sector because that brings dynamic, flexible practices.

The use of BIM in construction projects has been discussed by many researchers (Eastman *et al.*, 2011) (Mihindu and Arayici, 2008) however, there is a scarcity of reports into supply chain and BIM in research literature (Khosrowshahi and Arayici, 2012). This motivated Willmott Dixon, a national UK main contractor, to collaborate with Open BIM Network and Birmingham City University in a survey to find out their subcontractors' views on the adoption of BIM. Construction involves supply chains that converge on the construction site. Main contractors in tier 1 of the supply chain therefore play a key role in integrating tier 2 of the supply chain in a project and in promoting the use of BIM by tier 2 subcontractors.

Methodology

The views of the supply chain members' on their adoption and use of BIM were collected by an online survey. The survey questionnaire was designed through a review of literature on BIM, discussions with the main contractor's central BIM implementation team and the Open BIM Network, and by internal discussions of academics with special interest in BIM in Birmingham City University. The survey was aimed at the tier 2 supply chain members of the main contractor. The second tier supply chain firms comprised of three different company types who are suppliers to the main contractor: supply and fix specialist contractors, manufacturers and design consultants (architects and engineer designers).

The survey went out to a total 305 directors of these companies. 177 respondents returned the completed survey, a response rate of 58%. The extracted survey findings are based on these 177 responses. The survey questionnaire was divided into four sections: (i) benefits of adopting BIM (ii) barriers to adopting BIM (iii) readiness for adopting BIM (iv) priorities for support in adopting BIM. The survey also included questions on company type and size to allow for analysis. The nature of the sample is presented in Figures 1 and 2, and findings from the survey are explained below. Only descriptive statistics were used in the analysis.

Figure 1 illustrates that 48% of respondents were sub-contractors with design input, 23% were design consultants, 16% were sub-contractors without design input and 13% were 'other'. All companies who described themselves as 'other' were manufacturers. This means that subcontractors who have design input dominate the survey.

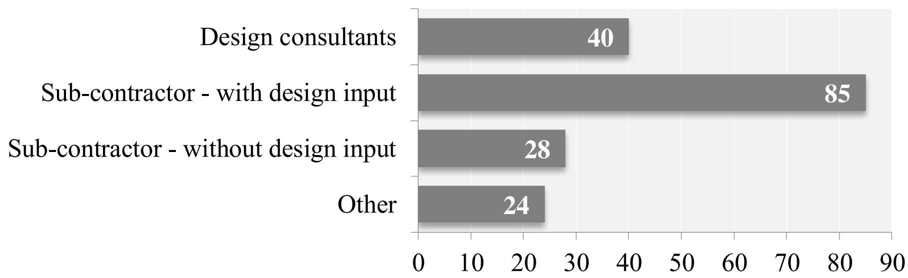

Figure 1: Responses by Company Type

Figure 2 shows that less than 5% of respondents were involved in companies of less than 10 employees. Nearly half, were involved in companies with between 10 and 50 employees, a third, 33%, were involved in companies with between 50 and 250 employees. This profile broadly reflects this highly fragmented structure of the UK construction sector, with its concentration of small firms (DTI, 2012). According to the Small Business Survey of Small and Medium Enterprises (SMEs) (i.e. companies with between 1 and 250 employees) construction sector companies tend to have fewer employees than other sectors and account for 12% of SMEs in the UK. The profile of respondents in this survey therefore broadly reflects the UK construction industry as a whole.

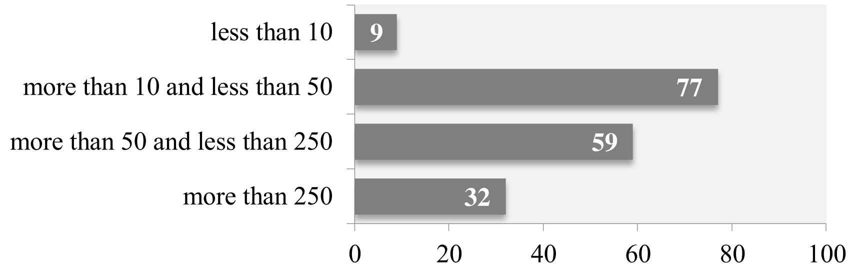

Figure 2: Responses by Company Size by Number of Employees

Results

Company Awareness and Levels of Collaboration in BIM

The survey asked respondents how they would describe their awareness of BIM. Figure 3 shows that a third of companies had already implemented BIM on projects and 38%, said their company had an early awareness of BIM. The remainder fell between these two extremes. Further analysis showed that early adoption of BIM varied significantly between company types, with design consultants nearly twice as likely to have already used BIM on projects, than sub-contractors with design input or manufacturers. No subcontractors without design input had already used BIM on projects. Company size influenced BIM awareness to a much lesser degree than company type. These survey findings reflect the early adoption of BIM amongst design consultants within the UK construction industry as a whole as BIM is step change in design information, replacing 2D drawings with data rich models (Eastman, Teicholz *et al.*, 2011).

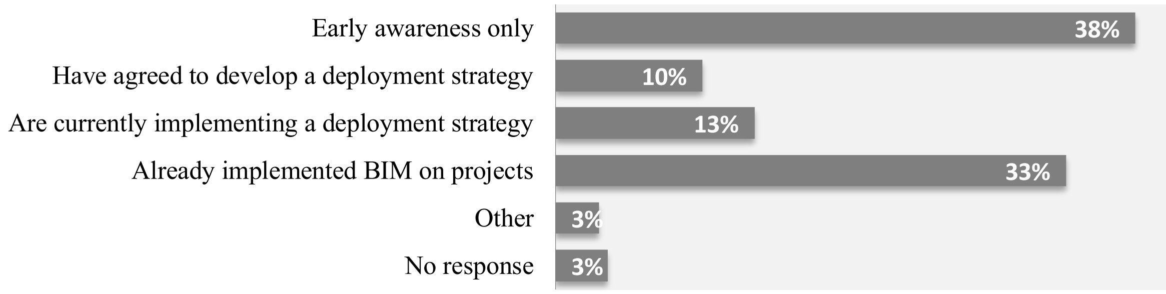

Figure 3: Companies awareness of BIM to date

Responses to questions about the level to which respondents had used BIM on projects (Figure 4) showed that a quarter of respondents had used BIM in collaboration to level 2 maturity. 13% had used BIM internally, 7% were identifying projects on which to implement BIM and 44% were not currently using BIM. Further analysis showed that level of adoption of BIM was less dependent on company size than early adoption; however company type was again a significant determining factor. Design consultants were five times more likely to have adopted BIM in collaboration to government level 2 than sub-contractors with design input and over seven times more likely than manufacturers. No subcontractors without design input had already used BIM in collaboration to government level 2 on projects. This late adoption of BIM by subcontractors with design input potentially presents a problem as Government requires all public projects to be delivered to level 2 (supplying design information across the whole supply chain) by 2016 (BIS, 2011). These results have significant implications for those second tier supply chain companies with design input.

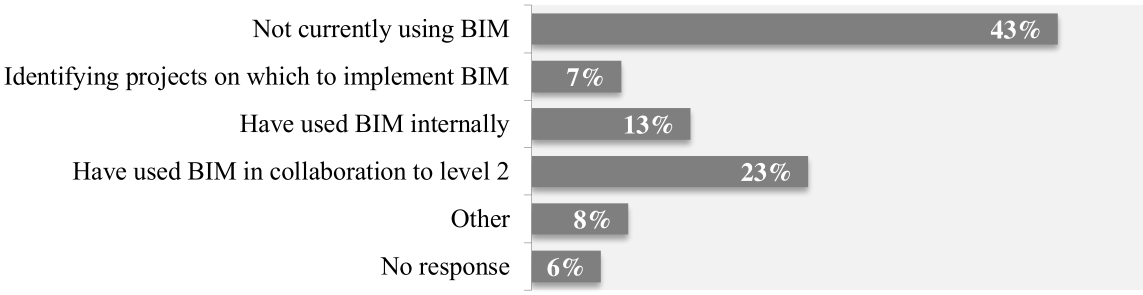

Figure 4: Companies use of BIM to date

Benefits and barriers in adopting BIM

Figure 5 shows that a clear consensus emerged amongst respondents about the issues that can potentially be overcome by the adoption of BIM in the supply chain. Respondents selected BIM's potential to (a) improve design coordination, (b) reduce risk through identifying potential problems early on, and (c) facilitate better communication of project data, as the main benefits of BIM, based on the weighting identified through the number of selections checked (but not weighted) by respondents. These priorities all concur with the aim of BIM in its widest and most ambitious sense, to enhance information sharing and collaboration across multiple firms in construction projects (Succar, 2009).

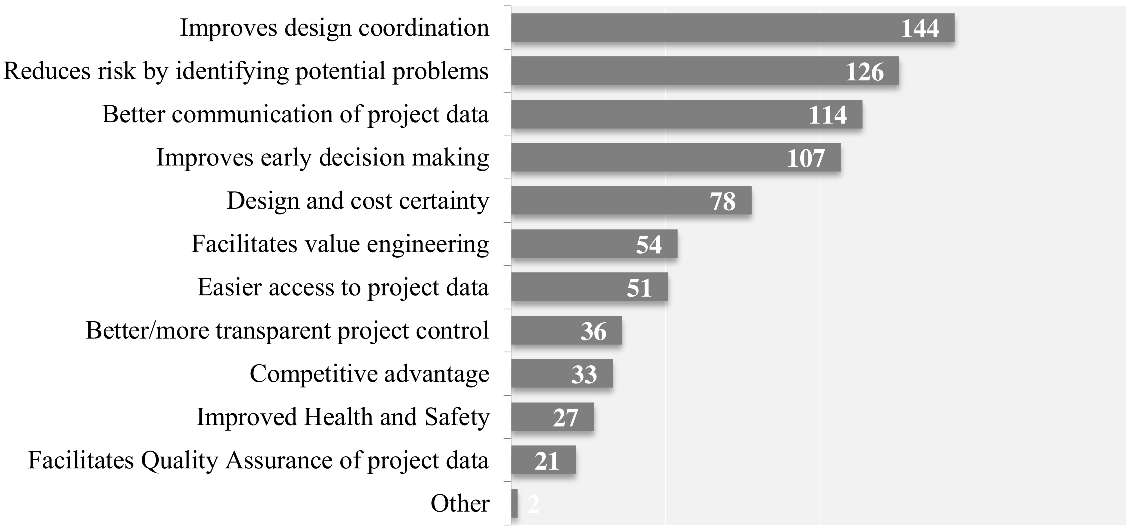

Figure 5: Companies' views on the benefits of adopting BIM

Whilst respondents priorities on the benefits of adopting BIM show a desire for greater collaboration through BIM, it is see in Figure 6 that the primary barriers to adopting BIM in their business centered on (a) vulnerability to the weakest link (where poor performance by one of the subcontractors becomes a limiting force in a set of supply chain relationships) (b) set up costs and (c) cultural change, based on the weighting identified by the number of selections by the respondents. These identified barriers show that the respondents have a desire for construction supply chains to emulate the secure, long-term supply chains of other industries, that are conducive to investment for innovation and show high levels of trust that make them open to cultural change.

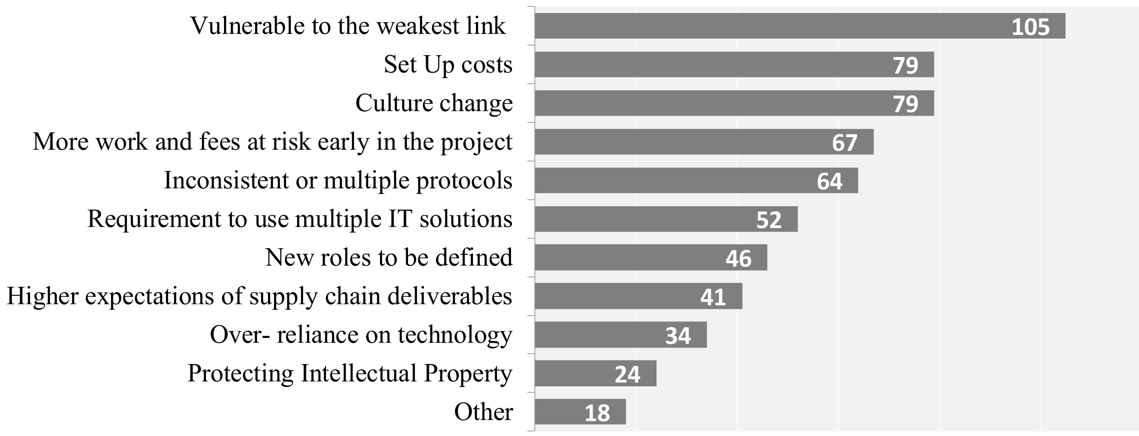

Figure 6: Companies' Views on the Barriers to Adopting BIM

Companies' priorities for support

Finally, the survey explored respondents' priorities for the type of support they would most welcome from the main contractor to help them in adopting BIM on projects. Figure 7 shows the order of supply chain members' priorities for support. It can be seen that commitment to a secure supply chain topped the list of priorities. This concurs with the finding on the barriers to adopting BIM, and shows that the respondents have a desire for construction to emulate other industries with secure, long-term supply chains. This concurs with literature on SCM that argues that collaboration is difficult to implement in construction because the industry is fragmented. Clear consistent protocols and BIM guidelines for the supply chain were second and third priorities in the list. This shows that supply chain members cannot wait for the construction industry to emulate other industries with secure, long term supply chains and are already grappling with the process changes involved in BIM within the construction industry's fragmented environment.

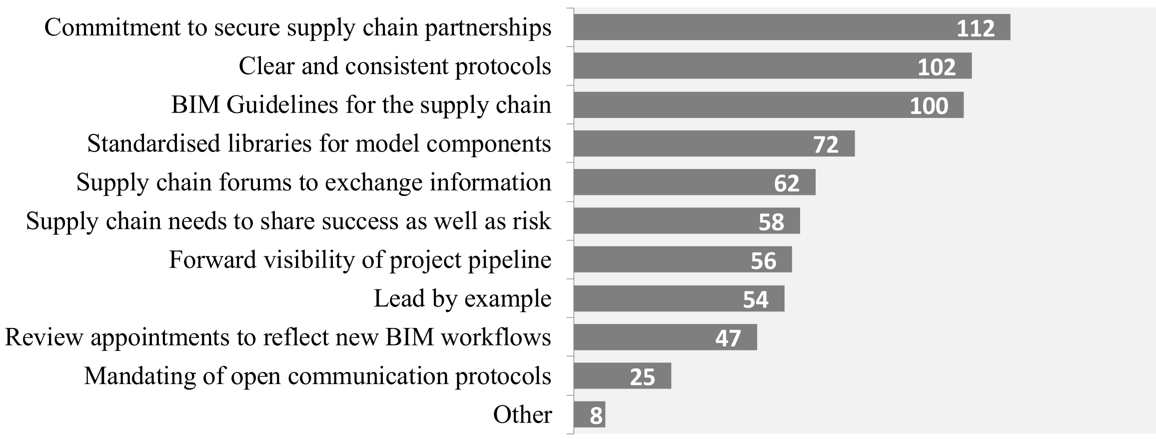

Figure 7: Priorities for Support from the Main Contractor

Discussion

It is promising that, in an industry that is traditionally locked in the mindset of competition between supply chain members, respondents views on the benefits of adopting BIM show the desire to achieve efficiencies through greater collaboration facilitated by BIM. However, the low levels of trust in the construction industry present challenges to achieving this. The findings show that the issue of trust is central to subcontractors' views on both the barriers to adopting BIM and the main priorities for support from the main contractor. Both point to a desire for collaboration to be achieved by consolidating the structure of supply chain networks. There is a desire for strategic change in the main contractor's supply chain management from the current short-term supply chain arrangements, in which firms seek access to the supply chain on a project-by-project basis, to longer term arrangements. Subcontractors can thus be said to desire the type of stable, long-term supply chains present in other industries that share efficiency gains and provide a workplace culture of trust. But this may be unrealistic.

The literature on SCM shows that to date 'new ways of working' through SCM initiatives that have taken an operational perspective overwhelmingly outweigh strategic initiatives that result in longer-term supply chain arrangements. This leads to a question about the realism of the subcontractors' desire for the supply chains in the construction industry to emulate other industries to any significant degree. The literature on 'dynamic capabilities' that points to the positive characteristics that construction companies possess as a result of the fragmented, short term, project based nature of the industry, identifies the problem of the degree of change in operation necessary for the construction supply chain to emulate other industries' supply chain practices. There is therefore a conflict between the aspirations of the supply chain and the reality of the construction industry. This needs to be resolved before the advantages of BIM can spread down the supply chain.

Conclusion

In conclusion, the survey has provided insight into the understanding by sub-contractors that the development of collaborative working is an imperative, nonetheless an imperative that cannot be seen irrespective of context. BIM is new and rapidly developing and has the potential to deliver great benefits, but doing so requires a consideration of current ways of working which itself requires a consideration of the climate of the UK construction industry. As BIM develops it needs to accommodate these dynamic capabilities, or the industry needs to consolidate its supply chains. If the rhetoric of collaboration is imposed on the supply chain members without reference to the nature of the industry, it will struggle to deliver its potential benefits for the supply chain.

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A3.2

Are Contractors' Cost Accounting Practices up to the Job of Establishing Improvements in Site Operations?

ARE CONTRACTORS' COST ACCOUNTING PRACTICES UP TO THE JOB OF ESTABLISHING IMPROVEMENT IN SITE OPERATIONS?

Abigail Robson[1], David Boyd and Niraj Thurairajah

Birmingham School of the Built Environment, Birmingham City University, Birmingham B4 7XG, UK

Construction industry clients and regulators repeatedly call for the industry to reduce the cost of construction projects. Real cost reduction requires improvement in site operations. However, much of the industry expends effort in merely buying more cheaply. If a main contractor is looking to a subcontractor to undertake improvement for the sake of the supply chain, they need to be able to assess this and motivate it by a payment process that passes on the reward. Research is described that explores whether current costing methods could account for improvements in work processes. It considers cost as information and explores how contractors derive and use it. A case study of a major main contractor and two subcontractors is described that involved semi-structured interviews and document reviews. The results show that firms recognised that the costing practices they were using had unintended negative strategic and operational consequences. The research concludes that information about cost, that would be useful in a programme that seeks to improve site operations, is hidden in layers of commercial assumptions and lost when it does not cross the boundaries between organisations. A key finding is that automation of current cost management methods in BIM will not improve construction site operations. It will only produce more convoluted details that do not reflect what people actually do.

Keywords: building information modelling, contractor, cost accounting, improvement.

INTRODUCTION

The role that cost information plays in a construction project is a central one. Construction is always being challenged on cost by government who, through its client and regulatory role, has continually pressed the industry to reduce the costs of projects (Department for Business, Innovation and Skills 2014; Egan 1998). The catalyst for cost reduction most recently proposed is the adoption of Building Information Modelling (BIM) (Department for Business, Innovation and Skills 2013). Through BIM the cost of collection, storage and manipulation of information is reducing dramatically and consequently it should be easy to access integrated information that can be used to change the industry.

It is BIM's ability to automate the creation of information and communicate it efficiently through a central hub that drives the construction industry's interest in developing cost information in BIM. Academic and industry research and software development in the area of cost BIM has, to date, focused on BIM's ability to automate current estimating and tendering practices. Montierio (2013) showed that the

[1] Abigail.robson@mail.bcu.ac.uk

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most well developed software uses knowledge-based systems to extract dimensions from Computer Aided Design (CAD) models. Meanwhile, current software for Computer Aided Estimating (CAE) uses library-based systems to manipulate historical cost data to create project related data. It is now timely to explore cost as information to establish its meaningfulness prior to the move to more integrated decision making via knowledge-based CAE decision support systems in BIM.

This paper therefore explores cost as information and asks what sorts of cost information contractors currently hold? To understand this, the research explored estimating and tendering practices and narratives in a national UK main contractor and two subcontractors from their supply chain. The study analysed the derivations and uses of cost information by different people. The exploration of contractor and subcontractor cost information in this pilot study is part of a wider project to make cost information more relevant to site operation decisions through the use of BIM. Results suggest that current approaches to contractor costing struggle to provide information that is meaningful for establishing how site operations influence construction costs and hence how site operations can be improved. It is suggested that further work is needed, to look at how different costing processes from manufacturing could be applied with benefit in construction.

LITERATURE

The challenge of pricing one-off projects in construction has led to industry and country specific standard practices for project estimating and tendering (Kirkham, 2007). Regardless of the type of procurement route (such as competitive tendering, negotiation, two–stage tendering) or contract (such as lump sum, measure and value, or cost reimbursement) and regardless of the final format of the price information (formal bills of quantities, informal bills of quantities, schedules of rates, or lump sums), contractors and subcontractors all have the task of creating a project cost from three distinct types of information, namely, estimates of the cost of their own resources, quotations for work from subcontractors and the overarching strategic tendering decisions.

Greenhalgh, (2013) explains that cost estimates for work directly carried out by a contractor are often built up from ‘first principles’; that is from the activities that consume internal resources of labour, materials and plant. The internal resource costs are allocated to either site overheads (preliminaries) or measured items. The estimator uses a combination of calculation and judgement to create the unit costs of measured items. For example, the ‘measured item’ of a brick wall has a quantity and a specification that both influence the resources required. The materials required are calculated by a simple mathematical relationship. The labour and plant required depends on judgements to optimise labour and plant productivity rates and minimise material waste. Greenhalgh (2013) argues that how a contractor makes best use of their internal resources is the main competitive differential between competing contractors. Ross and Williams (2013) identify that it is unlikely that this information on how a subcontractor makes best use of their internal resources will pass up the supply chain. Hence a contractor will not have a detailed understanding of their subcontractors’ estimating processes and the decisions involved.

The second type of information used in costing is quotations from subcontractors. Fryer *et al*., (2004) explain that subcontractor quotes make up the majority of a main contractor’s costs as a main contractor typically subcontracts over 80% of their work. Ross and Williams (2013) argue that this change in the industry means the contractor's skill in managing the subcontractor input into estimates is now a significant competitive differential between competing contractors. The process of managing the subcontractor needs unpacking. For instance Ross and Williams (2013) throw light on the usually hidden practice of price discounting. They describe the discounting 'spiral' in which the originally benign practice of expecting 'trade' discounts from subcontractors escalates in a project to the dis-benefit of subcontractors. In contrast to Greenhalgh's (2013) assertion that contractors main competitive advantage lies in how they make best use of their internal resources, Zimina *et al*. (2012) contend that the skill in commercial purchasing is a primary contributor to project profit.

The third type of information used in costing is the overarching strategic tendering decisions that convert an estimate into a tender. Greenhalgh (2013) shows that contractors make judgments about allowances for design and other risk contingencies, and the required margin to recover company overheads and earn a profit. This type of information relies heavily on an understanding of project uncertainties and market conditions. Ross and Williams (2013) point out that many contractors are guarded when it comes to conversations about margins. Others have shown how discussions about margins are clouded by decisions made through self-interest and opportunism. For example, Cattell (2012) identifies that firms may adopt weighting strategies to manipulate cashflow in their favour and Rooke *et al*. (2004) show there is a culture of planning for claims.

Two alternative procurement methods seeking to reward cost savings have been recently applied in UK contracting. The first is 'supply chain cost management' (Constructing Excellence, 2004), which is used in conjunction with early involvement in design, and seeks design savings by rewarding contractors and key subcontractors with a guaranteed total margin upfront. It achieves this by decoupling margin from each unit item in the cost model so that design savings can be made without eroding margin. Another alternative method is 'target costing' (NEDO, 1982), used when building to budget. This again requires early involvement in design, and seeks efficiency savings by rewarding contractors and key subcontractors with a pain/gain share. It achieves this by using a 'cost plus incentive fee' method that uses open book accounting to establish cost and shares the difference between target cost and actual cost. These alternatives are re-presentations of current project costing practices for budgeting and control, not new, analytical costing practices.

Construction project costing practices exist alongside costing practices in other industries, within the broader field of management accounting. Management accounting emerged to facilitate financial budgeting and control and broadened over time to encompass analytical measurement and evaluation of financial performance (Chapman *et al*., 2007)). The main approach in this shift has been the theoretically based model of transaction cost economics (TCE), which has sought to compensate for flaws in the market-orientated view of perfect competition by focusing on how organisations can avoid dependence and deal with opportunism (Williamson, 1985).

In manufacturing and retail sectors, new analytical tools for costing that reflect transactions in supply chains emerged alongside TCE during the 1990s. LaLonde and Pohlen (1996) compared the main four tools that account for the cost of transactions in supply chains. Activity based costing (ABC) (Kaplan and Cooper, 1988) as a method of assigning accurate costs to products or services based on the resources they consume. Total Cost of Ownership (TCO) (Carr and Christopher, 1992) that looks at the total costs between two neighbouring firms in a supply chain. Direct Product Profitability (DPP) (Kurt Salmon Associates, 1993) that considers the logistics of moving items between supply chain firms. And Efficient Customer Response (ECR) (Weeks and Crawford, 1994) that focuses on reducing whole supply chain costs through a better transfer of information, automating administration processes and unifying replenishment cycles. LaLonde and Pohlen (1996) argue that a hybrid of these techniques offers a new costing system that reflects supply chain relationships.

Despite the shift in cost accounting in the manufacturing and retail sectors and the pressure to embrace learning from other sectors such as aerospace (Green *et al.,* 2005) and automotive (Egan, 1998), project cost accounting in construction has remained largely within the realm of budgeting and control with few exceptions. Staub-French *et al*. (2003) applied ABC to account more explicitly for the cost of design features in construction projects. They created a prototype tool using the methodology of activity based costing to help estimators customise early stage construction cost information based on design features. O'Brien and Fisher (2000) applied ABC to calculate the capacity costs in the construction supply chain.

The literature shows that construction is embedded in its own costing practice and that this is challenged for accuracy, but not for efficacy. It keeps on doing the job it has always done because the industry works around the inadequacies. What is needed is a closer study of the thinking behind these construction cost practices so that their success in developing efficacy in decision making can be evaluated. The potential for different approaches to costing needs also to be assessed on this basis.

METHOD AND METHODOLOGY

The research is grounded in the interpretivist tradition. It explores the narrative around actions and decisions in order to know what organisations and individuals do and why they act as they do (Walliam, 2006; Easterby-Smith *et al*., 2008). The research adopts a position of 'cost as information' then sought to challenge the basis and practicalities of this by treating it as merely a representation of purchasing possibilities and resources. Cost information is made problematic when it is given wider meaning by people and becomes a fixed reference point in construction projects. This research did not therefore start from the hard propositional knowledge of current practices, but rather looked at where cost information is derived from and how it is used, seeking to better understand what cost information means to different people. The research did use some hard propositional knowledge from costing documents and reports but explored this from an experiential and performative perspective. The overall objective was to explain current approaches to costing and explore the potential for making better decisions.

The research involved collaboration with a UK national contractor. This allowed access to data in a case study approach to their costing practices with a view to establishing what was needed for them to apply BIM successfully. This also involved two subcontractors, a mechanical and electrical subcontractor and a suspended ceiling, partitions and dry-lining subcontractor, who entered into the research willingly, as they saw opportunities for better payment. The conflicts of interest and ethical decisions that the study involves have been managed with care so as to be sensitive to their position and gain full access to the reality of their situation. The study was undertaken using interrupted involvement to follow decisions and their consequences at intervals through projects. The research adopted an inductive approach to provide description, understanding and explanation of the sources and uses of cost information in estimating and tendering. The study also used documentary evidence of cost processes and written cost reports as well as narratives from semi-structured interviews with key participants from pre-construction and site operation teams to establish how they source and use cost information. In the middle of the study a reflective group discussion took place with key participants from the main contractor. To maintain confidentiality, the study used a different project for each organisation. However each project involved a similarly large, complex, one-off construction in which the contractor did not control the design phase. Interviews established that the same project costing processes and written cost reports were used on all projects. In general what people do is similar on all projects.

COSTING PRACTICE DATA

The empirical research aimed to establish whether the cost information collected by main and subcontractors during estimating and tendering was useful for promoting and accounting for improvements in site operations. The investigation sought to determine the reasoning behind the derivation and use of cost information and, importantly, what information was not created.

Based on the documents and narratives provided by the participants it was seen that, once a contractor or subcontractor had decided to submit a tender, their estimating, planning and buying functions face the task of building up project costs from a number of constituent parts while their commercial function faces the task of synthesising the information into a tender. It was seen that because subcontractors themselves subcontract work, there is no distinction between main contractor (MC) and subcontractor (SC1 and SC2) in terms of their costing process. In order to describe, understand and explain the costing processes and compare this with the literature, the investigation was structured around the same three distinct types of information categories as established in the literature review: estimates of the use of internal resources, quotations for work from subcontractors and overarching strategic tendering decisions.

Estimates of use of resources

An estimator creates 'first principle cost information' to forecast the price to pass on for work that will be carried out using their company's internal resources. They check, and hence improve, information received on quantities and specifications for 'measured items' then customise these for work that is under or over measured, or under or over specified. They create good information on their company's costs for directly employed labour using annually updated company information on salaries that are based on national wage agreements and salary on-costs. They also create good information on their company's costs for materials and plant, using regularly updated schedules of negotiated prices from suppliers. They then forecast the activities, resources and resource productivity rates for measured items. Company standard calculations that are derived from previous project experience are created. However the study found that the 'accuracy' of this information in representing site operations is made opaque by commercial practices.

"There are industry standard resource and productivity rates for activities but we create our own. We reviewed our labour productivity four years ago with our site operatives. We identified efficiencies, but then we didn't change our productivity rates because we were in a rising market and all costs were going up" SC1

"We have a standard productivity rate for our labour-only subcontractor who are required to work to a price. In a market upturn we have to use less productive labour but they take the hit" SC2

Quotations for work from subcontractors

For the main contractor, as much of 80% of the price passed on to the client comes from prices received from subcontractors. For a tier 1 subcontractor in one of the major trades, this can also be as much as 60% to 70%. The estimating and purchasing teams obtain and compare bids on the basis of price and technical issues and select a subcontract price to use in their tender. The selected subcontract price comes with a stipulated level of 'standard trading discount' that recognises trade business. The estimator creates a new figure by assuming a level of 'additional trading discount' on top of the standard. The risk is taken that the 'additional trading discount', or more, will be realised in further negotiations if and when the site operations team later place an order with subcontractor who's price has been selected at this stage.

"Quite often it's pre-discounted so already the client has had the benefit. The person carrying the risk [that the additional discount will be realised when an order is placed for the subcontract] is us." MC

"Sub-contractors never give the best price first. We pre-discount our price when we put our price in. So we take a discount off their prices so you add all these subbie costs. We'll pre-discount ours before we sell it." SC1

Overarching strategic tendering decisions

An analysis of estimated direct costs and subcontract prices is passed from the estimating and purchasing teams to an adjudicating group, who review the information and establish the project mark up. The 'mark up' is made up of judgements on (i) anticipated cost of 'design contingencies' for uncertainty and level of risk and (ii) a 'margin' to recover general, non project specific, overheads and a level of profit expected to be earned from the project.

"We've had some vigorous debates about what the correct level of risk contingency should be on those jobs. We've had similar debates on every single job and it's the most subjective point that you could take." MC

This establishes information on the total cost and is passed on as the going rate. The going rate is used as a target to budget and control costs within cost envelopes.

"We apply risk costs, OH&P as agreed in settlement meeting with directors and this form becomes the financial record of our tender. If successful this passes to the project delivery team and particularly procurement as a record of decisions made at tender stage to come to our offer" SC1

When the price is presented in a standardised format, such as a bill of quantities or schedule of rates, the contractor decides a gross price to put against each cost item in the model. The gross price is made up from the net price of measured items plus a share of the 'mark up'. Both the net and gross prices can be manipulated across cost items in the model.

"We like to have overvalue in our orders. So we get paid more than we pay out every month and that generates a surplus for our business." MC

Interviews established that participants recognised that the cost information that is created and the price information that is passed on throughout the supply chain has many forces acting on it from operational and strategic decisions made throughout the supply chain. Participants saw project costing as a process that results in firms in the supply chain winning and losing on projects at each other's expense.

"There's two layers. Some people might take a few bob off to win a job but the figure they take that from is a figure which people have already made assumptions on." MC

"Some contractors will make double the margin they expected to make and other contractors that'll make half the margin they expect to make. You can guarantee only one of them is going to bang your door." MC

Participants understood that the project cost information created is obscured by layers of commercial decisions that remove cost information from a good representation of work processes, site activities and the resources that are consumed by those activities. They also recognised that as a buyer, their line of visibility into their subcontractors' cost information is shallow.

DISCUSSION

This research sought to understand the problem of costing in a way that allows the industry to move on and account for improvements in work processes rather than rely on gains obtained through commercial buying practices and opportunism. Discussion on costing in the UK construction industry focuses a lot on reaffirming established methods currently used by practitioners and so, (with exception of Zimina *et al*. (2012) and Ross and Williams (2013)), does not ask important questions of efficacy for assessing work processes across the supply chain. This questioning needs to go beyond the concept of improving productivity (e.g. Sezer and Bröchner, 2013). As participants in this case study revealed, in their explanation of 'working to a price', the concept of productivity has the connotation of how much labour you can get out of someone. This privileges self-interest over improving wider processes.

If a contractor is looking to a subcontractor to undertake improvement for the sake of the supply chain, they need to be able to assess this and reflect it in their payment process (i.e. pass on the reward). Zimina *et al*. (2012) looked at target costing and concluded that UK commercial and cost management practices are a major barrier to rewarding efficiencies through a pain/gain sharing payment process. Ross and Williams (2013) look at supply chain cost management and conclude that lack of transparency is a major barrier to rewarding cost and waste reduction through a payment process that protects each company's margin. This study supports the conclusions of Zimina *et al*. (2012) and Ross and Williams (2013) that it is very difficult for the construction industry to get good cost information that reflects the different work processes across the supply chain. Without such cost information, the industry can only enter into buying decisions on the assumption that what is being brought is already fixed. This does not achieve improvement. In a wider critique of improvement in the construction industry, Green (2011) demonstrates the fallacy of the argument that in a market where costs are driven down, subcontractors will be forced to innovate to survive.

The problem of costing needs to be understood in a different way as current practice does not contain the information needed for achieving improvements. What is required then is for the construction industry to look more carefully at alternative accounting practices. Accounting practices that reflect transactions in supply chains may be useful as these were adopted by other industries through the 1990s in response to increased competition and alongside the emergence of TCE. The most developed of the four main tools that account for the cost of transactions in supply chains, as compared by LaLonde and Pohlen (1996), was Activity Based Costing (ABC), which assigns accurate costs to products or services based on the resources they consume (Kaplan and Cooper, 1988). Tsai (1998) gave a framework for measuring costs under ABC in a two dimensional model adapted from Tsai (1998) as shown in figure 1.

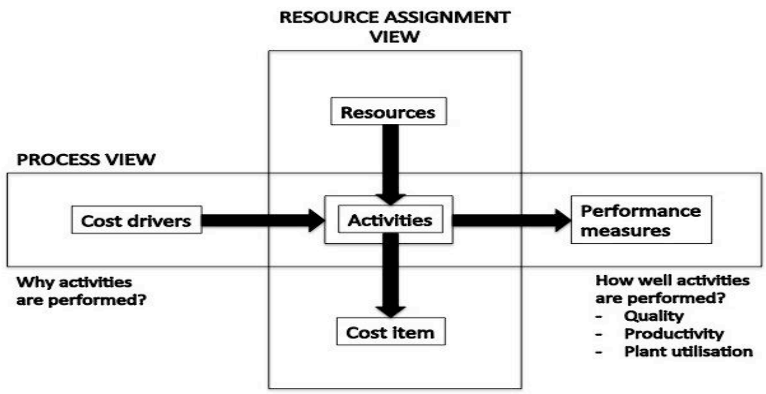

Figure 1: Two-dimensional model of ABC. Source: adapted from Tsai (1998)

The first dimension, the resource assignment view, includes information on labour, plant and materials but does not contain information on work processes (other than in labour which only assumes a measure of productivity). Without information on work processes the resource assignment view does not represent improvement well. However the second dimension, the process view, adds information on method in the form of 'cost drivers' that explain why activities are performed and 'performance measures' that explain how well activities are performed. Information on cost drivers can quantify improvements in work processes and information on performance measures can be used to fairly reward those improvements.

One barrier to accessing information on cost drivers and performance measures is the shift to larger supply chains in which both main contractors and subcontractors predominantly undertake to buying rather than making. Thus information is lost from the supply chain whenever information created about use of resources is missing as it is passed on as quotations for work. This is illustrated in figure 2.

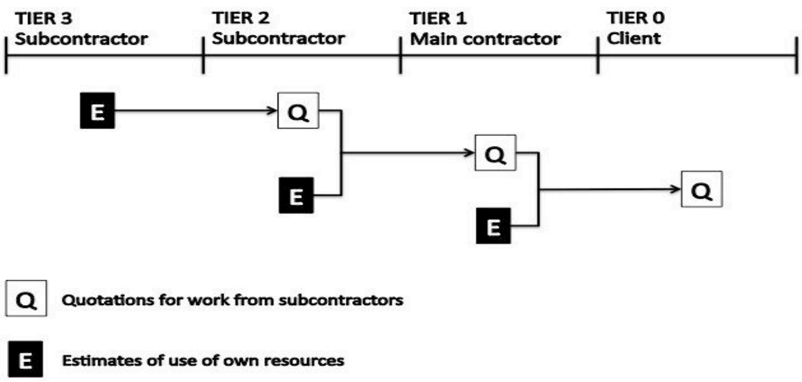

Figure 2: The flow of cost information through the supply chain.

The problem of information loss is exacerbated by different people interpreting the cost information that flows through the supply chain differently. Each of these people has a different use for the information and this dictates how the costs are interpreted. Most of the cost information in construction has been created for buying, payment and accounting purposes. So when it is used for other purposes it is inadequate. Because of this, getting even more of the current cost information, in no way improves the industry's ability to arrive at decisions that improve processes, or reward better site practice. Even worse, current cost information actually discriminates against improvement by driving perverse incentives and creating unintended consequences following cost information being wrongly used or underused.

BIM offers an immense amount of information that can be extracted from digital models into BIM based costing applications. Currently, digital costing applications are based on either simplistic object quantity take offs or the complexities of current approaches to quantity surveying. This sort of cost information does not adequately represent the reality of site operations; thus, automating this further or exploiting the greater level of detail of information offered by BIM cannot improve site operations as the cost information is at best constrained and at worst provides misleading information. To advance this situation, the construction industry needs to understand its costing processes better and to tie these more clearly to the purpose for which the costs are being used. In particular, the connection between site operations, the purpose for which costs are used, and the method of producing costs needs to be explored in much more detail to devise an alternative to current costing techniques.

CONCLUSIONS

This research has produced unique knowledge about costing by a main contractor and subcontractors. It has established how current costing practices lose information about site operations and methods, as it is transferred during a tendering situation. At each transfer, participants want different information from the costs; however, the ability to do this is limited by the original purpose of the cost. Current cost information is produced for buying, payment and accounting purposes. Thus, using the current costing methods in BIM is not helpful for use for a different purpose, such as evaluating and rewarding improved site practices and supply chain operation. It could, in fact, make things worse by producing more convoluted details that appear accurate but are not linked to what people do. If the industry needs BIM to deliver information that is useful for improving site operations, then this requires understanding cost information better and using costing methods that are tied to that aim. It is only this that will provide real benefits from BIM in relation to cost and improvement.

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Studying 'Cost as Information' to Account for Construction Improvements

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Abigail Robson, David Boyd & Niraj Thurairajah

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Studying 'cost as information' to account for construction improvements

ABIGAIL ROBSON*, DAVID BOYD and NIRAJ THURAIRAJAH

Birmingham School of the Built Environment, Birmingham City University, Birmingham B4 7XG, UK

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Contractors throughout the construction supply chain develop and use cost information. By treating 'cost as information', insights are generated into how cost information is created and flows from work carried out to a client cost. A case study of a main contractor's supply chain involved semi-structured interviews, workshops and document reviews. We considered whether contractors' current costing practices used for the purpose of pricing and cost control could support decision-making about improvements through the supply chain. The results show that firms recognize that current costing practices do not provide a good representation of work carried out. Cost information that is useful in a narrative that seeks to improve site operations is either not created or hidden in layers of assumptions and lost as it does not cross the boundaries between organizations. This implies that the implementation of current practices of costing in building information modelling will not increase the effectiveness of modelling construction costs for the purpose of improvements. However, cost information that is useful in decision-making about improvements could be created. This could be achieved but requires a systemic change, where new representations of cost are tied to work processes used within more stable procurement relationships.

Keywords: Building information modelling, contractor, cost information.

Introduction

The authority of costs appears everywhere in everyday life and cost information plays a central role in construction projects. The industry is challenged to innovate and reduce costs around the globe (Best and Meikle, 2015) and the digital representation and exchange of building information through building information modelling (BIM) is advocated across the world as an enabling technology to meet this aim (Eastman *et al.*, 2008). In the UK, the Cabinet Office (2011) called for a reduction of construction costs by 20% and the Department of Business, Innovation and Skills (2014) additionally called for a reduction in construction times and whole life costs. Both reports propose the uptake of BIM to enable change to meet their cost reduction targets. A review of international guidelines on the definition and expected outcomes of BIM undertaken by Succar (2009) included the potential for the adoption of BIM to reduce construction costs. Succar (2009) suggested that through BIM the cost of collection, storage and manipulation of information is reducing dramatically and consequently it should be easy to exchange integrated information that can be used to change the industry. However, a better understanding is needed of the type and purpose of contractors' cost information in current use in the UK and an assessment of its relevance for use in more integrated decision-making that will be possible in BIM to support change.

In this empirical study, the perspective of 'cost as information' is taken to seek to uncover the types of information that are behind the 'representations of costs' used in everyday practice. The findings reflect on the methods of calculation and the interpretations people put on the everyday representations of cost, in order to describe the actual praxis of cost reporting. The findings are then analysed to ask whether the representations of cost in everyday use by contractors and subcontractors are suitable to evaluate and reward improvements in subcontracting organization and practice? In seeking to understand the meaningfulness of

*Author for correspondence. E-mail: abigail.robson@mail.bcu.ac.uk

cost information against its uses, the findings from current practice are analysed using the terms of Dean (1993) who, working in the aerospace and space industry at NASA and looking into firms' ability to compete in emerging world markets, describes the 'variables behind cost information' and the 'types of information the cost of those variables are derived from' and 'the judgements people make' as cost information flows through their supply chain. Interviews, workshops and document reviews explore contractors' estimating, tendering and post-contract cost control practices and narratives in a case study of a supply chain involving a national UK main building contractor and five subcontractors from across three tiers of the supply chain. The findings suggest that cost information that flows up the supply chain consists of accepted representations of cost for the purposes of establishing market price, payment and budgeting. But potentially valuable cost information that is tied to the physical work carried out and useful for the purpose of evaluating and rewarding improvements in subcontracting organization and practice is either not created, or obscured and lost as cost information passes between organizations in the supply chain. Developments in management accounting show that this is not just a problem in construction, but in all industries (Chapman *et al.*, 2007). It will be shown that understanding how contractors derive and use 'cost as information' is key to developing cost information in BIM to support improvements across the supply chain. The study discusses the need to look at other practices of costing, e.g. from manufacturing, that have potential to be applied in construction in order to uncover cost information that is tied to physical work. In addition, the study explores how the complex nature of costing and procurement practices makes improvements difficult.

Cost as information

Cost models in construction

Cost is one type of information used in the construction industry. The costing practices that produce this information differ around the world; however, construction everywhere is criticized for its high cost and low predictability (Best and Meikle, 2015). The practices used by contractors to establish price and to control costs in construction projects fall within the general sphere of management accounting. Johnson and Kaplan (1987) in their seminal management accounting textbook in the US, drew attention to the shortcomings of management accounting arguing that it had become disinterested in direct measures of activities in the firm, relying instead on what they call 'surrogate' financial numbers, and thus reducing the instrumental value of cost information in providing management with a tool to better manage a business. This problem of 'surrogate' financial numbers, where there is a gap between the representation of cost and its meaning for activities, has been little addressed in construction research, even in the UK and its many Commonwealth countries that share a detailed and specialized costing process.

Formal costing models proposed by researchers for UK contractors' estimating, tendering and post-contract cost control practices reside substantially in quantity surveying textbooks. In the sphere of estimating and tendering, these textbooks (Kirkham, 2007; Towey, 2012; Greenhalgh, 2013) draw on the Chartered Institute of Building's (2009) code of estimating practice. All the texts identify the same cost model with three categories of cost as described by Kirkham (2007): estimates of the use of their own resources, quotations for work from subcontractors and overarching strategic tendering decisions. Kirkham (2007) contends that regardless of the project delivery method main contractors and subcontractors have the same task of building up a tender price from these three distinct categories of cost information.

Even as these formal cost models proposed in textbooks work on the detail, the gap between the representations of cost created and their meaning for practice is not acknowledged. For example, Greenhalgh (2013) analyses the three categories of cost in the model. Firstly in terms of a firm's estimates of the use of their own resources: he explains that cost estimates for work directly carried out by a contracting firm can be built up from 'first principles'; that is from the activities that consume internal resources of labour, materials and plant. These internal resource costs can be allocated to either site overheads (in preliminaries) or 'end items' (in unit costs). He explains that an 'end item', such as a brick wall, has a measured quantity and specification that influences the resources required. The materials required can be calculated by a simple mathematical relationship that includes allowances for material waste. The labour and plant required can be based on standardized rates for labour and plant productivity that are either captured in a work study or published in price books, and the estimator's expert judgement to adjust these for project factors. He argues that how contractors make best use of their internal resources is the main competitive differential between competing contractors.

The second type of cost information in the model described by Greenhalgh (2013) is quotations for packages of work obtained from subcontractors in competition. Here, the calculation and interpretation of the use of labour, material, plant in activities and the apportionment of risk contingencies, overheads and profit are usually all hidden from the receiving buyer who can only compare subcontractor quotations, negotiate and include the most favourable quotation on the basis of either lowest price or best value. In other words, the cost information available is based on comparative prices received.

Greenhalgh (2013) describes the third type of cost information in the model: the overarching strategic tendering decisions that convert an estimate into a tender. He describes how contractors must make expert judgements and best guesses about allowances for design and other risk contingencies and about the required margin to recover company overheads and earn a profit that the market will bear. The allocation of company overheads in the model is based on the use of internal resources allocated to the project using a calculation based on predicted company annual turnover. The allowance for design and other risk contingencies in the model is based on thinking about the degree of project uncertainty. The allowance for profit in the model is based on thinking about competition within the complex and dynamic project market. In other words, with the exception of company overheads, the costs in this category are based on expert judgement and best guesses.

The models proposed by academic researchers have sought to prescribe how project costs are built up to bidding price. However, even as the models describe the types of information that costs are derived from, the meaning of this for practice is not clearly documented and the transition in thinking made by Johnson and Kaplan (1987) towards a recognition that accounting uses 'surrogate' numbers rather than a direct measure of activities is not reflected.

Effects of commercial management on cost models

Researchers who have documented contractors' commercial management practices see the world differently and better recognize the problem of how the use of 'surrogate' numbers, based on expert judgement, comparative prices and best guesses, reduces the efficacy of cost information for accounting for improvements. Brooke (2008) documents his experience of how contractors' standard estimating guidelines are used in practice and argues that 'sometimes contractors have difficulty finding time to apply "first principle" costing to tenders'.

Ross and Williams (2013), draw on their experience and past research on commercial accounting in construction firms, to look at the flow of cost information up the supply chain from the firm that will do the physical work. They identify that it is unlikely that 'first-principle' cost information that shows how subcontractors make best use of their internal resources will pass up the supply chain, so contractors may not have a detailed understanding of their subcontractors' costing basis and decision-making. They also point out that as cost information flows up the supply chain many contractors are guarded when it comes to conversations about risk and margins so information on assumptions about contingencies, overheads and profit may be obscured in the allocation of costs in a cost model.

Others have shown that as information flows up the supply chain, information about use of resources may be obscured when the allocation of costs is treated as an opportunity to manage risk or maximize income or cash flow. For example, Laryea and Hughes (2011) in research into the actual process of how contractors price risk, show that different individuals and teams might influence pricing levels at different stages of bid. This may obscure information about the use of resources. Kenley (2003) and Cattell (2012) in empirical studies found that many contractors implement tactical pricing using weighting strategies to manipulate cash flow in their favour. Rooke *et al.* (2004), in an ethnographic study of contractors across seven construction projects, found a culture of planning for claims. In extreme instances, illegal practices may be used to distort cost models; such as 'bid shopping' in which the lowest price is disclosed to competitors who are invited to beat it (Vee and Skitmore, 2003) or overpricing, also known as 'cover pricing', an extreme instance of which is collusion (Lowe and Skitmore, 2006). These examples show how cost information that is tied to activities may be lost when it is obscured before it is passed across the boundaries between organizations.

The increase in the extent of subcontracting increases information loss across the boundaries between organizations. In a review of specialist trade contracting Hughes *et al.* (1997) explain that main contractors' general reduction in directly employed workforce and general increase in the level of subcontracting has been driven by technological, political, social and economic change since the 1970s. In a review of the construction industry structure from government statistics, Abdel-Razek and McCaffer (1987) suggest that success in obtaining tighter and tighter quotations from subcontractors during the recession of the early 1980s is amongst these factors contributing to the increase in the extent of subcontracting. Fryer *et al.* (2004) found that subcontractor quotes made up the majority of a main contractor's costs with main contractors typically subcontracting over 80% of their work. Ross and Williams (2013) argue that this fundamental change in the industry's structure means that the contractor's skill in negotiating quotations with subcontractors is now 'a significant competitive differential between competing contractors'. However, Hughes *et al.* (2006) suggest that the imperfect market, in which main contractors negotiate within a limited pool of subcontractors, acts as a limit to the competitive differential between main contractors. This, and the work of Ross and Williams (2013), contrasts with Greenhalgh's (2013) assertion that 'contractors main competitive advantage lies in how they make best use of their internal resources'. However, the increased use of subcontracting acts as a limit to this source of competitive advantage.

Ross and Williams (2013) describe how once the estimators have won a project the site team has the job of post-contract cost control to build the project within the budget they have been given. They describe how the site team will often get new material and subcontractor prices and compare these to the budget. This opportunistic, but standard, practice of undertaking a secondary competitive process with subcontractors near the commencement of the works often requires subcontractors to give an 'additional' trading discount on top of the standard trading discount offered in the first competitive process. As new prices are obtained, the site team carries out regular reconciliation of costs to completion against the budget allowance in a 'cost value reconciliation'. Ross and Hugill (2006), in an empirical study that involved a detailed examination of contractors' post-contract cost reporting processes in practice, found that the effectiveness of modelling 'true' construction costs during the post-contract stage is reduced due to 'entanglement of cost and price data'. They further argue that few organizations have formalized systems for capturing and analysing data from site to refresh standard 'surrogate' numbers in estimating.

Thus researchers who have documented contractors' commercial management practices from empirical studies about what contractors actually do have recognized that representations of the costs of activities that would help to prescribe improvements may not be created due to lack of time, or may be obscured by strategies to recover the cost of risks, maximize cash flow or maximize income post contract.

Moves to costing that accounts for improvements

Within the debate on construction improvement there is a move towards building financial incentives for improvements into construction delivery models. Target costing became a widespread strategic management tool in manufacturing (Ansari *et al.*, 1997) and has been adapted to construction through 'target value design' (TVD) (Zimina *et al.*, 2012). This requires early involvement in design, and seeks efficiency savings by rewarding contractors and key subcontractors with a financial pain/gain share. It achieves this using a 'cost plus incentive fee' method that uses open book accounting to establish cost and share the difference between target cost and actual cost. Amongst the body of research into target costing in construction (Ansari *et al.*, 2007; Ballard, 2011) there is a small strand of empirical research into the application of target costing from the contractors' perspective. These empirical studies from contractors' viewpoints report significant limitations. Nicolini *et al.* (2000), in a study of two demonstration projects that used target costing and allowed praxis to become available for analytical description and critical account, conclude that UK commercial and cost management practices are a major barrier to rewarding efficiencies through a pain/gain sharing payment process. Pennanen *et al.* (2011) looked at TVD in theory and conclude that more transparency of information is needed to gain commitment, but do not address specifically the problem of cost information. Zimina *et al.* (2012) looked at TVD in practice and conclude its application is limited by factors including the cost information available for setting a target cost. Only Nicolini *et al.* (2000) focus specifically on limitations due to the type of cost information available.

A simpler way to build financial incentives into a construction delivery model is the decoupling of profit margins from savings in a lump sum contract through supply chain cost management (Pryke, 2009). Used in conjunction with early involvement in design, this facilitates design savings by decoupling margin from each unit cost in the cost model so that design savings can be made without eroding margin. This would mean that contractors and key subcontractors are guaranteed a total margin upfront. Ross and Williams (2013) argue that this alternative way to reduce costs directly addresses the disincentive to make savings created by the predominant business model adopted by contractors, to maximize cash flow. However, they conclude that lack of transparency in UK costing practices is a major barrier to rewarding cost and waste reduction through a payment process that protects each company's margin. Thus, studies of the use of cost information in practice have shown that the improvement aims of these two new delivery methods are compromized by the representations of cost in current use that rely on 'surrogate' financial numbers.

Better information on costs is promoted as an end point for developments in BIM. But this is a fallacy, as it does not address the problem of 'surrogate' financial numbers. Literature on cost information in BIM, such as Monteiro and Poças Martins (2013), shows that academic and industry research and software development in costing applications in BIM have to date focused on BIM's ability to automate the current practices in estimating, tendering and post-contract cost control. Monteiro and Poças Martins (2013) show that software is most developed for automating the process of measuring quantities using rules-based systems to extract dimensions from computer-aided design models. Wu *et al.* (2014) show that computer-aided estimating (CAE) software that uses rules-based systems to manipulate historical cost data on unit costs to create project related data, has been slower to develop. Lawrence *et al.* (2014) argue that development of CAE software that reproduces current representations of cost and do not challenge the way that cost information is interpreted will not lend itself well to automation.

Researchers who have looked at the cost information available to support the types of cost models proposed in incentive contracts, have recognized the current representations of cost may be inadequate for motivating improvements. Thus, the use of current representations of cost in BIM will not motivate improvements.

Alternative cost models from other industries

Addressing the accounting problem in other industries researchers Chapman *et al.* (2007), explain in a management accounting textbook that the field of management accounting emerged to facilitate financial budgeting and control but broadened over time to encompass new types of analytical cost reduction practices. The main source for these analytical costing practices has been Williamson's (1981) analytical research that produced a theoretical model of transaction cost economics (TCE), which sought to compensate for flaws in the market-oriented view of perfect competition by focusing on how organizations can avoid dependence and deal with opportunism. TCE has been criticized for sticking to the limited solutions of make or buy, ignoring the possibility of intermediate solutions based on relational contracts (Ghoshal and Moran, 1996). Nevertheless, the new analytical tools for costing that emerged in manufacturing and retail sectors alongside TCE during the 1990s provide an array of analytical tools that span different levels of accounting, but nevertheless have the potential to uncover some models for cost information that are tied more closely to physical work as advocated by Johnson and Kaplan (1987). LaLonde and Pohlen (1996) compared four such models: (i) Kaplan and Cooper's (1988) activity-based costing (ABC) method of assigning accurate costs to products or services based on the resources they consume; (ii) Carr and Christopher's (1992) total cost of ownership method that looks at the total costs between two neighbouring firms in a supply chain; (iii) Kurt Salmon Associates', (1993) direct product profitability method that considers the logistics of moving items between supply chain firms and (iv) Weeks and Crawford's (1994) efficient customer response method that focuses on reducing whole supply chain costs through a better transfer of information, automating administration processes and unifying replenishment cycles. LaLonde and Pohlen (1996) argue that a hybrid of these tools offers a new costing system that reflects the several different facets of supply chain relationships that need to be accounted. Of these analytical tools ABC has been most researched and applied in practice as a means of providing costs that are a good representation of work carried out. Dean (1993) also took a similar position to Johnson and Kaplan (1987) concluding that project cost information has little relationship to the work carried out and advocated ABC as a way of better representing work carried out. However, he also described the accounting 'noise' inherent in even the most detailed ABC costing tools. He described the competent estimator as someone who uses a combination of calculation (data), standard rates (analogy) and judgement (expert opinion) to create predicted costs. He identified the variables that are included in a project cost that obscure costs from a good representation of work such as the cost basis of a firm's resources, the buyer a firm will buy from, the existence of trading discounts, the personal skills of negotiation, inflation and market conditions and risk evaluation. Thus, alternative cost models from other industries offer new analytical tools but a realistic assessment is required of the representations of cost they provide.

Despite this shift in cost accounting in manufacturing, retail and aerospace industries and the pressure for the construction industry to embrace learning from other sectors such as the automotive industry as advocated by Egan (1998) and the aerospace industry as advocated by Green *et al.* (2005), construction project cost accounting literature has remained largely within the realm of establishing representations of cost for the purpose of pricing and budgeting. The few exceptions include O'Brien and Fischer (2000) who used a practice-based case example and applied ABC to calculate the capacity costs to account explicitly for the cost of fixed expenses within firms in the construction supply chain. Also Staub-French *et al.* (2003), who carried out a practice-based case study and applied ABC to account more explicitly for the cost of design features in construction projects based on the preferences estimators had for when to adjust standard costs. This aimed to help estimators customize early stage construction cost information based on design features. Lawrence *et al.* (2014) subsequently developed this approach, enabling this in BIM. However, even with major changes in delivery methods, e.g. early contractor involvement and relational contracts, and in technology, e.g. BIM, the industry is still largely locked into its current practices of costing and the basis of this and its consequences needs investigating further in order for it to benefit from the changes. Understanding how contractors derive and use cost as information is key to developing cost information in BIM for the purpose of supporting decision-making on improvements across the supply chain.

Method and methodology

Methodology

The research is grounded in the interpretivist tradition and explores the narrative around cost and costing, in order to know what organizations and individuals do and why they act as they do (Walliman, 2006; Easterby-Smith *et al.*, 2008). The research uses the concept of 'cost as information' to challenge the basis and practicalities of costing practices. Cost, then, is merely a representation of resources, purchasing possibilities and risk, but this is made problematic when unit costs are given meaning by people and become fixed reference points in construction projects. This research did not therefore start from propositional knowledge of current practices, but rather looked at the variables behind cost information, where that cost information is derived from and how it is used, seeking to better understand what cost information means to different people. The research did use propositional knowledge from costing documents and reports but explored this from an experiential and performative perspective. This allowed the study to explore narratives from the calculative world of costing. Its objective was to explain current approaches to costing and explore the potential for accounting for improvements. The research questions addressed were: How does cost accounting currently work in relation to work processes in the supply chain?; How do subcontractor accounting processes facilitate knowledge transfer, integration and management of the supply chain?; and How can information infrastructure and platforms such as BIM more accurately represent net supply chain benefits through accounting?

Research method

To address these research questions this study used a case study of a supply chain involving a UK main contractor and two links of their supply chain. The main contractor (tier 1) is a large, national organization with an annual turnover of over £1 bn of which around 70% is spent in a supply chain of around 3000 firms. The subcontractor (tier 2) in link A is a large, national mechanical and electrical subcontractor with an annual turnover of over £350 m of which 60–70% is spent in their supply chain. This subcontractor facilitated access to one of their subcontractors (tier 3), who in turn facilitated access to one of their subcontractors (tier 4). The subcontractor (tier 2) in link B is a small, regional suspended ceilings, partitions and dry-lining subcontractor with an annual turnover of under £10 m. This subcontractor facilitated access to one of their subcontractors (tier 3). The relationships between the organizations is shown in Figure 1 where the main contractor is notated as MC and the subcontractors are notated as *SCA1, SCA2, SCA3, SCB1, SCB2* to reflect links A and B and the tiers in the supply chain.

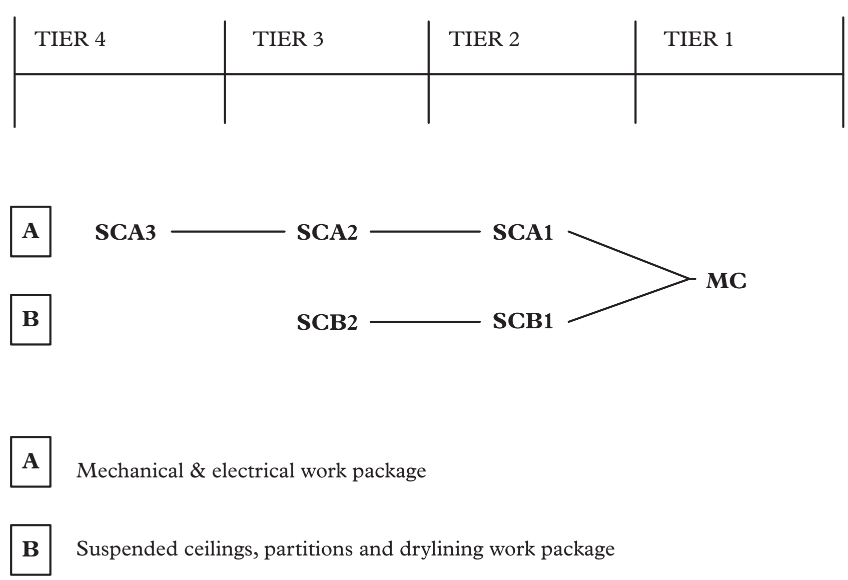

Figure 1 The relationships between organizations in the case study

The sample represents two typical links of a main contractor's supply chain in the UK. The two trades studied are similarly subservient to the same financial, contractual and procedural control of the main contractor. The major difference between the two trades is that the mechanical and electrical subcontractor has significant design contribution, which adds vulnerability to the main contractors design programme. This difference has been taken into account in the analysis of the findings.

This case study involved the main researcher as a non-participant observer, observing, listening and following decisions through projects as part of the main contractor's organization and carrying out semi-structured interviews and workshops with the main contractor and subcontractors involved. This allowed access to detailed data on each company's costing practices in a case study of a supply chain. A contractor's supply chain is an ephemeral, temporary organizational relationship and as such it is difficult to investigate the problems of construction supply chains. The conflicts of interest and the ethics that the study involved were carefully managed to be sensitive to the contractors' positions so as to gain full access to the reality of their situation. To maintain confidentiality, the study used a different project for each organization. However, each project involved the construction of a similarly large, complex, one-off building in which the contractor did not control the design phase. Interviews established that similar processes are carried out on all similarly large, complex, one-off projects.

Data collection and analysis

The researcher observed 10 of the main contractor's site meetings over two projects in order to follow decisions. Data collection with the main contractor and tier 2 subcontractors then involved semi-structured interviews to evidence what people do when sourcing and using cost information and document collection to evidence cost processes through written cost reports. The interviews firstly asked questions about how the company goes about putting a price together for a project and controlling costs once a project has been won. This aimed to find out what cost information is created and how methods of costing reach through the supply chain. The interviews then asked questions about how key relationships work to find out about organizational behaviour and decision-making in relation to the supply chain. The interviews gave the researcher the opportunity to get participants ideas, thoughts and intentions on current practice and on changes to current practice. The documents collected consisted of the full estimating build-ups, priced tender documents and post-contract cost control documents for a completed project from the main contractor and the two tier 2 subcontractors. Access to this confidential data was provided on the basis of confidentiality conditions being met.

Two workshops were held during the course of the project. In the middle of the project a reflective group discussion took place with five key participants in the main contractor's pre-construction and site operation teams. Towards the end of the project participants from each of the four tiers of the mechanical and electrical supply chain were brought together for a reflective group discussion. These discussions gave the researcher the opportunity to help the participants explore the use and implications of cost information across the firms and in projects.

The interviews and workshops were recorded and transcribed by a member of the research team. In order to describe, understand and explain contractors' practices of costing and compare these to literature thematic coding was used in alignment with the four main themes established in the literature review: estimates of use of internal resources, quotations for work from subcontractors, overarching strategic tendering decisions and post-contract cost control. Through focused coding each main theme was further categorized to identify examples of methods of costing, organizational behaviour and decision-making, help or hindrance to improvements in site operations. The work of Dean (1993) was used as a framework to analyse the cost information that contractors create to determine, in Dean's (1993) terms, the variables behind cost information used in the practice of costing, the types of information the costs of those variables were derived from (which might be data, analogies, expert opinion, best guesses, comparative prices) and the flow of cost information through the supply chain.

Real practices of costing: empirical findings

This empirical research aimed to establish whether the cost information created by a main contractor and subcontractors during estimating, tendering and post-contract cost control is useful for assessing improvements in site operations. In these findings the main contractor is notated as MC and the subcontractors are notated as *SCA1, SCA2, SCA3, SCB1, SCB2* to reflect links A and B and the tiers in the supply chain. Documents and interviews established that, once the main contractor or subcontractor had decided to submit a tender, their estimating and buying functions face the task of building up project costs from a number of constituent parts and their commercial function has the task of synthesizing the information into a commercial tender. Once a project has been won the site team has the job of building to the budget. It was seen that because subcontractors themselves subcontract work, the distinction between main contractor and the subcontractors falls away in terms of their practices of costing. The practices of costing described in these results therefore show no distinction between those of the main contractor and the five subcontractors. The only exception is SCB2, the labour-only subcontractor at the end of link B.

Estimates of use of internal resources

Participants explained that the estimator creates 'first principle' cost information to forecast their direct costs for work that will be carried out using their company's internal resources. To establish the scope of these works the estimator checks, and hence improves, data received on quantities and specifications for 'end items' of work and customizes these for work that is under or over measured, or under or over specified. Once the scope of the works has been established, the estimator sets about creating project cost information based on, in Dean's (1993) terms, variables in 'the cost basis of the firm's resources'. The cost basis for directly employed labour is derived from annually updated company schedules on salaries that are based on national wage agreements and salary on-costs. The cost basis for directly owned plant comes from company schedules. The cost basis of regularly used materials and hired plant is derived from regularly updated company schedules of negotiated prices from suppliers. The estimator's information about the supply cost of direct labour, material and plant was thus found to be derived from, in Dean's (1993) terms, a high level of detailed cost 'data' closely related to final cost.

The estimator then forecasts the activities, resources and resource productivity rates for 'end items'. The cost basis of labour productivity rates, plant utilization rates and materials wastage are derived from either company or industry standard rates based on previous project experience. One contractor explained how feedback on company standard productivity rates from colleagues working on site was treated as a way to build in contingencies, so that the relationship between productivity rates used to the actual work done was obscured.

> There are industry standard resource and productivity rates for activities but we create our own. We reviewed our labour productivity four years ago with our site operatives. We identified efficiencies, but then we didn't change our productivity rates because we were in a rising market and all costs were going up. (SCA1)

The estimator's information about the productivity of direct labour, material and plant was thus found to be derived from, in Dean's (1993) terms, a high level of detailed cost 'analogies'. It was found the original industry or company standard analogies were based on detailed data from site operations, but the context of any particular project and sometimes a layer of commercial decisions, somewhat lowered the relationship of this type of cost information created to the actual work done and thus became 'surrogate' numbers to represent activities.

Quotations from subcontractors

For the main contractor, 70% of the price information building up to the cost to the client comes from quotations received from subcontractors. SCA1 and SCB1 also subcontract as much as 60–70% of their work. Within the main contractor and subcontractors, the buyer, sets about creating project cost information knowing that the variables include their judgements about the firm they are buying from, their skill at negotiating and the existence of discounts.

Participants explained that the existence of discounts has a unique hold on the construction industry. One of the features of subcontracting is a two-stage competitive tendering process, where competition is imposed on subcontractors both before a bid is placed and again before an order is placed. The secondary competitive process takes place much nearer to the commencement of the subcontract works. Participants explained that it is standard practice that a selected subcontract price comes with a stipulated level of 'standard trading discount' that recognizes trade business. On top of this, the buyer often assumes a further level of 'additional trading discount'. The discount is usually passed down the supply chain to the dis-benefit of the subcontractor at the bottom. However, participants explained how knowledge of additional trade discounts were treated as a way to obtain competitive advantage before the discount was secured from a subcontractor through the secondary competitive process. Two contractors explained that they usually take the risk that an additional trading discount, or more, will be realized in further negotiations if and when an order is placed. Thus, participants recognized that trade discounts are part of the 'noise' in the accounting system that may or may not make cost information closer to the 'real' cost of work carried out.

> Subcontractors never give their best price first. We pre-discount our price when we put our price in. So we take a discount off their prices so you add all these subbie costs. We'll pre-discount ours before we sell it. (SCA1)

> Quite often it's pre-discounted so already the client has had the benefit. The person carrying the risk [that the additional discount will be realised when an order is placed for the subcontract] is us. (MC)

As explained by one contractor, the relationship between the buyer's information on cost obtained through quotations and the final work carried out is largely unknown.

> Some contractors will make double the margin they expected to make and other contractors, they'll make half the margin they expect to make. You can guarantee only one of them is going to bang your door. (MC)

SCB1 explained they subcontract all their site labour to labour-only subcontractors, such as SCB2. They engage SCB2 on an output related incentive scheme. A daily price is set based on an expected output and SCB2, the end of the supply chain, takes the full risk of exceeding or falling short of the expected output rate. Tier 2 does not need an accurate output rate as they pass the risk on to tier 3. When the risk of poor productivity is passed on in this way the 'real' productivity on site remains largely unknown.

> All the labour instead of being paid on day rate is paid on price. The more they put up the more they earn. It gives them an incentive. If they bust a gut they will earn more than on a day rate. But if they slack off, it doesn't hit our pockets, it hits them. (SCB1)

The buyer's information about the cost of subcontracted works was thus found to be derived from comparative prices, in Dean's (1993) terms, costs of 'perceived purchases'. It was found that the layers of commercial decisions in subcontract prices effectively hid the status of the relationship between cost information created and the actual work done, becoming 'surrogate' numbers to represent activities as cost information was passed between firms in the supply chain.

Strategic tendering decisions

Within the main contractor and subcontractors, an analysis of estimated direct costs and subcontract prices is passed from the estimators and buyers to the commercial managers, who review the information and establish the project mark up. The mark up is made up of expert opinion on (i) anticipated cost of 'design contingencies' for uncertainty and level of risk (ii) a margin to recover head office overheads and a level of profit that is expected to be earned from the project and (iii) desire to win the project to deliver cash flow. One contractor explained how mark up information relies heavily on risk analysis and market intelligence to come to a figure that best accounts for project uncertainties and what the market will bear.

> We've had some vigorous debates about what the correct level of risk contingency should be on those jobs. We've had similar debates on every single job and it's the most subjective point that you could take. (MC)

The commercial manager's information about the cost of the project was thus found to be derived from, in Dean's (1993) terms, costs based on 'expert opinion' and sometimes 'best guesses'. It was found that commercial decisions about mark up, even at the lowest level of the supply chain, impart a weak relationship of this type of cost information created to the actual work done. The commercial manager reports to the director's team, who establish the total price to be tendered for the work in question.

When a tender is presented in a standardized format, such as a bill of quantities or schedule of rates, the contractor decides a gross price to be passed up in the unit cost for each 'end item' in the cost model. The gross price is made up of the net price of the measured item plus a share of the 'mark up'. Both the net and gross prices can be manipulated across cost items in a model.

> We like to have overvalue in our orders. So we get paid more than we pay out every month and that generates a surplus for our business. (MC)

The interviews establish that participants recognized that the cost information that is created and the price information that is passed on throughout the supply chain has many forces acting on it. Participants saw project costing as a process in which the relationship between cost information and work carried out can be slim and one that results in firms in the supply chain winning and losing on projects at each other's expense.

> There are two layers. Some people might take a few bob off to win a job but the figure they take that from is a figure which people have already made assumptions on. (MC)

> We usually list our clarifications and assumptions. Most people ignore that. (SCA2)

> There is a lot of manipulation in bills and a lot of game playing. So to try and get the truth we'd love to see what the true net costs are. There are so many people playing different versions of the same game it's really difficult to strike a line through and say, that's reality. Because we know that it's the rough with the smooth you don't really entertain that because their opportunity is in the

next job too. So that's the drive for the game playing you get. (MC)

One participant described the limitations of current cost data in supporting improvements through value engineering exercises that are superimposed on traditional procurement models based on transactional forms of contract and competitive tenders.

> When you get involved in the value engineering process, you start off with the job that's been well considered, but then we embark upon this period when we undo all that work and we pick at all the edges of it. So that the coordinated piece of design now has got different assumptions. (MC)

Post-contract cost control on site

Participants explained how a successful tender becomes a target for the site team to budget and control costs against, providing cost envelopes for the post-contract project phase on site.

> We apply risk costs, overheads and profit, as agreed in the settlement meeting with directors and this form becomes the financial record of our tender. If successful this passes to the project delivery team and particularly procurement as a record of decisions made at tender stage to come to our offer. (SCA1)

Participants showed that information on variances from the budget comes from records of internal resources and records of buying losses or gains for subcontracted work. The focus is on overall predicted profit on the job.

> I look back at jobs and think, oh, we made a good percentage margin on that, we did really well. But actually, what should we have made if we had been more effective at design coordination and sequencing? (SCA1)

> When we get invoices in, we record the invoice date, who its from, and the value and each month we do an application to the main contractor that goes in the sales figure rather than purchases and we keep a running tally which will give us our profit at the end of a job. (SCB1)

Participants recognized that firms across the supply chain each hold their own version of project cost and even the cost information held by the firm that carries out the physical work has many factors acting on it. The result is so much accounting 'noise' that a 'true' project cost that is an accurate representation of the costs of production and useful for discussions about improvements, remains unknown.

Discussion

The problem of current practises of costing

The literature on construction costing substantively fails to ask important questions about the efficacy of cost information for assessing work processes across the supply chain and (with exception of Nicolini *et al.* (2000) and Ross and Williams (2013)) instead focuses on reaffirming established practices of costing. Participants showed how, as cost information flows through the supply chain, information about the use of resources is either not created by the subcontractor who will actually do the physical work, or obscured as it is passed on simply as quotations for work in a tendering situation. Participants talked openly about the layers of commercial decisions that remove cost information from a good representation of use of resources and result in 'surrogate' numbers from the bottom of the supply chain upwards build up to the cost to the client. This information loss has increased as the industry's structure has shifted to an increasingly multi-tiered system of subcontracts in which each subcontractor in turn parcels out smaller and smaller packages of work as illustrated in Figure 2.

This information loss is not a problem when merely using cost information for client reporting, buying, payment and budgeting purposes, but when cost information is used for the purpose of reflecting improvements across the supply chain, the information loss matters because the cost information available does not adequately reflect the work carried out. Because of this, getting more of this current cost information in no way improves the industry's ability to inform decisions that improve processes across the supply chain. Even worse, current cost information discriminates against improvement by driving perverse incentives and creating unintended consequences through cost information being wrongly used or underused.

The construction world is currently dominated by the advent of BIM, which presents an opportunity to handle a greater volume of information more meaningfully. BIM may therefore be the opportunity to use cost information that has a strong relationship to work carried out as an analytical tool. However, the main software applications for costing in BIM, such as BIM Measure, Cost X and QTO, all connect costs to objects. This limits the possibility of connecting costs to work methods. Thus, the introduction of BIM that will facilitate, and in some cases automate, information analysis will not meet a purpose of improving construction site operations if it only reproduces current cost information. Incorporating current practices of costing in BIM is in fact dangerous as more detailed information is assumed to be more 'accurate' and more

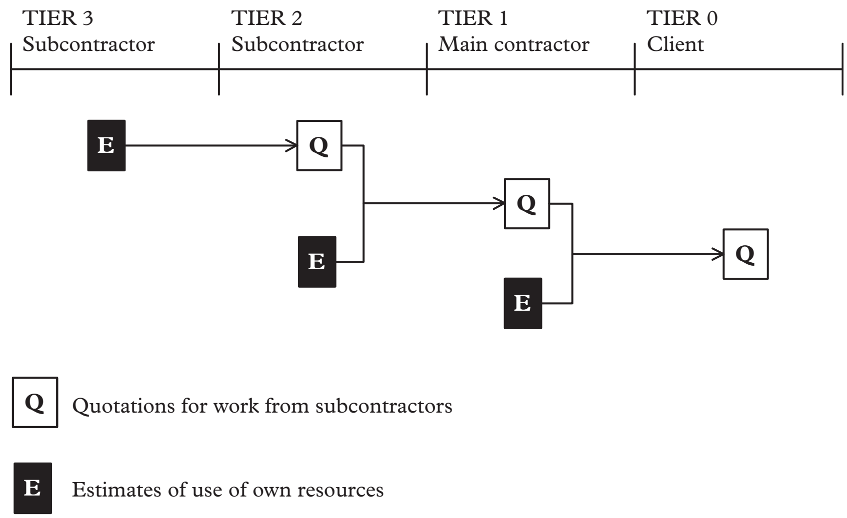

Figure 2 The flow of cost information through the supply chain

'valuable' but will only produce more convoluted details that are not tied to what people do.

Different accounting practices

This being the case, then efforts to consider alternative costing practices that better represent work done are required. The problems of costing in construction can be illustrated by considering work from management accounting practices on process costs of transactions in supply chains, as adopted by other industries through the 1990s in response to increased competition and alongside the emergence of TCE. Of the four main tools that account for transaction costs in supply chains compared by LaLonde and Pohlen (1996), ABC is the most developed method of assigning accurate costs to products or services based on the resources they consume (Kaplan and Cooper, 1988). Tsai (1998) presented a conceptual framework for measuring quality costs under ABC in a two-dimensional model, which can be adapted for construction as in Figure 3.

The first dimension, the cost assignment view as represented in a bill of quantities or schedule of rates, incorporates information on labour, plant and materials that is related to the volume of work done in an activity (such as building a brick wall) but does not contain information on method (other than in labour which only assumes a measure of productivity). Without information on method the cost assignment view does not represent improvements in work processes well. However, the second dimension, the process view, adds information on method, in the form of cost drivers that explain why activities are performed and performance measures that explain how well activities are performed. Tsai (1998) defines a process as 'a series of activities that are linked to perform a specific objective'. Although this is a careful perception, this overlooks the fact that there is an important difference in the meaning of 'activities' between the resource and process views. For example, a typical activity in a resource assignment view would be 'building a brick wall'. An activity in a process assignment view would in fact be series of linked activities, which are themselves part of an overall system that brings about the brick wall. Dean (1993) recognized that systemic costs can be derived from 'measurable characteristics' of either the 'product' or the 'system to develop the product' and that both need to be controlled and managed. If the product and the system to develop the product are described, then the 'measurable characteristics' that drive cost can also be described: such as company standards, the degree to which participative management is used, requirements in method statements, the degree and type of training and contractual obligations. This difference between discrete 'activities' related to volume and systemic linked 'activities' unrelated to volume and part of an overall system is lost in Tsai's (1998) two-dimensional model, where the 'activities' appear to be common between the resource assignment and process views.

Thus, promotion of new procurement models in construction that include new models of pricing, such as supply chain cost management and target costing practices, will struggle to support improvement because continued use of 'surrogate' cost information does not represent a good understanding of work done. Thus, this study supports the conclusions of Nicolini *et al.* (2000) and Ross and Williams (2013) that these accounting practices are not immediately transferrable to the construction industry.

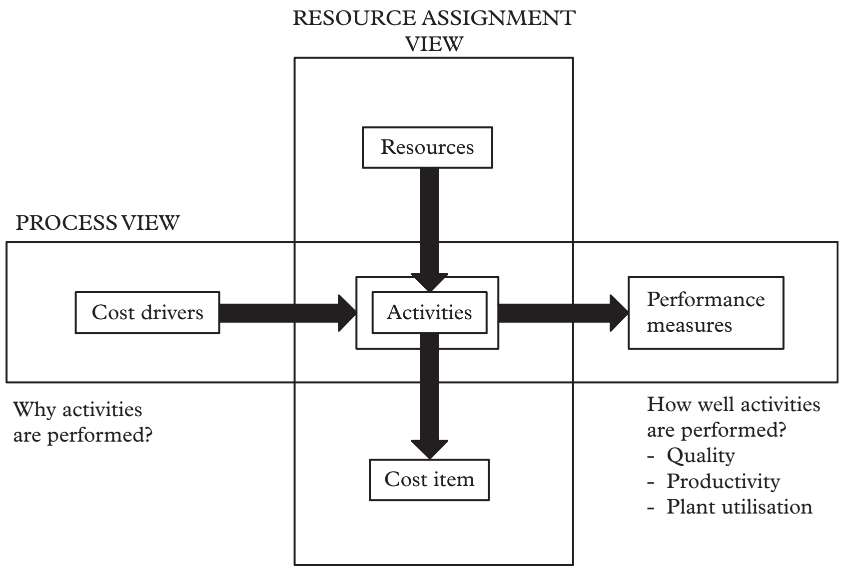

Figure 3 Two-dimensional model of ABC.
Source: Adapted from Tsai (1998).

Future opportunities

The complexity of the situation of costing must also be seen in relation to the operation of the industry. Green (2011) shows that the continued problems of the construction industry demonstrate the fallaciousness of merely adopting a different management tool (or costing practice) and to argue that solutions are 'just round the corner'. The solutions are not 'just round the corner' by adopting the rhetoric of supply chain costing or target costing. This study argues that the solution needs to be much more meaningful for the purpose of assessing improvement in site operations and that this needs to be rewarded in procurement and displayed in BIM if this is to be useful in improving supply chain practices.

Robson *et al.* (2014) undertook work on the attitudes of construction subcontractors to the advent of BIM. They found that BIM and new forms of cost information were attractive only in more stable supply chains. However, they used evidence from Green *et al.* (2008) that the industry works effectively and sustainably because of its dynamic capabilities, i.e. the flexibility to form short-term project supply chains associated with the fragmented structure of the industry. Thus, this research contends that the challenge for costing is to find a model where multi-layered supply chains can see the value in, and be rewarded for, working differently. If a new cost accounting system is to have any impact, it needs to be applicable to one–off, project-based supply chains as well as longer term supply chains.

The implication from this is that future opportunities in costing that can account for improvements lie in better understanding the realities of construction projects. The ability of systems thinking to comprehend and address the whole (people, processes, information and structures) offers a way forward through taking an information approach to learning to improve within the supply chain. Thus, information on 'measurable characteristics' of both the product, and the system to create the product, needs to be used to account for improvements in construction projects. For example, as participants in this study revealed there is the expectation that some subcontractors doing the physical work will cover the costs of poor collaboration and others will side step these costs, but the costs of this are currently unacknowledged, so at the moment costing is not fit for the purpose of accounting for improvements in work processes. BIM may offer the opportunity to implement change but only if it can work with more transparent cost information that has not just a strong relationship to the product, but also to the system that brings about the product. A future system of cost accounting that ties costs to both the product in the BIM design model and the system that brings about the product in connected BIM models would be a powerful tool for implementing change. This requires a systemic change in which new costing tools are an aid to an information approach to learning that is set within new supply chain relationships (including procurement practices and payment practices), which can deliver improvement in the delivery of work.

Conclusions

This research has produced unique knowledge about the real costing practices of a main contractor and subcontractors. The empirical research ascertained what a main contractor and two of their subcontracting trades at tiers 1 and 2, and in one case tier 3, actually do about costing across the estimating, tendering and post-contract cost control processes. This was achieved through a case study with a comprehensive method for observing and reflecting on what participants do when they produce and use cost information. Whilst the case study is of a single contractor's supply chain, and variations certainly occur in other contractors and internationally, the parties reiterated that these practices were universal in the projects they work on. This might not be the case elsewhere but, other studies, in both construction and other industries, have found that the same problem of 'surrogate' numbers is a barrier to implementing improvements. The findings establish how current costing practices both may not create information about site operations and methods and may lose this information as it is transferred during a tendering situation. Current cost information is produced, really only, for buying, payment and budgeting purposes. The industry faces a problem for achieving improvements in supply chain practices, as costing tools, such as target costing with open book accounting, are inadequate for the job when based on current representations of cost. The problems with costing and the actual management practices in the industry require a systemic change to effect improvement involving not just new templates, but new cost information and changed supply chain relationships. The advent of BIM has been presented as enabling more accurate information in formal analytical models. BIM could be part of this; but if BIM is used to merely reproduce current cost information, BIM will not produce any better information for improvements. Indeed, the automation of current costing practices in BIM could make things worse by producing more convoluted details that are not tied to what people do. This requires more research into 'cost as information'. If the industry needs BIM to deliver information that is useful for improving practice then this requires understanding cost information better and using different costing practices that are tied to this purpose. It is only through this that it is possible to have better information for decisions about real improvement in supply chain practices.

Disclosure statement

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