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GORDON INSTITUTE
OF BUSINESS SCIENCE
University of Pretoria

Managing the Quality of Engineering on Large Construction Projects in the South African Context.

By Francois Lombard

A research project submitted to the Gordon Institute of Business Science, University of Pretoria, in partial fulfilment of the requirements for the degree of Masters of Business Administration.

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Abstract

This research focussed on improving the quality of construction in South Africa by exploring best practices for the quality management of engineering. The research was motivated by several international studies and local press reports pointing to a general lack of quality focus in the construction industry and that engineering is one of the major causes of quality problems in construction.

The research approach was to obtain expert opinion through a series of semi-structured interviews on the best practices for managing the quality of engineering in the South African construction industry, comparing these practices to international best practices and determining if the experts believe fundamentally unique practices are required by the South African environment.

The findings of this research make a contribution to improving the quality of construction in South Africa by providing a number of best practices suggested by South African experts that are aligned with the international literature, providing a number of recommended international best practices, that local experts believe are appropriate to South Africa and finally by concluding that experts believe that, apart from special practices needed to address shortages of engineering skills, international practices, techniques, tools and systems are applicable in South Africa.

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Declaration

I declare that this research is my own work. It is submitted in partial fulfilment of the requirements for the degree Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University.

Francois Lombard November 2006

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1 Introduction to Research Problem

1.1 The Global Construction Industry

The construction industry delivers its products in complex environments that are unique to each specific project with regard to attributes such as workforce, technologies, contract arrangement, location and owner requirements. The global construction industry contributes about 10% of the world economy (Construction Industry Development Board, 2004). The construction sector is one of the most important parts of most countries' economy. The efficiency and effectiveness of the sector's products determines the overhead costs paid for built infrastructure by the entire economy and this has a critical influence of the competitiveness of each nation (Toakley & Marosszeky, 2003).

Many governments are actively promoting more efficient and effective local construction industries to improve resource utilisation and productivity for the greater good of their local populations. Love, Irani and Edwards (2004) cite studies in Australia, Finland, Hong Kong, Norway, Sweden, Singapore, and the United Kingdom that calls for radical improvement of quality and productivity in the construction industries of these countries. Many studies in these and other countries point towards a general lack of a quality management focus in the construction industry (CII, 1989; Jafaari, 1996; Love, Li & Mandal, 1999a; Love, Mandal & Li 1999b; Love, Smith & Li, 1999c; Oakland & Aldridge, 1995; Love & Li, 2000a; Love, Smith, Treloar & Li, 2000b). This lack of quality focus seems to be a global phenomenon and has been attributed to various causes such as the fragmented nature of project supply chains, a lack of holistic understanding of quality management principles, the difficulty in applying a consistent approach to quality across multiple unique project environments and the perceived lack of clear financial benefits from implementing quality systems.

1.2 The South African Industry

South Africa has not escaped the problem of a lack of quality focus in the construction industry. The South African construction industry is under pressure due to a combination of factors such as skills shortages, lack of standardisation, delays in payment, increased fee competition and variable quality (Loxton, 2004). A report on construction industry status (CIDB, 2004) states that only about half of projects are delivered on schedule, within budget and relatively defect free, and that there is low satisfaction with the performance of contractors and consulting professionals. A paper presented at the 2002 International Conference on Construction in the 21st Century (Dlungwana, Nxumalo, van Huysteen, Rwelamila and Noyana, 2002) describes some of the problems caused by poor performance of contractors in the South African construction industry. One of the predominant problems described is poor quality.

A decline in demand for construction services in South Africa in the last decades of the previous millennium led to instability and interconnected structural problems within the industry. In 2000 the South Africa Government enacted legislation (Government Gazette, 2000) that called for the establishment of a Construction Industry Development Board (CIDB). The purpose of the CIDB is to implement an integrated strategy for the reconstruction, growth and development of the construction industry in South Africa. Government has a vision of developing a growing, internationally competitive local construction industry, while in the process creating sustainable employment and addressing historic imbalances. In this process it is clear that industry will require strong leadership and the promotion of best practices.

The construction industry is the third largest employer in South Africa and provides work for more than 500 000 people (SA Builder, 2004). According to the CIDB (2004) construction and construction related activities contributed approximately 5% to GDP in

2002. The total construction spend in South Africa in 2002 exceeded R 57.3 billion, with R 24.9 billion and R 20.5 billion contributed by the building industry and engineering works sectors respectively. Annual construction spend is expected to increase to more than R 75 billion in 2010, similar to peak expenditure levels experienced in the early to mid 1980s. Government predicts that expenditure for the infrastructure required to host the 2010 Soccer World Cup alone will amount to R 375 billion over the next four years (Mantshantsha, 2006). Construction spending is booming with public and private sector spending predicted to rise to levels unprecedented in 30 years (Hill, 2006; Venter, 2006).

Increasing infrastructure spending has made South Africa an attractive market for foreign contractors. The South African construction industry has recently come under increasing pressure due to globalisation and the opening up of local markets. The recent award of a major infrastructure project to a Chinese contractor has rocked the local industry. Creamer (2006a) notes that concerns have been raised that Chinese contractors entering the market are subsidised by their government and are competing based on non-market related cost structures and may ultimately overwhelm the local construction industry. The South African Federation of Civil Engineering Contractors (SAFCEC) questions whether the South African industry is ready to meet the challenge of international competition, specifically from China who has developed a surplus capacity in their domestic construction industry (Hill, 2006). China are reportedly "churning out" engineers and are able to offer engineering service on a very cost competitive basis.

Urgent action has been called for to prepare the local industry for global competition (Hill, 2006). SAFCEC has called for in depth dialogue between all stakeholders to ensure the preservation of the local construction industry. Issues to be addressed include ensuring that foreign companies abide by South African law, domestic skills are grown sustainably over the long term, domestic labour is used and that the social needs of South Africa are taken into consideration.

Despite calls for measures to protect the local construction against foreign competition, the Minister of Public Enterprise has in July 2006 made it clear that government will not intervene to protect local companies from foreign multinationals competing for tenders in South Africa (Mantshantsha, 2006). The minister has stressed that the local construction industry must become internationally competitive, this is in line with the vision that government articulated for the construction industry (Government Gazette, 2000).

Recent trends are also showing a reduction in skills in the construction industry in South Africa. The Engineering Council of South Africa have noted that the number of professional engineers registering, although more representative, have declined in recent years (CIDB, 2004). The numbers of students registering for engineering and related studies have also declined. ECSA have also recorded a fourfold increase in the number of complaints over registered professionals in the last three years (Venter, 2006). The ratio of engineers to general population in South Africa also compare dismally when compared to other countries (Theunissen, 2005); South Africa has 3166 people for every engineer, China has 130, India has 157, the UK has 311 and the USA has 389. Van Huyssteen (2002) in a summary of an industry status report notes that even where clients are satisfied with the quality of the delivered construction product, they are often dissatisfied with the level of quality of the professional services offered.

1.3 Causes of Quality Problems

Many studies have been conducted to determine the cost of rework caused by quality problems in the construction industry. These studies invariably state that the quoted figures only include the directly measurable cost of rework, and that many hidden costs are not captured. The cost of rework can range from 3% (Love *et al.*, 1999c) to as high as 20% (Cnuddle, 1991 cited Love & Li, 2000a). An often cited study is one that was conducted by the Construction Industry Institute (1989) on 9 large industrial construction projects. This study found that rework on average made up 12.4% of total project cost. Generally it seems that rework can conservatively be assumed to amount to roughly 10% of total project cost. A telling study by the Australian Construction Industry Development Agency (cited Love *et al.*, 1999b) noted that rework can be reduced to less than 1% of total project cost where quality systems are properly implemented.

In analysing construction quality problems, various studies have stated that the single largest contributor to rework on construction projects is design (Love & Li, 2000a; Abdul-Rahman, 1995; Love, Mandal, Smith & Li, 2000; Tan & Lu, 1995; Love *et al.*, 2000b; CII, 1989). The Construction Industry Institute (1989) study of 9 large industrial construction projects found that rework due to design error contributed an average of 79% of total rework cost. In many of the cases cited in the literature, design contributed more than 50% of rework costs.

1.4 Motivating the Research

A recent study of the South African standards and quality infrastructure commissioned by NEDLAC (*2001*) noted that it is widely recognised that the promotion of quality is of vital importance to a developing nation such as South Africa. The evidence from studies conducted in other countries and the problems experienced in the South African construction industry, suggest that the local industry can benefit greatly from improved quality.

No studies have been conducted to quantify the cost of rework in the South African construction industry, but based on studies elsewhere, the cost of rework in the South

African industry can reasonably be assumed to be 10% of the R 60 billion annual construction spend. Improvements in industry quality to reduce rework could save as much as R 6 billion annually. In addition such improvement will undoubtedly make the industry more competitive, which is in line with government's stated vision for the construction industry and will make the industry better able to respond to international competition.

Quality management should without a doubt take a holistic view of the entire project value chain (Barrett, 2000), but considering that engineering or design is possibly the single largest cause of rework in projects, and that South Africa suffers an increasing shortage of skilled design professionals, this research project specifically focussed on the quality management aspects of design in the construction industry. Considering Government's clearly stated intent to promote best practices in the construction industry (Government Gazette, 2000), the research focussed on determining best practices for managing the quality of engineering in the construction industry.

In the author's opinion there are also certain unique aspects to the South African construction environment that may warrant unique approaches to quality management of engineering. These aspects include Black Economic Empowerment requirements and shortages of specific skilled workers such as engineers and artisans (Olivier, 2005; CIDB, 2004). This opinion is supported by yearly studies (Weirauch, 2006, 2003, 2001) conducted to rank the selection criteria that owners use globally to appoint construction and engineering contractors. The degree of local knowledge of the contractor has invariably been one of the top selection criteria over the past five years. The importance of local knowledge in this ranking suggests a realisation by owners that each project location is unique and requires distinctive local expertise, knowledge and practices. Considering that no specific research has been conducted in South Africa to determine best practices and that the South African industry may warrant unique approaches, identified South African best practices was compared to international best practices to determine whether they are significantly different.

1.5 Research Problem

The evidence provided above indicates that there are quality problems in the South African construction industry. Research has shown that engineering or design can be the single largest contributor to quality problems in construction. Despite this, no research has been in conducted in South Africa, and no local body of knowledge exists on methods to improve the quality of engineering in construction.

Unless methods and best practices for managing and improving the quality of construction and specifically the engineering aspects thereof are identified and implemented, quality problems in construction will continue to occur at great cost to the economy, the companies involved and the taxpayer.

Through a series of expert interviews this study has explored the best practices for the management of the quality of engineering on large construction projects executed in South Africa.

The research has focussed on:

- Identifying the best practices for managing quality of engineering on large construction projects in South Africa.
- Comparing South African best practices to international trends from the literature.
- Determining if, in the opinion of experts, SA requires a different approach to international best practices.

This study aims to improve quality in the construction industry by providing an inventory and of techniques, tools and practices that are considered appropriate for managing the quality of engineering by experts in industry. References detailing these techniques, tools and practices and providing guidance on implementation are also provided. The study therefore contributes to the body of knowledge of practices to improve the quality of engineering, and therefore the quality of construction in South Africa.

2 Literature Review

2.1 Introduction

The literature review first broadly considers the construction industry, key aspect of quality and the impacts of quality on firm performance is then considered, quality in service and then specifically service quality in engineering is discussed, then quality in the construction industry is discussed in more detail, finally a number of best practices that may be appropriate to quality management of engineering in construction is reviewed and discussed. The terms engineering and design are used synonymously throughout.

2.2 The Construction Industry

The construction industry can be defined as "*the broad conglomeration of industries and sectors which add value in the creation and maintenance of fixed assets within the built environment*" (Government Gazette, 2000, p4). Construction works can be defined as "*the provision of a combination of goods and services for the development, extension, installation, repair, maintenance, renewal, removal, renovation, alteration, dismantling or demolition of a fixed asset including building and engineering infrastructure.*"

The International Federation of Consulting Engineers (FIDIC) define consulting services (FIDIC, 2003) as "*technology based intellectual services for the built and natural environment.*" Such services include a variety of activities related to the construction environment, including engineering design and quality management.

These definitions point towards construction containing both components of product and service and that engineering is one of the service aspects of construction.

As discussed in the introduction of this report, the global industry is beset by quality problems. Evidence suggests that engineering or design is one of the main contributors to these problems. Very little academic study has been conducted on this topic in South Africa, but the latest CIDB Industry Status Report (2004) points towards similar problems in South Africa.

2.3 Quality

In this section a brief history of the evolution of quality management is given, some of the more influential contributors to quality are briefly discussed, Total Quality Management (TQM) is discussed, ISO 9000 as one of the most ubiquitous quality management standards is touched upon and the relationship between Total Quality Management and firm performance is considered.

2.3.1 History of Quality

Throughout the ages there has been a need for conforming products (FIDIC, 2001). As communities became larger and society and products became more complex, assessing and ensuring quality became ever more troublesome. Quality methods evolved to meet these needs and early trade guilds can be seen as an attempt to regulate product quality.

In the modern industrial era quality practices have evolved through various stages from operator quality control, foreman quality control, inspector quality control, statistical quality control, total quality control and total quality management (Hassan, Baksh & Shahroun, 2000). These quality practices are mostly manufacturing based and evolved in tandem with the development of manufacturing practices.

Modern mass production of complex multi-component products really set the scene for the development of the modern quality discipline (FIDIC, 2001). Three quality "gurus" Deming, Juran and Crosby have been profoundly influential in the development of modern quality management practices (Venters, 2004). Deming was considered instrumental in the resurgence of quality in Japanese industry which started in the 1950s (Pycraft, Singh & Phihlela, 1995). Deming focussed on the improvement of conformance to specification by reducing variability and uncertainty in the design and manufacturing processes. He stressed that quality starts with top management and is a strategic activity. He also stressed the client's needs and focussing the organisation on meeting those needs. Deming claimed that improved quality led to increased productivity and lowered cost, all of which translated into competitive advantage for the firm. Juran was also influential in Japanese industry in the late 1950s. He emphasised that products should be fit-for-use rather purely conforming to specification. He also contended that employees at different levels in the organisation speak different "languages," e.g. top managers are interested in the monetary aspects of quality while first line production personnel understands conformance to requirements and reduction of defects. Crosby focussed on the costs of quality and non-conformance and claimed that many organisations do not know how much they spend on quality.

Quality is often written about, with many different views and perspectives on the subject. Total Quality Management (TQM) is one of the more influential approaches to quality (Pycraft *et al.,* 1995). Deming (1986) in his original writings on TQM stressed the importance of long-term supplier relationships. New quality approaches such as the European Foundation for Quality Management's (EFQM) Excellence Model broadens this approach by focussing on external partnership from both a supplier and customer perspective (Jenster, Pedersen, Plackett and Hussey, 2005).

2.3.2 Total Quality Management

Total Quality Management (TQM) is a philosophy based on the work of these gurus and many others and is concerned with meeting the needs and expectations of customers (Pycraft *et al.*, 1995). TQM emphasises quality as a top management supported, organisation wide activity that does not only reside in the production department; quality is the responsibility of every individual. TQM is also concerned with the reduction of the cost of quality and espouses the process of continuous improvement. Scientific methods for the measurement of different aspects of quality are an important part of TQM. Silvestro (1997, 1998, 2001) proposed a generic model of TQM that consist of six core precepts: Customer Orientation, Leadership, Empowerment, Continuous Improvement, Elimination of Waste and Quality Measurement. TQM has also been described as a holistic management philosophy or quality concept applied from acquisition of resources to customer service after sales (Kaynak, 2003).

2.3.3 What is quality

Table 1 - Definition of Quality **SOURCE: Hassan *et al., 2000***

Quality Guru / Authority	Definition
Juran	Fitness for use (1964), conformance to specifications (Juran, 1988)
Crosby	Conformance to requirements (Crosby, 1979)
Feigenbaum	Total composite . . . will meet the expectations of customers (Feigenbaum, 1983)
Deming	Aims at the needs of the customer, present and future (Deming, 1986)
Taguchi	Loss to society (Taguchi, 1986)
ISO 9000	Totality of features and characteristics of a product or service . . . to satisfy stated or implied need (IS0 9000, 1992)

Quality has been defined in many different ways by different people (Hassan *et al.,* 2000). The definition of quality has evolved over time and the essence of some common definitions are shown in Table 1. The definition of quality has broadened from pure conformance to specification to satisfying customer needs. Most modern definitions of quality address satisfaction of customer needs or requirements.

2.3.4 Quality Accreditations

The International Organisation for Standardisation (ISO – after the Greek "isos" meaning equal) developed the ISO 9000 series of quality management standards in the pursuit of harmonising quality standards and reducing barriers to international trade. Since inception in 1987, the ISO 9000 series of standard have become on of the most ubiquitous international standards, having been adopted in more than 75 countries without editorial change (FIDIC, 2001)

Unfortunately, simply obtaining an ISO 9000 accreditation, or for that matter any other, quality accreditation does not necessarily mean quality will improve (Mawson, 2005). Quality accreditation ensures that quality systems, documents and procedures are in place, but does not guarantee the quality of the work performed. Quality should be a holistic process that is an integral part of day-to-day activities for quality systems to positively affect product quality. In a study specific to the construction industry (Ng, 2005) it was shown that the benefits of implementing ISO 9000 based quality systems are often not as great as expected. The study suggests that quality system implementation should be driven by a drive to improve service quality rather than a mechanistic implementation of ISO processes and requirements.

Over time the quality focus has migrated from a simplistic product quality focus to a total quality focus taking into account company wide systems and processes. This is perhaps best illustrated by the criteria for international quality awards such as the

Baldridge Award, which typically allocates only about a 20% weighting to product quality (Toakley & Marosszeky, 2003). The construction industry has been slow in following this migration and still has a strong product focus.

2.3.5 Quality and firm performance

In recent decades numerous accounts of both successful and unsuccessful TQM implementations have been recorded. Kaynak (2000) conducted a comprehensive study of the effects of TQM on the firm, which included more than 380 respondents from both manufacturing and service sector. The study focussed on both the internal relationships between TQM practices themselves and quality performance and the relationship with external financial and market performance. The study showed that there is a positive relationship between the extent of TQM implementation and firm performance, and also that there is a strong interdependence between the various TQM practices. This suggests that previous records of unsuccessful TQM performance may be due to partial or fragmented TQM implementation. Despite critiques on methodology and the constructs used to assess TQM in various studies, there is sufficient evidence that supports improved firm performance where TQM is implemented as a holistic, firm-wide philosophy (Kaynak, 2000; Prajogo, 2005).

Quality management practices have evolved in tandem with developments in the manufacturing, and to a lesser extent, the services sectors and will in all likelihood continue to do so as the nature and demands of business change. Current best quality practices are encapsulated in the TQM philosophy and codified in various forms such as ISO 9000. There is clear evidence that successful implementation of these practices has a positive impact on firm performance.

2.4 Quality in Service

In this section quality in service as opposed to manufacturing is considered. To fully understand the implications the attributes on service is reviewed, developments in the service quality literature is reviewed, quality of professional services is discussed, and then the application of these aspects to engineering as a professional service is discussed. Finally the limited literature on service quality in engineering is reviewed.

2.4.1 Service Attributes

The generally accepted classification of services versus goods state that pure services are intangible, inseparable, heterogeneous and perishable while pure goods are tangible, separable, homogeneous and not perishable (Langford & Cosenza, 1998). In reality these are not absolute measures, but services and goods are located on a continuum between these opposites and are classified as service or good based on the strength of the various attributes. This is further complicated by the fact that many current product offerings are in fact combinations of services and goods. Products delivered by the construction industry are good examples of such a service and goods combination (Government Gazette, 2000).

The nature of services makes it difficult for the customer to assess the quality of the service and also for the firm to manage the quality of the service (Asubonteng, McCleary & Swan, 1996; Sureshchandar, Rajendran & Anathataman, 2001; Silvestro, 1998). The fact that there is no physical product to assess (intangible) and that the product is often created as it is delivered (inseparable) means it is very difficult for customers to assess the quality of the product prior to acquisition and even thereafter. Customers often rely on other cues, such as how the service was delivered, to assess the quality of the product. The inseparable nature of services makes it difficult for the firm to control the quality of the service delivery, as direct intervention at the point of consumption is often impossible. The fact that each service encounter is typically unique (heterogeneous) further complicates the firm's ability to manage the quality of the service, as fixed standards for product delivery is not always possible. Firms often rely on training and creating a service culture to address these problems.

2.4.2 Service Quality

Silvestro (2001) has noted that developments in the manufacturing quality field has been heavily practitioner driven and have not always been subject to rigorous academic scrutiny. The service quality literature, although influenced by manufacturing quality literature, has developed separately and has a much more academic flavour.

The most widely used and commonly accepted tool for the measuring service quality is the SERVQUAL scale (Parasuruman, Zeithaml & Berry, 1988). The SERVQUAL scale is a 22 question scale measuring five basic dimensions of service quality: reliability, responsiveness, empathy, assurance and tangibles (Asubonteng *et al.,* 1996). Each dimension is assessed on customer expectation and perception of performance. The final rating of service quality is based on actual performance in comparison to expected performance. Customer expectation therefore plays a central role in service quality as measured by this scale.

The SERVQUAL model has been used to measure service quality in various settings (Asubonteng *et al.*, 1996) including the construction industry (Hoxley, 2000). The scale has been widely discussed and researched and questions have been raised as to the linkages between quality and satisfaction and also the dimensions of service quality. Researchers have argued about the direction of causality between quality and satisfaction and they have also questioned the five SERVQUAL dimensions and have proposed more and less dimensions. It has also been stated that the scale may not be universally applicable to all industries and that some form of adaptation may be needed for specific industries.

2.4.3 Quality in Professional service

The term “professional” is often associated with highly respected occupations such as medicine, engineering, accounting and law. Haywood-Farmer and Stuart (1990 cited Haywood-Farmer and Nollet, 1994) argue that professionalism should be considered a continuum where professionals have to a reasonable degree, several of the following characteristics:

- specialised knowledge, intellectual rather than physical skills,
- use of individual judgement and autonomous and independent action,
- performance of work that intimately affect the affairs of others,
- development of a profession’s body of knowledge,
- service is advisory or problem solving in nature,
- self motivation,
- identification with and adherence to standards of conduct of the profession.

Considering that engineering relies on knowledge and intellectual skills, often relies on individual judgement, has a professional body of knowledge, is problem solving in nature and has standards of conduct, it can without a doubt be considered as a professional service.

Measuring and managing professional services are even more problematic than other services (Stewart, Hope & Muhlemann, 1998). The normal difficulties associated with services are increased by the highly intangible, labour-intensive nature of professional services. The client often does not have the ability or specialist knowledge to effectively assess the quality of the professional service provided. Despite these shortcomings clients do evaluate the quality of the professional service delivered to them by not only looking at the technical content (what) of the service, but also at the process of service delivery (how).

It has been argued that the SERVQUAL scale is not appropriate in professional services environments and Woo and Ennew (2004) have proposed an alternate method for the measurement of professional service quality. This method is transaction based and is suited to the business-to-business environment and has been validated in the consulting engineering industry. The method is based on the assumption that service quality is based on the nature of the interaction and the outcome of the process. The method proposes six dimensions for service quality: product / service exchange, financial exchange, information exchange, social exchange, cooperation and adaptation. Service quality is then also related to customer satisfaction and behavioural intent. Although this model takes a fundamentally different approach to SERVQUAL, both methods are based on the contention that the product or service (the what) and the process of delivery (the how) matters.

2.4.4 Managing a Professional Service Firm

On managing a professional services firm Maister (1993) suggests that there are three types of work that professionals perform, Procedural, Brain and Grey Hair. Procedural work is work for which the approach or solution is well known and can easily be delegated to inexperienced staff; key to this type of work is efficiency. Brain refers to work which requires a lot of creativity and the approach or solution can not be specified in advance; key to this type of work is the expertise of the professional. Grey Hair work is equally unique and solutions and approaches can not be predicted, but in this case the experience of the professional in additions to breadth of expertise is key to successful execution. The different types of work require different expertise and require different types of management. Often firms specialise in only one type of work, but in many cases, such as often happen in construction engineering firms, where all three types are present, firms have to carefully consider how they effectively manage the different types.

2.4.5 Service quality in Engineering

The engineering or design work conducted on construction projects is a complex process, jointly executed by professionals from various disciplines. Essentially these professional deliver a service, because although they produce some tangible deliverables in the form of design documentation, the knowledge they impart in producing these documents is intangible. The intangible nature of such services that rely on the knowledge of the practitioner means that it is often difficult to assess the quality of the service once it has been delivered, if at all (Harris, 2001).

Despite such difficulties services firms have begun to adopt some TQM principles, however, TQM remain rooted in the manufacturing industries (Silvestro, 2001). Some work has been done to develop a service quality assessment scale for the construction industry in the United Kingdom (Hoxley, 2000).

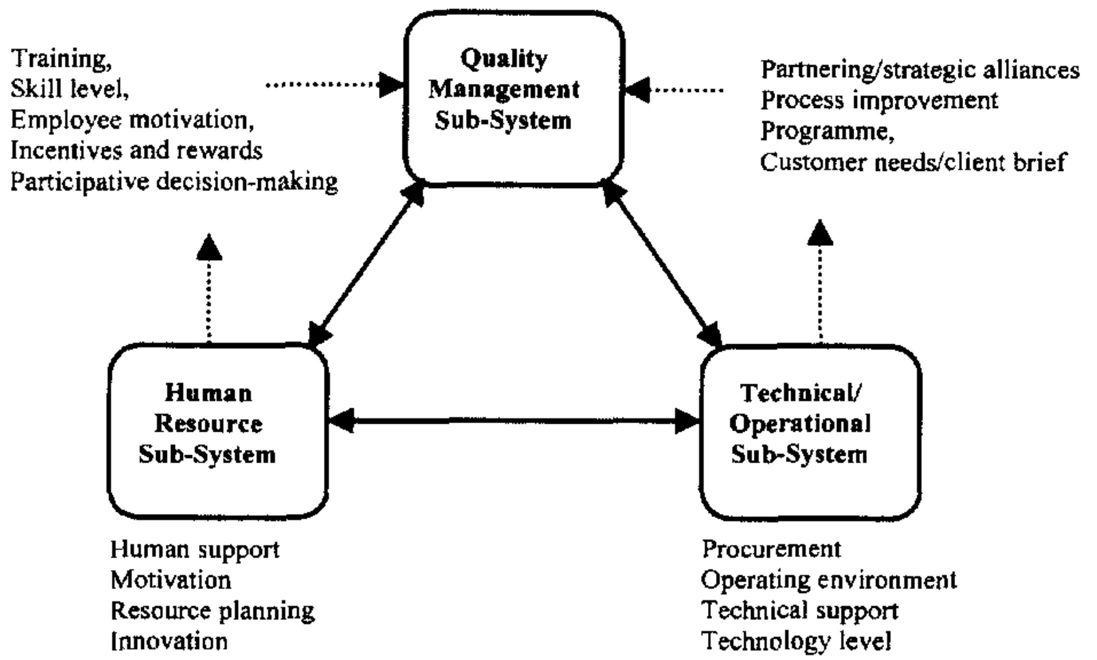
2.5 Quality in Construction Industry

This section of the report specifically considers the construction industry. The causes of quality problems or rework in the construction industry and then more specifically in engineering are considered, approaches to improved project performance are discussed, and then specifically the limited literature specific to engineering in construction is reviewed.

2.5.1 Causes of Rework

Love *et al.* (1999b) conducted an insightful study into the causality of quality problems in construction. The study takes the holistic view of the project environment and identifies three sub-systems as shown in Figure 1. The study produced influence diagrams that visually depict the causality of rework in construction in each of these sub-systems. The authors acknowledge that the details of the diagrams may vary from project to project, but argue that the fundamental themes should remain similar.

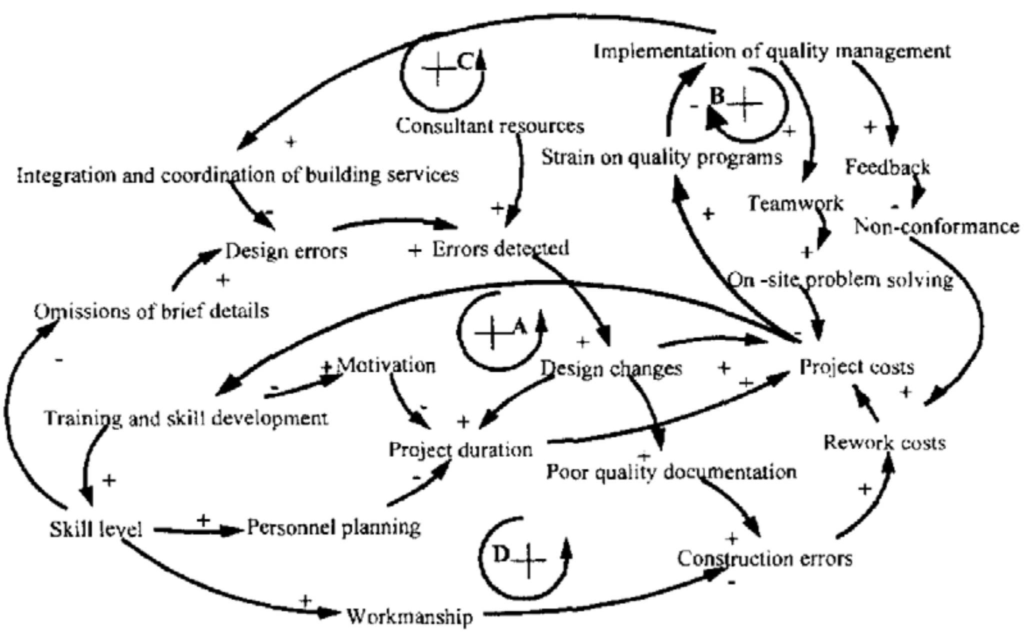
Figure 1- Interaction amongst project sub-systems. (Love *et al.*, 1999b)



The combined causal loop diagram for the entire system is given in Figure 2. A review of this model offers several insights. The implementation of quality management positively impacts on both project cost and rework costs. Training and skill development through skill levels and motivation impacts on the number of design errors and changes and the number of construction errors, thereby affecting project and rework costs. Improved skill levels can also have a positive impact on project duration. Design errors and design changes also impact on construction errors through poor quality documentation.

Love *et al.* (1999b) also argue that several positive feedback loops or vicious circles can be set up in this project structure as depicted by loops A to D in the diagram. As an example feedback loop A shows that if it is assumed that project costs increase, profit margins will be reduced and spending on training and skills development could be reduced to compensate. However, this reduction in spending in turn could ultimately increase project duration, rework costs and project costs, thus leading to a vicious circle. Feedback loops B and C depict negative effects of decreased spending on quality management when projects come under cost pressure and feedback loop D shows how reduced training and development spending impacts on construction errors through poor workmanship.

Figure 2 - Overall Causal Loop Diagram of the Project System

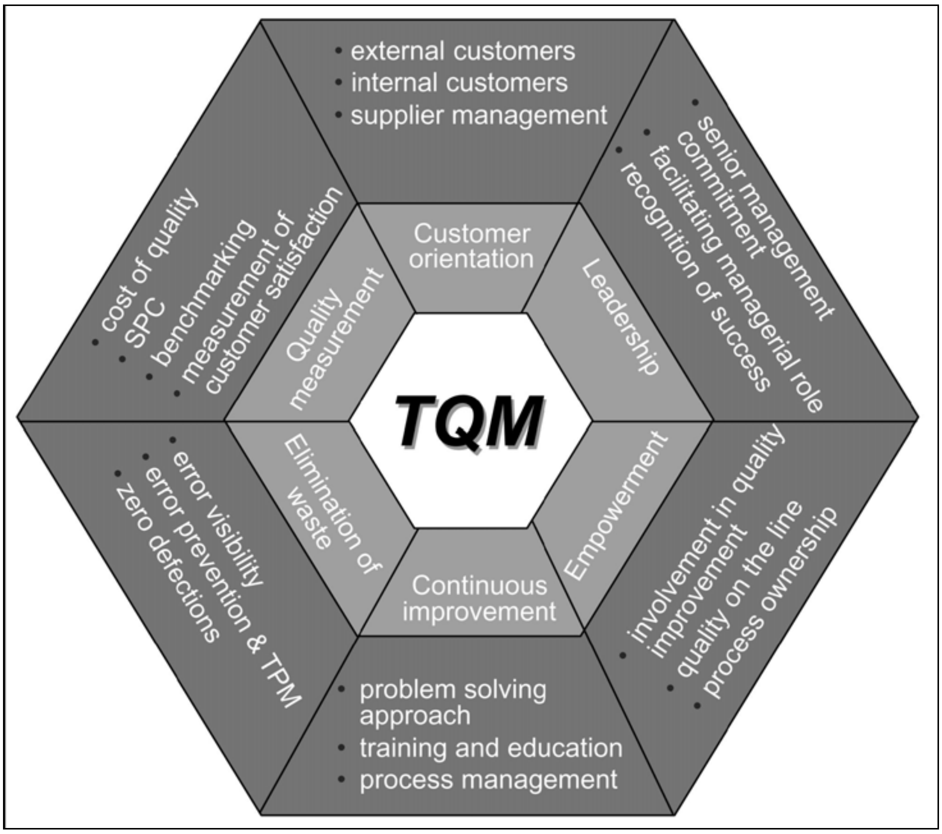


2.5.2 SCM & TQM

Barrett (2000) argues convincingly that in order to effectively manage quality in the construction project environment, firms need two things. Firstly an externally orientated, flexible quality improvement system, and, secondly a targeted approach to developing key relationship in the supply network in which they operate. Essentially an outward focussed TQM system in conjunction with effective supply chain management (SCM) is required. The importance of SCM is underlined by Drucker (2002, p78) who states:

"*Every organisation must take management responsibility for all the people whose productivity and performance it relies on – whether they're employees of the organisation itself, or employees of its outsourcers, suppliers and distributors.*"

Figure 3- Generic TQM Model (Silvestro, 2001)



Based on an extensive review of the literature, Silvestro (2001) has proposed a Generic Model of TQM (see Figure 3) which incorporates enhancements based on the service literature. The model proposes that for the realisation of TQM, six core precepts are required. These core precepts are only realised through the implementation of the supporting or peripheral precepts.

2.5.3 COQ

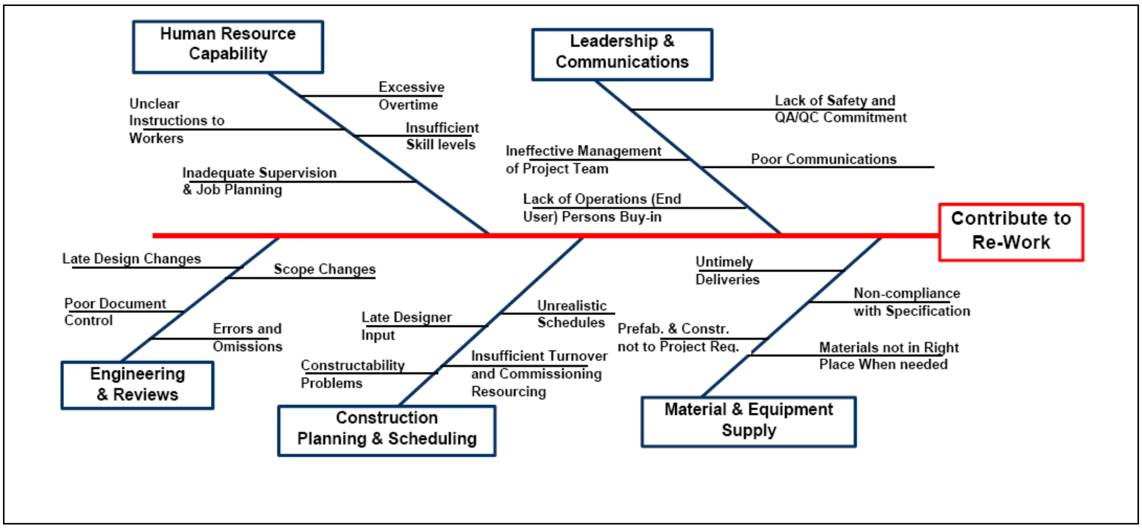
The cost of quality (COQ) approach was pioneered by Juran (Venters, 2004) and argues that quality issues need to conveyed in financial terms for executives to really understand and take notice. The costs of quality can be broken down into three main categories, the cost of prevention, the cost of appraisal and the cost of failure. Juran argued that traditionally firms did not focus sufficiently on investing in prevention and that quality costs can be significantly reduced by focussing more on this aspect. The COQ approach has been used in the construction industry on several occasions (CII, 1989; Toakley & Marosszeky, 2003; Aoieong, Tang & Ahmed, 2002; Venters, 2004; Abdul-Rahman, 1995).

Two schools of thought exist around COQ (Toakley & Marosszeky, 2003). The traditional approach classifying costs as prevention, appraisal or failure costs, this is commonly referred to as the PAF model. It has been argued that the PAF model does not consider processes, which is a fundamental aspect of TQM and that it is very difficult to identify prevention costs. As an alternative, a breakdown of COQ into cost of conformance (COC) and cost of non-conformance (CONC) has been proposed. This model takes a process view and includes the cost of non-conforming processes under CONC.

2.5.4 Engineering / Design

A study (Love, Mandal, Smith and Li, 2000c) on the dynamics of design error in construction that follows from Love *et al.'s* (1999b) earlier work, developed a model incorporating the factors that led to design error induced rework. The design error model is not as intuitively robust as the influence diagrams developed under the previous study, but it still provides some insight into the causes of design errors. The influence diagrams from this study are attached in Appendix 1. The study offers the following insights. The experience of designers in general, and the duration of their involvement on a specific project directly affect the error proneness of the designer. This suggests that not only designer experience, but continuity is an important factor to reduce design errors. Other aspects that affect error proneness is schedule pressure and design fee pressure, both these aspect limit the amount of time and man-hours available for design, thereby leading to sub-standard work. Design fee pressure has the added affect of limiting the level of experience of the employed designers, or where low salaries are paid, acting as a de-motivator. Parallelism, where design activities that are normally sequential are conducted in parallel also increases error proneness because the number of interactions where mistakes can be made increase. The authors suggest that short term measures such as recruiting designers from outside sources to cope with rise in demand, submitting low fees and agreeing to tight schedules to win contracts and paying low salaries to designers to counteract fee pressures are ineffective and will lead to increased design error and rework.

Figure 4 - Rework Fishbone Diagram (Fayek *et al.*, 2003)



A recent pilot study (Fayek, Dissanayake & Campero, 2003) conducted to measure rework during the construction phase of a project produced a detailed fishbone diagram of the various causes of rework, and showed that engineering / design was the single largest contributing factor to rework for the project analysed. The fishbone diagram used in this study is shown in Figure 4. The detailed breakdown of the Engineering and Review causes are given in Appendix 3. According to this analysis engineering and reviews contribute to rework through late design changes, scope changes, poor document control and errors and omissions. The first two items can be argued to be part of scope management rather than related to design, but these items also touch upon client requirements, schedule pressure and constructability which are clearly related to design. The details stress the importance of controlling the output of engineering, i.e. documentation as this is the primary tool to communicate the design. Low skill levels, inexperience, lack of continuity, high workload, incorrect inputs, complexity and lack of coordination all contribute to errors and omissions in design.

Stating that the design phase is one of the most critical phases that affect construction project quality, Tan & Lu, (1995) developed an overall model of quality in engineering design projects. The model is shown in Appendix 2 and is based on the quality of the design system viewed from the perspective of the quality of inputs, the design process, the outputs and quality as perceived by downstream receiving sub-systems, i.e. the manufacturers and contractors who build the physical facility based on the provided design. The study was based on TQM principles and produced eight major quality criteria. These are qualified manpower, conformance to codes and standards, conformance to owner's requirements, conformance to design processes and procedures, conformance to schedule requirements, conformance to cost requirements, completeness of and conformance to output standards and constructability. Owners and contracting firms ranked, in order of preference, conformance to codes and standards, constructability and conformance to owner's requirements as the top three criteria.

2.6 Best Practices

The Construction Industry Institute (CII) guide to best practices to improve project performance is briefly discussed to provide some context. Then a number of practices from various sources that are applicable to the quality management of engineering in the construction environment are presented below. A detail review of these practices is beyond the scope of this study, but the practices are outlined and their application in the construction industry is discussed. The provided references can be used if further details of the practices are needed.

2.6.1 CII Best Practices Guide

The Construction Industry Institute is a research based organisation who has been conducting research in the engineering and construction industry for more than 20 years. In this period they have developed several best practices for improving project performance (CII, 2006). Although many of these best practices focus much wider that engineering alone, the current CII best practices are listed here to provide context to the discussions below. The current best practices are Pre-Project Planning, Alignment, Constructability, Design Effectiveness, Materials Management, Planning for Start-up, Team Building, Partnering, Quality Management, Implementation of Products, Benchmarking and Metrics, Change Management, Dispute Prevention and Resolution and Zero Accident Techniques. Some of these practices and various others are discussed below.

2.6.2 Total Quality Management

TQM has been discussed in detail above as a holistic approach looking at the organisation from the acquisition of resources to the delivery of the product or service. The potential firm level benefits were also discussed. Although TQM applies to a much wider front than engineering, it is mentioned here because of the contention that TQM is one of the critical requirements for construction quality (Barrett, 2000) and many of the practices mentioned in this section are consistent with TQM principles. Guidelines for the application of TQM in engineering and construction firms have been developed by the Construction Industry Institute (1992) and FIDIC (2001).

2.6.3 Supply Chain Management

In addition to TQM, Barrett (2000) argues that supply chain management (SCM) is the other critical requirement for construction quality. Construction quality relies on the entire construction value chain, of which engineering is only one component. Ultimate success depends on the interaction of all the components. Engineering can therefore not be viewed in isolation. Thus for construction to be successful, a holistic SCM view of the entire value chain must be taken. This has important implications for several of the practices discussed below, such as concurrent engineering, managing client expectations, Quality Function Deployment and onsite design.

2.6.4 Cost of Quality

Cost of Quality is discussed in detail above. It is an important quality practice since all modern quality systems, including ISO 9000 and TQM, stress the importance of fact based decision making. COQ is an approach and potential tool for obtaining information for fact based decision making with regard to quality. As noted above, COQ has been implemented in several cases in the construction industry.

2.6.5 Quality Function Deployment

Quality Function deployment (QFD) is a structured process that was developed to identify and carry the customer's requirements through each stage of the product or service development and implementation process (Costin, 1999). The approach is also known as "House of Quality" due to the distinctive house-like shape of the diagram that is used within QFD to match customer requirements to design aspects.

The construction industry traditionally has had difficulty in determining customer requirements and then translating these into specifications for the construction of a facility (Abdul-Rahman, Kwan & Woods, 1999). QFD has been identified as a tool for use in the construction industry to identify customer requirements and translate these into accurate technical requirements throughout each stage of the project.

The Construction Industry Institute (1993) conducted a comprehensive study on QFD in the construction industry. The CII found that QFD is viable and productive practice for enhancing engineering and construction project definition. The practice is most effective in feasibility, conceptual engineering and preliminary engineering phases where the overall project is considered. It also has application in the detail engineering phase, but in discrete design situations, rather than for the whole project as in the earlier phases. The practice can be used to obtain, organise, focus and deploy vital customer requirements throughout the design and engineering process. Furthermore QFD assists designers in prioritising activities and focussing on those activities that most directly impact on customer requirements. Simply put, QFD has been developed as a tool for defining and linking customer requirements and expectations of quality to the parameters designers use to define, design and produce products (Toakley & Marosseky, 2003).

2.6.6 Managing Client Expectation

As discussed above, managing the quality of services and specifically professional services warrants a special approach. The expectations of the customer are a key component of how service quality is measured. Ojasalo (2001) argues that in the case of professional services, especially where long term relationships are at stake, expectation management pays off. Steps should be taken to make fuzzy expectation precise, implicit expectation explicit and unrealistic expectation realistic. Customer satisfaction should also be considered in the short and long term, and where there are conflicts, long term satisfaction or quality should be sought. Fuzzy expectations increase the probability that services will not meet expectations; these fuzzy expectations must be focussed or made more precise. Implicit expectations also raise the probability that service expectation will not be met. Implicit expectations are very common in long relationships between companies where interaction have become standardised and routine. Professional service providers must ensure they reveal implicit expectations so they can be addressed. Customers often have unrealistic expectations, even more so in the professional services environment where the customer often does not have the expertise to anticipate and evaluate the service.

Expectations may be unrealistically high or low, and it is up to the professional service provider to calibrate customer expectations.

Considering that engineering conducted in the construction industry is a professional service, and the service is often delivered as part of a long term relationship, expectation management may be a useful practice in the industry. Tools such as QFD can be used to assist in expectation management.

Another approach that is suggested is that briefing, whereby client requirements is communicated to the contractor, should be considered to be an ongoing process, rather than a single event at the outset of a project (Barrett & Stanley, 1999). Using this approach, client and contractor would meet on a regular basis to communicate, re-affirm and re-align on client requirements.

2.6.7 Design Management

Ahire & Dreyfus (2000, p 552) define design management as: "*Design of product and process quality through advanced managerial and technical practices.*" The authors argue that design management forms part of TQM and shows that design management improves both internal and external quality in the manufacturing industry. They also stress the importance of training in design management for the practice to be effective.

In a study specific to the construction industry, Smith, O'Keeffe, Georgiou and Love (2004) argue that due to fragmented nature of the construction project value chain, the once off nature of projects, the use of separate highly specialised design professionals and several other factors, design management is warranted in the construction industry. Design management calls for design management professionals with both management and technological / design skills who are able to bridge the gap between management and design. The authors suggest that a design manager be appointed who reports to the project manager. The design manager would be responsible for issuing all documentation, facilitating communication between all designers and ensuring the designers remain within the boundaries of the project brief and quality requirements. In addition to the design manager, it is suggested a design cost manager be appointed to manage the design in terms of the approved budget in conjunction with the design manager.

Bibby, Austin and Bouchlaghem (2006) conducted research on a training initiative designed to entrench design management in a UK construction firm. The design management approach is based on a design management handbook that was previously developed and provides guidance on design management practices and a suite of 25 related tools. The most significant impacts of this design management initiative were on timely delivery of design, meeting client requirements, coordination of design and fewer late design changes. These tools however do not improve cost certainty of design. This work defines nine key areas of design management:

1. Establishing and communicating design briefs
2. Design management roles and responsibilities
3. Selecting team members
4. Integrated design planning
5. Ensuring design delivery
6. Managing information flow
7. Developing the design
8. Value considerations in the design process
9. Managing design changes

A matrix for assessing the design management maturity of an organisation is presented in Appendix 5.

2.6.8 Concurrent Engineering

Concurrent engineering allows companies to conceive, develop, produce and deliver new products to customers between 25 and 45 percent faster than with conventional approaches (Costin, 1999). Multifunctional teams are used to attempt to replace the traditional serial development and communication process of engineering ("toss it over the wall") with continuous collaboration and communication between multi-functional team members. Teams typically include representatives from marketing, engineering, production, maintenance, field support and in some cases even suppliers and customers.

Gunasekaran and Love (1998) argue that the fragmented nature of the construction industry, the divisions between functional disciplines, different objectives and values between disciplines and poor communication are some of the reasons why the construction industry may benefit from concurrent engineering. As projects become more complex a holistic view of design is needed and many problems need to be addressed from a multi-disciplinary perspective. Concurrent engineering offers a practice for the construction industry that is aimed at bringing together the design inputs and expertise of the various fragmented components of the construction value chain. Apart from potentially reducing the design cycle duration, such an approach also directly addresses two of the top three ranked major components of design quality as identified by Tan & Lu (1995), i.e. conformance to owner requirements and constructability by involving the owner and constructors in the design process.

Costin (1999) warns that effective implementation of concurrent engineering is not an easy matter, and that changes in organisational culture and structure , work processes, methods of communication and information technology may be required.

2.6.9 Onsite Design

The interface between design and construction is one of the most critical interfaces in the construction project environment. Where design information is communicated clearly, in a timely fashion and is understood, construction is more efficient (CII, 2003). Performing selected design activities onsite to bridge this interface gap is a common practice. However the degree and scope of onsite design varies widely based on project complexity, scope, team composition, execution strategy, location and other factors.

In a study on onsite design the Construction Industry Institute (2003) has found conclusive evidence that onsite design is beneficial and contributes to project success. The study also proposes a computer based decision support tool that permits users to identify the specific activities that should be performed onsite to improve project performance given the specific attributes of the project.

2.6.10 Design Effectiveness

The Construction Industry Institute (1986) developed a systematic process for the evaluation of design effectiveness. They argue that design effectiveness is much more appropriate than purely attempting to measure design productivity, because the various design outputs are typically not standardised and straightforward productivity measures are difficult to identify. Furthermore, real indications of design effectiveness are only found at later stages during construction, start-up and operation of the facility. The method requires that seven criteria be evaluation after the completion of construction. Criteria pertaining to plant operation are not evaluated due to project team dispersal after construction. The criteria are accuracy and usability of design documentation, cost of design effort, constructability of design, economy of design, performance against schedule and ease of start-up. Depending on the nature of the specific project, different weights are assigned to each criterion to determine the overall effectiveness of the design. A criticism of this approach is that the evaluation can only be conducted after the completion of construction; it does not provide a method for monitoring design effectiveness during execution.

In a related study the CII (1987) determined the impact of design input variables on design effectiveness. In this case design effectiveness included design quality, constructability, schedule, cost, plant start-up, performance and safety. The study identified 10 input variables that have significant impacts on these outcome parameters. The input variables are, in order as ranked by designers, scope definition, pre-project planning, project objectives and priorities, owner profile and participation, basic design data, project manager qualification, designer qualification, construction input, type of contract and equipment sources. The input variables are related to various aspects of design effectiveness in a matrix. The matrix is useful in a number of ways, for example identifying the inputs to focus on to achieve a specific objective, or alternately which outcome parameters are under threat if an input is known to be sub-standard. The input variables that have a high impact on outcome variables other than cost and schedule are designer selection and qualification, basic design data and construction involvement.

2.6.11 Contractor Selection

The contractor responsible for the engineering of a construction project has a major impact on the eventual outcome, but typically the fees paid for the engineering is a small percentage of the overall project cost. Therefore the International Federation of Consulting Engineers (FIDIC) recommend that selection of consultants or contractors to perform this engineering be based on quality criteria rather than price (FIDIC, 2003). FIDIC recommends Quality Based Selection as an approach where selection is based on quality criteria such as contractor competence, experience, managerial ability, availability of resources, integrity and other quality factors. Contractors still have to bid within a price range determined by estimation prior to the bidding phase, but the final appointment is based in quality criteria alone. As an alternate FIDIC suggest Quality and Cost Base Selection where cost is only one of the selection criteria with a weighting typically in the range 0 to 10%, with 20% as an absolute maximum. These approaches stress quality criteria, rather than cost as the most important aspects in appointing engineering contractors or consultants.

2.6.12 CII Exceptional Projects

The CII (1999) conducted a study of 30 projects where work processes had to be changed or re-engineered to meet reduced schedules necessitated by external drivers, such as emergency rebuilds or market forces. In all cases significant schedule reductions were made and 50% of the projects showed reduced cost compared to similar projects. In all cases quality levels were maintained. The purpose of the study was to establish which practices that were used on these projects can be transferred to new projects to achieve similar results. Improvements were identified in each phase of project execution, including the engineering / design phase. No single practice could be identified as the sole cause of significant schedule improvement; rather it was the cumulative impact of work process changes that led to improvements. The top four categories of change that accounted for 70% of improvement were the delivery approach / execution plan, engineer’s role, design process and procurement process.

In exceptional projects (CII, 1999) the engineer’s role is changed by making more use of engineering conducted in the field and at the fabrication shop. The percentage of designer relocated to field offices varied between projects, but this was characteristic of all the projects investigated. Engineers on these projects were also freed up from all other responsibilities to ensure they remained focussed on the job at hand. In the design process, these projects optimised the use of pre-existing designs, relied on continuous reviews, reduced design details and placed supplier and construction personnel on the design teams.

2.6.13 CII 2% Engineering

Research into innovative and non-traditional practices in engineering in the construction industry identified 20 such practices (CII, 1997). The practices are grouped into three categories: organisational culture, contracting strategies and design philosophies. These practices were identified by studying pioneering companies who reported lower engineering and capital cost and improved schedules in applying these practices. The practices related to design philosophies include:

a) Identifying minimum facility requirements to meet operating goals.
b) Using a minimum facilities approach with justification of any additions or changes to baseline.
c) Streamlining the preliminary engineering approach by using a small, focussed group of key professionals and relying heavily on past experience and intuitive technical judgement of the group.
d) Using minimum specifications and focussing only on performance requirements.
e) Standardising products and equipment as much as possible to eliminate premiums caused by non-standard solutions.
f) Avoiding over-engineering.
g) Identifying and providing only those design documents necessary for fabrication and field operations.
h) Not reviewing detail design documents.

The CII (1997) emphasises that organisations need to have a clear understanding of the practices and the possible negative consequences before implementing them. What is also clear is that these practices are interdependent and that the innovative design practices can not be implemented without the necessary supporting practices in the organisational culture and contracting strategy categories. Key practices in these categories include buying equipment and services on a lump sum basis from highly reputable suppliers, incentives for engineers and project managers, creating a prudent risk taking environment and effectively using outsourcing and alliances to minimise number of suppliers. Although these practices are clearly applicable to engineering and quality performance has reportedly not deteriorated, it must be borne in mind that they were developed to improve the schedule performance of projects, rather than quality performance.

2.7 South Africa

Very little research has been conducted on the South African construction industry, and even less so in relation to the quality management aspects thereof.

A conference paper by Dlungwana *et al.* (2002) points out some of the problems in the local construction industry and proposes and South African Construction Excellence Model (SACEM) that is based on the South African Excellence Model which is in turn based on the European Model. It is not clear to what extent this paper is based on actual research.

In a literature based study on the critical success factors for the implementation and maintenance of TQM in the South African construction industry (building sector), Joubert (2002) notes that there are several obstacles to the implementation of TQM in the construction environment, but stresses the potential benefits of adoption of quality practices.

No research has been found that is specific to the management of the quality of engineering within South Africa. The intent of this research project will be to explore this subject within the South African context.

2.8 Conclusions from the Literature

The literature points towards quality problems in the construction industries of many countries. Although no specific research on this topic has been conducted in South Africa, several reports in the press and elsewhere suggest that South Africa suffer similar problems. Several studies have shown that engineering or design in many cases is the largest contributor to quality problems in construction, therefore the specific focus of this study on engineering.

This literature first provides context for the study by reviewing a brief history of quality, considering what quality actually means, looking at the concept of Total Quality Management and quality accreditations, and then showing that the there is a link between the application of quality management approaches such as TQM and improved firm performance.

The service quality literature was also reviewed, because engineering is essentially a professional service. Service quality is a distinct and different field to product quality. The nature of services and specifically professional services make service quality difficult to assess. Service quality is heavily reliant on client perception and the what (product or service) and the how (delivery process) matters in determining service quality. It was also noted that professional service firms may require special management practices due to the nature of the work and the workers.

Quality in the construction environment was reviewed. The literature suggests that at a project level TQM and SCM are required to improve project performance. Causes of rework at the project level and specifically in engineering were considered. Several different models giving causes of rework were reviewed. A model describing the various components or criteria for quality of engineering on construction projects was also reviewed. The causes of quality problems and the components of quality are useful in determining to what extent practices suggested by interviewees address these problem areas or components of quality.

Finally a number of proven best practices from the literature for improving the quality of engineering on construction projects were identified. These best practices were reviewed and discussed in sufficient detail to enable an understanding of the practices and their application.

The literature review provides context to the study by considering quality in general, quality in service and quality of engineering as a service in the construction industry. The best practices identified in the literature can potentially improve the quality of engineering in the South African industry if they are found to be applicable in this country and they will allow comparison to identified South African best practices.

3 Research Questions & Propositions

The literature points towards quality problems in the construction industry in many countries. Although very little formal research has been conducted on the South African construction industry, evidence suggests that similar problems exist in the South African. Several best practices have been developed internationally to improve the management of the quality of engineering in construction. The research was conducted to determine the best practices recommended by experts for South Africa, how these compare to international practices and whether unique South African conditions warrant fundamentally different approaches.

The research questions that were specifically explored are:

1. In expert opinion, what are the best practices for the management of quality of engineering on large construction projects executed in South Africa?
2. How do these practices compare to international best practices as described in the literature?
3. Do experts believe selected best practices from the literature are appropriate to South Africa?
4. Do experts believe that a different approach to quality management of engineering is warranted in South Africa?

Based on the literature, popular press and the experiences of the researcher the following propositions were put forward:

1. Most best practices suggested by experts for South Africa are aligned with international practices.
2. Experts will consider most of the best practices from literature appropriate to South Africa.
3. Some specific local practices are required to address skills shortages, small markets and other unique attributes.

4 Research Methodology

4.1 Research Overview

The nature of the research was explorative and intended to determine the best practices for the quality management of engineering on construction projects within South Africa. Semi-structured interviews were used to explore the opinions of experts in the industry.

Despite extensive writings on quality management and research on the subject in the construction industry and services industry in many other countries, little or no research had been conducted on the subject of quality management of engineering in the South African context. Therefore the research was qualitative in nature as this is the most appropriate approach in cases where little is written on a subject and the objective is a better understanding of the phenomenon under investigation (Creswell, 1994).

Welman and Kruger (2001) state that unstructured interviews are usually used for explorative research because the area being entered is so unfamiliar that it is usually impossible to compile an interview schedule. Semi-structured interviews were selected in this case as a more appropriate choice because a relevant theory base was available in the international literature upon which to base an interview schedule. Semi-structured interviews still allowed the interviewer to explore the subject matter and use probes to clear up vague responses and incomplete answers (Welman and Kruger, 2001). The danger of checklists and structured interview schedules is that the researcher forces an inappropriate structure on the phenomenon being studied (Welman and Kruger, 2001). This danger could have been reduced by pilot studies, but an in-depth pilot study was not appropriate considering the limited time and resources available for this study. This problem was taken into consideration during finalisation of the interview schedule. In addition a mock interview was conducted with a subject matter expert who had research experience. Feedback from this interview was used to update the interview schedule before data collection commenced.

Thematic content analysis was used to analyse the interview transcripts and determine major themes and practices that recur in the text. Content analysis is a technique that can be used to report in a quantitative way on interview feedback which is essentially qualitative (Welman and Kruger, 2001).

4.2 Population of Relevance

The population of relevance for this study consisted of all individuals involved in engineering and the quality management aspects thereof on large capital projects within the construction industries of South Africa. The construction industry covers a very wide spectrum from low cost housing at one end to technically complex process plants, power stations and even nuclear facilities at the other end. The study focussed on the more technically complex end of the spectrum where engineering is conducted by multi-disciplinary teams, such as in the industrial sector (petrochemical, mining, food & beverage, utilities etc.). The reason for this selection was that it was expected that quality management of engineering will be more advanced in this category due to the higher demands of more technically complex engineering. To increase the likelihood of detecting best practices, preference was given to larger contracting companies who are considered more advanced in terms of systems and tools that are used (CIDB, 2004). For the purpose of this study, large projects were considered to be projects with a capital cost of more than R 50 million. Individuals from both the client and supplier side were included in the population of relevance.

The intent of the study was to determine best practices; therefore the unit of analysis for this study was experts working in this industry, who were knowledgeable on the best practices used to manage the quality of engineering on large construction projects. To ensure the information obtained stood up to internal and external criticism (Welman and Kruger, 2001), specific guidelines of what constitutes an expert was developed. Of interest were experts with a holistic view of the project environment, but with a specific focus on the quality management aspects of engineering. Experts were considered to be individuals with 10 or more years of relevant experience in engineering and / or quality. Typical positions included Quality Managers, Engineering Managers, Project Managers and Managers of Engineering Departments or

Companies. Responsibilities included direct project involvement, responsibility for multiple projects at a managerial level, or quality consulting.

4.3 Sampling Method and Size

Non-probability sampling was used for this research. No comprehensive list or sampling frame exists for the population of relevance, therefore making it almost impossible to conduct probability sampling. The necessary time and resources were also not available to compile such as list. The selection of experts from the population was based on the judgement of the researcher within the constraints of the guidelines set out above and referrals within the industry. In such cases probability sampling is not practical. Non-probability sampling also has the advantage of being less complicated and more economical than probability sampling (Welman and Kruger, 2001). Purposive and snowball sampling is often used to obtain individuals for unstructured interviews, preference is then given to informants who are more knowledgeable than other group members (Welman and Kruger, 2001). These sampling methods are also deemed appropriate in the case of semi-structured interviews where the objective is exploratory.

At the outset purposive sampling was used to identify likely experts to interview. The researcher deliberately selected interviewees who were considered experts on the subject matter, and also matched the search criteria specified above. Several existing contacts within the industry were utilised to assist in the initial purposive sampling. The South African Quality Institute, The Engineering Council of South Africa, The South African Association of Consulting Engineers and The Construction Industry Development Board were also contacted to obtain references to likely subject matter experts.

The sample was further expanded using snowball sampling whereby interviewees were asked for references of further experts that they believed could meaningfully contribute to the research project. To allow sufficient time to set up interviews with snowball sampled candidates, referrals were obtained when initial interviews were scheduled.

Table 2 - Interviewee Demographics

No	Position	Years*	Size of Projects / Responsibility**	Industry Sectors	Role	Background
1	HSEQ Manager	20	~R 500 Million	Petrochemicals, Mining, Nuclear, Power, Pharmaceuticals	Contractor	Quality
2	QC Manager	35	~R 500 Million	Petrochemicals, Mining, Nuclear, Power, Pharmaceuticals	Contractor	Quality
3	QA Manager	25	~R 1 Billion	Petrochemical, Power, Mining, Metals	Contractor	Quality
4	Quality Manager	30	~R 1 Billion	Petrochemical, Mining, Material Handling, Pharmaceuticals	Contractor	Quality
5	Quality Auditor and Consultant	26	n/a	Construction and Automotive	Consultant	Quality
6	Quality Auditor and Consultant	30	n/a	Automotive and General Engineering	Consultant	Quality
7	Manager Engineering	25	~R 1 Billion	Petrochemical, Mining, Power, Metals	Contractor	Engineering
8	Manager Engineering	25	~R 1 Billion	Petrochemical, Mining, Material Handling, Pharmaceuticals	Contractor	Engineering
9	Engineering Manager	21	~R 4.5 Billion	Petrochemical	Client	Engineering
10	Engineering Manager	11	~R 5 Billion	Petrochemical	Client	Engineering
11	QA Manager	13	~R 5 Billion	Petrochemical	Client	Engineering
12	Manager Engineering	20	~R 5 Billion	Petrochemical	Client	Engineering
13	Manager: Project Governance	20	~US$ 500 million	Mining	Client	Engineering

Notes:
* Years of experience in engineering and / or quality field
** Based on estimated cash flow capability for contractors or typical annual capital spend for clients

The final sample consisted of 13 interviewees all meeting the criteria specified. The demographics of the interviewees are shown in Table 2. Participation in the research was entirely voluntary and interviewees were promised that the final report would be disseminated to them, with the researcher being available to discuss the findings if needed.

4.4 Data Gathering Process

4.4.1 Interview Process

Data was gathered using semi-structured interviews based on an interview schedule that is discussed in the next section of this report. Interviews were recorded with the permission of the interviewee and later transcribed. Interview notes were also be taken as a memory aid and a back-up to the recording and to capture interviewer impression on body language and other cues (Welman and Kruger, 2001). At the outset the interviewer explained the nature of the research and the purpose of the interview. Interviewees were assured of complete anonymity.

The required data was expert opinion on best practices for the quality management of engineering in the construction industry. Interviewee opinion on selected best practices from the literature was also obtained. Finally expert opinion was obtained on whether the South African environment requires unique practices.

4.4.2 Interview Schedule

The interview schedule was developed to facilitate a semi-structured, explorative interview. The first set of questions was designed to be open-ended and non-leading to capture expert opinion without enforcing the researcher's bias on the interviewee. Once the open ended line of questioning had come to an end, the second set of questions were designed to probe for specific concepts and practices from the literature that had not already been touched upon. The final set of questions was developed to determine expert opinion on differences between South African and International practices. The interview schedule was developed to ensure consistency between the interviews and is attached in Appendix 4.

At the outset of the interview relevant demographic data was captured, this data is presented in Table 2. This data was used to record and establish the credentials of the experts that were interviewed.

The unstructured questions were developed to explore expert opinion on best practices for the quality management of engineering in construction. Practices that are in use and potential new practices were captured. These first questions were entirely open-ended and intended to obtain expert opinion without undue influence and leading by the interviewer. This was intentionally done to avoid the danger of enforcing an inappropriate structure on the interviewee's responses (Welman & Kruger, 2001).

The second, structured set of questions was designed to probe for specific best practices from literature that the expert had not touched upon during the open-ended, unstructured section of the interview. The practices that were probed for are discussed in Section 2.6 of this report.

The final section of the interview schedule on uniquely South African aspects was developed to determine if there are unique aspects to the South African industry that warrants practices that are specific to South Africa. Interviewees were asked if they have relevant international experience that informs their views on this specific aspect.

4.5 Analysis Approach

The interview feedback was analysed in three different sections. The unstructured portion of the interviews, the structured portion of the interviews and the section of the interviews on uniquely South African aspects were all analysed separately.

The transcripts of the unstructured section of the interviews and the section on uniquely South African aspects were analysed using content analysis to make sense of the common themes arising from the interviews (Welman and Kruger, 2001). The transcripts were systematically examined and coded for the various themes that were encountered. This required that visible content that was indicative of the various themes or constructs were identified. The problem of coder inconsistency was avoided as all the coding was done by the researcher. The reporting on the data was limited to determining the number of occurrence of the various themes or constructs (Welman and Kruger, 2001).

Table 3 - Content Analysis Themes and Coding

Themes	**Typical Indicative Content**
Skills Shortage	Skills, Competence, Training, Development, Coaching, Mentoring, People / Staff / Engineers
Requirements	Requirements, Alignment, Client / Customer, Needs / Requirements, Voice of Customer, Perceptions
Schedule & Planning	Schedule, Planning
Quality Systems	Quality Systems, Procedures, Peer Review, Quality Plans
Demand Side	Automation, Tools, Productivity, Intelligent Systems
Risk Management	Risk, Risk Management, Mitigation
Teams – Relationships	Team, Team Building, Relationships, Alliances, Partnerships, Integration
Continuous Improvement	Continuous Improvement, Improvement, Lessons Learnt, Knowledge Management, Metrics
Accountability	Accountability, responsibility
Cost	Cost, Manhours
Change Management	Change, Change Management
Audits	Audits
Constructability	Constructability, Manufacturability,

Interview transcripts were reviewed to determine common themes, these themes were coded for and the process was repeated until all major points raised by the interviewees were categorised within these themes. In total thirteen themes were identified in the unstructured portion of the interview. The typical content associated with each theme is shown in Table 3.

The structured section of the interviews was separately analysed to determine interviewee feedback on each practice. The categorisation given in Table 4 was used to rate interviewee responses on each of the practices. Differences between client and contractor responses and engineering and quality practitioner responses were also examined.

Table 4 - Classification of Structured Interview Feedback

Key	These practices where highlighted in the unstructured portion of the interview, or received an overwhelming positive response during the structured section of the interview
Positive	These practices received a positive response during the structured section of the interview
Contingent	These practices received a positive response during the structured section of the interview, but it was pointed out that the practices where only appropriate in certain specific cases
Neutral	These practices received a neutral or non-committal response during the structured section of the interview
Negative	These practices received a negative response during the structured section of the interview

A similar coding approach used on the unstructured section of the interviews was used on the section on aspects unique to South Africa. This section of the interviews was typically much shorter, and the only significant theme that was identified was that of skills shortages.

4.6 Limitations

The research potentially suffers from the following limitations:

- The sample was relatively small and subjectively selected. It can be questioned whether the sample is representative and to what extend conclusion can be generalised (Welman and Kruger, 2001).
- In qualitative research the researcher becomes the primary research instrument, it requires exceptional discipline to remain objective and critically scrutinise any new insights (Welman and Kruger, 2001).

- Some respondents may have been less frank in their discussion because the researcher / interviewer was from a client organisation in the construction industry. Every effort was be made to put interviewees at ease and assure them of their anonymity.
- The research is based on the personal opinion of experts, these opinions, although expert, remain subjective and open to criticism. No secondary data was gathered to triangulate and corroborate these opinions (Welman and Kruger, 2001).

5 Results

The results from the different sections of the interviews are reported on separately. The unstructured and uniquely South African feedback is given first, followed by the feedback on the structured section of the interviews.

5.1 Unstructured Questions

5.1.1 General

This section will report on the common trends and recommended practices noted from the unstructured section of the interviews, it will also report on innovative approaches that have been suggested that may warrant further investigation. This section of the report excludes the structured questions on the best practices identified from the literature and also excludes the final set of question on aspects unique to South Africa.

Table 5 - Unstructured Interview Categories and Frequencies

Category	Interviewees	Mentions*
Skills Shortage	**13**	**50**
• *Systems only as good as the people*		*4*
• *Rotation of non-permanent staff bad for training*		*6*
• *Match competency to project complexity*		*7*
• *More and improved training required*		*13*
• *Cost and schedule pressure allows no time for training*		*3*
• *Cooperation needed to improve training*		*3*
• *More emphasis in practical training*		*2*

• *More emphasis on cross-discipline / big picture training*		*4*
• *Increase coaching and mentoring*		*5*
• *Retention*		*2*
Requirements	**11**	**28**
• *Importance of alignment and understanding*		*19*
• *Alignment meetings*		*9*
• *Detailed review of requirements*		*2*
• *Manage client perceptions*		*2*
• *Quality of Process Design*		*2*
Schedule and Planning	**9**	**23**
• *Increased pressure negatively impacts quality*		*6*
• *Planning*		*5*
• *Engineers must understand schedule impacts*		*2*
Quality Systems	**10**	**25**
• *Systems and Processes*		*4*
• *Customise per Project*		*3*
• *Peer Review*		*10*
• *Quality Plans*		*5*
Demand Side	**7**	**14**
• *Automation and Productivity Tools*		*9*
• *Intelligent systems*		*3*
• *Engineering Data Control*		*6*
• *Automated Generation of Deliverables*		*3*
• *Improved Productivity*		*3*
• *Improved Quality*		*2*
• *Resistance to Technology*		*2*
Risk Management	**6**	**9**
Teams – Relationships	**6**	**7**
• *Team Building*		*3*
• *Less confrontational, more partnering and alliances*		*2*
• *Integrated teams*		*2*
Continuous Improvement	**6**	**11**
• *Lessons Learnt*		*2*
• *Increase Quality Focus of Management Reviews*		*2*
• *Measurement*		*2*
Accountability	**4**	**5**
• *Clear EC Accountability for Outcome*		*2*
• *Clear Roles and Responsibilities*		*2*
Cost	**4**	**6**
• *Increasing cost pressure*		*3*
• *Cost is part of quality*		*3*
Change Management	**4**	**6**
Audits	**3**	**4**
• *Discipline audits*		*3*
Constructability	**4**	**5**
• *Design / Planning for Construction*		*3*
*NOTE: Only sub-categories with two or more mentions are reported in this table, therefore the number of mentions will not be consistent between main and sub-categories		

The feedback from the unstructured interviews was grouped around several major themes that were identified upon analysis of the transcripts of the interviews. A high-level summary of the themes and sub-categories found is presented in Table 5.

5.1.1.1 Skills

The single most prevalent topic that came up in the interviews was skills or competency and the shortage thereof. All but one of the interviewees referred to the skills shortage in one form or another during the unstructured section of the interview. The one interviewee, who did not, was a quality consultant and was more systems focussed during this section of the interview; but in the final part of the interview, this interviewee pointed out that the skills shortage was probably the only unique aspect to South Africa. In this part of the interview there were no less than fifty separate references to skills, competence, training or development across the thirteen interviews. Four interviewees specifically stated that you can have the best quality system and tools, but they will not work if you do not have skilled and competent people to drive them. One quality consultant also noted that good specifications and standards are not enough to ensure quality; engineering judgement is required in their application. The rotation of engineers (six mentions) between contracting companies is one of the aspects that contributes to the problem, as there is not sufficient training in place for these individuals. Several other uniquely South African factors that contribute to the problem are discussed in the section that addresses aspects unique to South Africa.

The importance of selection of competent resources to match project complexity was mentioned seven times and is also supported by the feedback on the structured section of the interviews. One interviewee pointed out that this does not only apply to individuals, but that different companies have different strengths and weaknesses and should be selected accordingly.

A stronger emphasis on training and improving training practices was mentioned thirteen times. There is not sufficient time for training (three mentions) due to schedule and costs constraints, this is even worse in the case of engineering resources that are not permanent staff and rotate between contractors. Cooperation within industry and specifically between contractors and clients in terms of longer term workload agreements which will allow for a stronger focus on the training of engineers was suggested (three mentions). A greater emphasis on practical training was also mentioned twice, cross discipline training and the ability to see the “Big Picture” was mentioned four times. Other practices such as rotation of engineers between client and contractor organisations were also mentioned.

The increased use of mentoring and coaching to accelerate the pace of development of engineers and to increase productivity and effectiveness of engineers was mentioned five times. It was even suggested that retired engineers be brought back into industry to do this, thereby not putting further strain on an already limited resource pool.

The retention of staff also received two mentions, with several techniques suggested to improve retention. These methods include training and development, remuneration, bursary and graduate programs, technical mentoring and coaching, rotation to international offices for high potential candidates and accelerated leadership development programs. One interviewee also questioned how to “switch on” the new generation in terms of attracting them to engineering in the first place and then retaining them.

5.1.1.2 Requirements

The issue of the understanding of client requirements came up in the unstructured section of the interviews on 28 separate occasions. Eleven of the thirteen interviewees made references to the issue of understanding client requirements in some form or another. The importance of understanding client requirements and alignment was emphasised (nineteen mentions). The use of various forms of alignment meetings was highlighted in nine instances. Such meetings include bid-clarification meetings, kick-off meetings (with contractors and suppliers), pre-manufacturing meetings, internal and external alignment meetings, reviews and project meetings.

The detailed review of the contract and requirements was also mentioned as a way to improve understanding of client requirements in two instances; this would include raising any uncertainties or interpretation issues with the client. The importance of client perceptions and making sure that expectations are realistic was mentioned in two cases. Having a well developed process design which forms the input to further design steps was raised as an important factor in two instances

One interviewee also noted that the problem of obtaining alignment on and understanding of requirements is much worse in cases where the client and contractor or supplier has not worked together previously. One interviewee also suggested the use of roaming quality people with a good understanding of the requirements to communicate and enforce understanding of requirements at suppliers. The quality consultant with both automotive and construction experience suggested that due to alignment problems on requirements, clients tend to over-specify to compensate for possible non-compliance, this makes requirements more difficult to understand and align on and further exacerbates the problem.

5.1.1.3 Schedule and planning

Nine of the thirteen interviewees raised schedule and planning as an issue. The topic received a total of 23 separate mentions during the unstructured section of the interviews. In six cases interviewees stated that there is an increasing tendency to put project schedules under pressure, this ultimately has negative effects on engineering quality. In five cases the interviewees emphasised the importance of planning in terms of meeting schedule requirements, but also ensuring the schedule allows sufficient time and resource to allow adequate engineering work to be done. In two cases it was noted that it is also important for engineers to understand the schedule and their impacts and thereon.

A number of noteworthy statements were made by individual interviewees on this subject. One noted that in the current fast track project environment, many engineering decisions are based on assumptions; this inevitably leads to re-work, but has great impact in improving schedule. It was also noted that the schedule is determined by the number of work fronts that can be engaged simultaneously. Finally, one interviewee said that in terms of a quality project, both schedule and cost conformance, in addition to technical conformance are aspects of quality.

5.1.1.4 Quality systems

Twenty five separate references where made to quality systems or components thereof by ten interviewees during the unstructured section of the interviews. In four instances the importance of quality systems and processes were emphasised by interviewees. One contractor interviewee specifically noted that their quality system was based on TQM principles. On three occasions interviewees stressed the importance of customising the quality system for each separate project. The use of reviews such as squad checks or peer reviews, where groups of inter-disciplinary peers review the quality of engineering deliverables, was also suggested on ten occasions. The use of quality plans, where all quality activities are planned and documented in advance of a project phase, was also suggested on five separate occasions. Discipline specific activity plans and the clear assignment of discipline responsibilities were also suggested by one interviewee. One contracting company also noted that they had converted most of their procedures to flow chart based (rather than written) procedures to promote ease of understanding and use. One contractor also suggested the use of a project requirements checklist, where project requirements are recorded and only checked once fulfilled. One of the quality consultant also noted that the construction industry tends to have a heavy inspection focus, rather than a systems and process focus. He suggested that this is driven, to a certain extent, by standards and specifications which rely heavily on signatures and approvals.

5.1.1.5 Demand side

Reducing the reliance on manpower through addressing demand side issues was raised by seven interviewees on fourteen different occasions. On nine occasions the use of automation and productivity tools to increase the effectiveness of engineering man-hours was discussed. Many engineering contractors (including all three contractors involved in this study) have intelligent engineering systems that are able to link flow sheets, 3D models, engineering data, datasheets, isometrics and other engineering deliverables in an intelligent way; thereby ensuring engineering data is maintained in a consistent fashion at a central point and updates are reflected on all deliverables and communicated to all affected parties. These systems are also able to automatically generate certain engineering deliverables such as isometric drawings and datasheets. The importance of such intelligent systems was stressed on three occasions. The importance of these systems in controlling the consistency and updating of engineering data and controlling the flow of this data to engineers and other stakeholders was mentioned on six occasions. In three instances interviewees mentioned the positive benefits of the automatic generation of deliverables using these systems. Interviewees explained on three occasions that these systems have a positive impact on engineering productivity, on two occasion interviewees also explicitly pointed out that such systems improve engineering quality.

On two occasions interviewees suggested that in some cases there is a reluctance to embrace such automation and productivity tools due to a fear of technology and unfamiliarity with the tools itself. One interviewee also suggested that as the productivity frontier expands due to the use of such systems and tools, business continues to place the system under pressure by increasing demands for cost and schedule improvement; therefore these systems continue to remain under pressure despite vast improvements in productivity and effectiveness over the last several decades.

One client interviewee mentioned a case of 500% difference in productivity in producing isometric drawings between two contractors, where the more productive contractor had intelligent systems and the other relied on manual systems; the interviewee did point out that the experience of the engineers involved, in addition to the automation tools, contributed to this huge difference in productivity. It was also noted that as automation increases, many of the everyday activities that were used to train young engineers in the practical application of engineering requirements are lost, and that special innovative training practices would have to be develop to compensate for this.

It was also suggested that engineers should work smarter and that the use of engineers for everyday mundane activities should be minimised, in order to focus their engineering hours on critical engineering activities. A number of other techniques to address demand side issues were suggested. The consolidation of engineering activities, such as bulk approval of documents that are repeatedly used on different jobs and combining manufacturing (or other) meetings where multiple jobs are executed by the same vendor was suggested. Balancing front end versus detail design activities to ensure the use of engineering man-hours where they are the most effective was also proposed. Methods to ensure that action items are carried over and closed out between meetings were also recommended, this could involve automation or a simple consolidated activity list of action items to be addressed.

5.1.1.6 Risk Management

Six interviewees mentioned risk management on nine separate occasions. They all stressed the importance of technical risk management in terms of identifying technical risks and then mitigating them as appropriate.

5.1.1.7 Teams – Relationships

Aspects related to team work and relationship building was mentioned on seven occasions by six different interviewees. The importance of team building at the outset of projects to build relationships between contractor and client team members and improve alignment and understanding between the parties in order to reduce later conflict was mentioned on three occasions. One interviewee suggested that current practices in this regard need to be revisited and improved. In two cases interviewees suggested that client and contractors should become less confrontational and consider partnering or alliance type approaches. One interviewee pointed out that the relationship or chemistry between parties, specifically the client and contractor project managers, is crucial to creating an environment conducive to successful project execution. One interviewee stressed the importance of teams by stating that in successful teams the whole is more than the parts, but that soft skills are important in making this work. Two interviewees stated that the practice of using integrated contractor and client teams is currently under utilised.

5.1.1.8 Continuous improvement

Six interviewees made reference to continuous improvement, lessons learnt or knowledge management in some form or another on eleven separate occasions. On two occasions reference was made to improving the use of lessons learnt as a feedback mechanism and input to continuous improvement. On two occasions client representatives noted that management reviews should become more quality focussed. One contractor interviewee also stated the client satisfaction feedback through formal surveys and informal discussion is considered an important input to their continuous improvement efforts. One client interviewee also stated that non-conformance systems are an important source of feedback for continuous improvement and is currently under-utilised. One contractor (two mentions) has an online knowledge management system where personnel from all their international offices can submit best practices and learnings; these are then moderated by full time subject matter experts and published for global consumption if considered best practice. This practice can also be considered to fall within the field of knowledge management, but also leads to continuous improvement. One interviewee also stressed the importance of measurement and the use of metrics for monitoring, control and improvement purposes. The suggested methodology involves identifying the critical parameters for success and then identifying key measurements that will be indicative of these parameters.

5.1.1.9 Accountability

The issue of accountability and responsibility was raised on five occasions by four separate interviewees. Two client interviewees stated that the engineering contractor must clearly be made accountable for the outcome of engineering. It was also noted that roles and responsibilities must be clearly specified (two mentions). It was suggested that contracts often are not effective in allocating such accountabilities, and that relying on long term relationships between client and contractor might be more effective. It was also noted that relying on inspection is not an appropriate alternative to allocating clear accountabilities for successful outcomes.

5.1.1.10 Cost

Four of the interviewees raised cost or man-hours spent as an issue on six separate occasions. On three occasions interviewees noted that cost pressure is increasing in the industry and that this has knock on effects on quality. Three interviewees also noted that cost can be considered part of client requirements and therefore an aspect of quality. One client interviewee also suggested that client organisations in some cases are not prepared to pay for fair value and this places pressure on contractors and suppliers to perform.

5.1.1.11 Change management

The importance of change management was highlighted by four interviewees on six separate occasions. Two of the interviewees simply stressed the importance of the carefully managing engineering change through the project life. One interviewee pointed out the importance of understanding the technical, cost and schedule impact of changes, having clear decision criteria for accepting changes and suggested that having an objective, independent decision maker screening changes before acceptance might improve engineering quality, by preventing unnecessary change. Another interviewee noted that the control of data at a central point, such as a master document, ensuring that all deliverables are updated to reflect changes and checking philosophies, assumptions and other inputs to changes, are critical parts of managing change.

5.1.1.12 Audits

The use of audits was discussed by three interviewees on four separate occasions. In three cases the importance of discipline audits were highlighted. The comment was made that normal quality audits can only confirm that systems and procedures are in place and are being followed. A discipline audit, where a team of independent peers (i.e. from an unrelated project) review the engineering content, is the only way that an audit can confirm the technical quality of engineering. One client interviewee also suggested the importance of auditing or reviewing of contractor systems to understand the possibilities and potential limitations of the contractor system and procedures. Another interviewee stated that there seems to be an increasing emphasis on auditing as a practice to improve quality.

5.1.1.13 Constructability

The importance of constructability of the design was emphasised by four different interviewees on five occasions. In three instances it was noted that planning for construction must be accounted for during the engineering phase, i.e. the design needs to take into account how the physical plant will be constructed. The importance of involving individuals with construction experience and insight in the design process was emphasised. It was also noted that construction risks need to be identified, planned and designed for and mitigated where practical. One of the quality consultants with both construction and automotive industry experience noted that in the automotive industry there is an extra step not present in the construction industry process. Prior to constructing a new facility, the automotive industry has a specific project phase allocated to the planning of construction. However, where current construction planning activities in the construction industry only considers construction sequencing and the timing of activities, in the automotive industry this step includes technical, engineering and quality considerations.

5.1.2 South Africa

The shortage of engineering skills is the most significant common thread that emerged from the questions about the uniqueness of South Africa. Nine of the thirteen interviewees believe that the shortage of engineering skills in South Africa, although not entirely unique, is worse than in other countries. Several reasons are cited for this disparity including substandard or insufficient education and training (four interviewees), the migration of skilled engineers to other countries (three interviewees) and socio / political issues like crime and infrastructure which may be driving the migration of engineers. Two interviewees also noted that the anticipated increasing workload over the next few years will worsen the skills shortage. Although not directly related to the research topic, several interviewees noted that the shortage of construction skills may even be worse than the shortage of engineering skills.

Several approaches to the skills problems were suggested. At a high level it was suggested that industry plan for and develop capacity ahead of large capital projects. To allow this to happen, agreements in terms of workload will have to be made ahead of these projects to allow such pre-investment. Increased training and training for multi-skilled engineers who can see the “big picture” was suggested as a way to compensate for the shortage of skills. Rotation of engineers between client and contractor companies for training purposes was also discussed. It was also suggested that due to shortages of competent construction resources, more detailed definition of requirements for construction are needed from designers to compensate. Greater use of shop fabrication and modular construction was suggested to compensate for low construction productivity.

One of the quality consultants suggested that South African companies are not serious enough about quality systems; this is often driven by clients who do not consider quality systems important to their businesses. According to this interviewee ISO based quality systems are also often seen as a marketing tool rather than a way to improve the business.

One client representative noted that South Africa and South African companies are small players on the global stage, this interviewee suggested that South Africa is seen as a third world company where sub-standard products and services can be dumped.

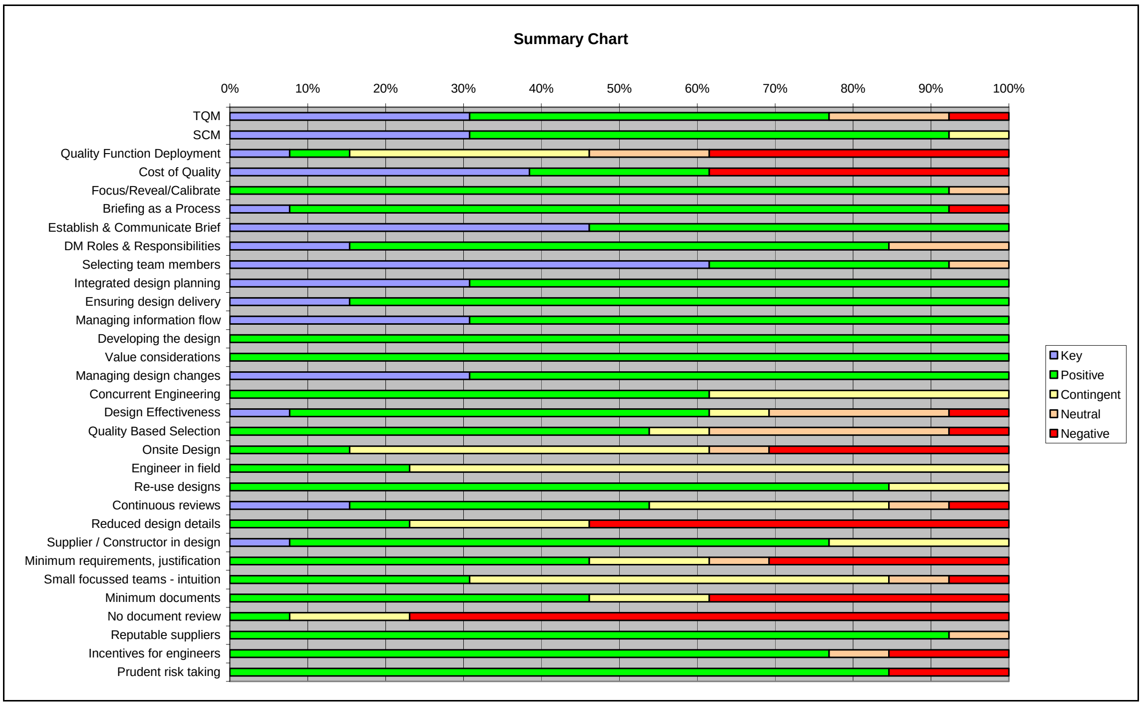
Six interviewees highlighted some positive aspects that they believe are unique to South Africa. Two stated outright that South Africa is better than other countries due to becoming self sufficient during previous isolation and because of the application of quality management in engineering. The others all raised some positive aspects as to the engineering skills in South Africa which were described as innovative, adaptable, multi-skilled and better able to interact with diverse cultures.

Apart from the skills shortage, no interviewees suggested that any fundamentally different approaches to the quality management of engineering are warranted in South Africa.

5.2 Structured Questions

This section of the interviews tested the opinion of interviewees on specific best practices from the literature as described in Chapter 2 and detailed in the interview guideline in Appendix 4. A summary chart of interviewee responses is shown in Figure 5. Thirteen experts where interviewed in total.

Figure 5 - Summary of Structured Responses



The concepts of TQM and SCM both received positive responses form more than 70% of the interviewees, with key and positive responses from ten (>75%) and twelve (>90%) of the interviewees respectively. On TQM one neutral response was motivated on the basis that only certain specific TQM practices are appropriated, but not the entire philosophy. The second neutral response was qualified by stating that TQM was a good philosophy, with few successful implementations and that it was not appropriate to the South African environment. The negative response was based on the interviewee's own experience of an unsuccessful TQM implementation; this interviewee added that TQM is not appropriate to South African culture. The interviewee who gave a contingent response on SCM stated that SCM will only work if the entire value chain can be aligned around the approach.

Quality function deployment was an unfamiliar technique to nine (~70%) out of thirteen interviewees. The one key and one positive responses were from interviewees who stated that the technique would be appropriate to the earlier, process design phases of engineering. The four contingent responses also supported the notion of using the tool in the early phases of engineering, but only if it could be simplified and made applicable to the construction environment. The two neutral and five negative responses where ambivalent or thought the technique was not appropriate.

Cost of Quality received five key and three positive responses (>60% positive). The remaining five interviewees gave a negative response on the technique. Negative responses where qualified by stating that Cost of Quality is more appropriate to production environments and not once-off project environments. Some interviewees also stated that the benefit derived from measuring Cost of Quality in detail does not justify the effort needed to capture these costs. One client representative stated that COQ is used as a planning tool, but not a monitoring tool. The key and positive responders stated that it is important to understand the distribution of quality costs to be able to improve the balance. Several interviewees indicated that currently the emphasis in too much on appraisal at the expense of prevention.

Twelve (>90%) of thirteen interviewees were of the opinion that focussing, revealing and calibrating client expectations would improve quality. The one neutral respondent believed that the current alignment practices used in industry is sufficient and that this technique will not add further benefit. Only one interviewee was negative about Briefing as a Process, stating that this technique may lead to scope growth. Eleven interviewees were positive and one believed Briefing as a Process to be a key practice. Several of the positive respondents stressed that this process will have to be carefully managed to avoid it resulting in scope growth.

The feedback on the Design Management construct was overwhelmingly positive, with only three neutral responses, 84 positive responses and 30 key responses (>97% key and positive responses). Establish and Communicate the Brief received seven positive and six key responses. Design Management Roles and Responsibilities received two key, nine positive and two neutral responses. One neutral respondent did not believe that defining design roles and responsibilities was possible at a detail level, and the second neutral respondent stated that he was not aware that the practice was in use. Eight interviewees believed that Selecting Team Members was a key practice, with four positive responses and one neutral response. The neutral response was by an interviewee who believes a strong team is a given, and therefore team selection is not that important. Integrated Design Planning received four key and nine positive responses. Ensuring Design Delivery received two key and eleven positive responses. Managing Information Flow received four key and nine positive responses. Developing the Design received thirteen positive responses. Value Consideration received thirteen positive responses, with all client respondents stating that this only happens when driven by the client. Managing Design Changes received four key and nine positive responses.

Concurrent Engineering received eight (>60%) positive responses and five contingent responses. The contingent responses where because interviewees believe that concurrent engineering is resources intensive and is therefore not warranted in all cases, and should only be used in selected cases. Examples of such selected cases that were given included large and complex projects.

Design Effectiveness received one key, seven positive, one contingent, three neutral and one negative response. The negative respondent stated that an aggregate design effectiveness measure was not needed if the Design Management principles as discussed above were in place. The neutral respondents either were not involved in the measurement of design metrics and was therefore unable to comment or stated that some of the individual components measures were in place, but that an aggregate measure was probably not warranted. The contingent response was from an interviewee who believed that such a design effectiveness measure would only be appropriate on more complex projects.

Seven (>50%) interviewees were positive on Quality Based Selection, one gave a contingent response, four remained neutral and one was negative on the approach. Eight (>60%) out of thirteen interviewees stated that the industry in South Africa is overly cost focussed at the expense of quality. The contingent responder stated that the approach can be used if it helps to make objective decisions. One neutral respondent stated that the client decides on the selection approach, a second that reliance should rather be on a good suppliers list than an elaborate selection process and a third that there is a good balance between cost and quality in the industry and the approach is therefore not needed. The negative respondent stated that cost focus is driven by shareholders and therefore Quality Based Selection is not appropriate.

Two respondents were positive, six gave contingent responses, one was neutral and four gave negative responses on the concept of Onsite Design. Reasons for negative responses were that small site teams were driven by costs constraints, that companies were only set up to effectively do design in their design offices, that previous bad experience had indicated that the design must be complete before construction commences and that the advantages of such an approach was not evident. The contingent responses were all qualified that the approach was only applicable in selected cases, with brown field type jobs often cited as an example.

Engineer in Field received three positive and ten (>75%) contingent responses. The contingent responders all stated that this approach is resource intensive, and therefore only appropriate in selected cases.

Re-use of Designs received eleven (>80%) positive responses and two contingent responses. The two contingent responders indicated that the approach was only applicable where the design was appropriate for use in the new application, and that this had to be checked.

Two interviewees believed Continuous Reviews was a key practice, five were positive, four gave contingent responses, one was neutral and one negative on the subject. The contingent responders stated that people learn bad habits, therefore the process needs to be formally managed and controlled, that such a process can be resource intensive and will only work if the right people are available at the rights time and that the approach will only work if geographical proximity permits. The neutral responder also noted that formal reviews are still needed to capture input from the reviews. The negative responder noted that Continuous reviews will be resource intensive, and that reliance should rather be on formal reviews scheduled on a regular basis.

Seven (>50%) interviewees were negative on the concept of Reduced Design Details, three gave contingent responses and three gave positive responses. The contingent responders noted that this approach can only be done with competent constructors, who are closely managed; decision makers also need to be at the site when called upon. The negative responders stated that approach will lead to clashes and rework and with current skill levels in South Africa the approach is not appropriate. One responder noted that with modern design tools it is much easier to provide these design details up front, thereby reducing interface problems and congestion on site.

Supplier / Constructor in Design received one key response, nine positive responses (>75% key and positive) and three contingent responses. The contingent responders all stated that this approach is only appropriate in selected cases such as special equipment and that suppliers and contractors should only be involved in such cases.

The Minimum Requirements approach received six (<50%) positive responses, two contingent responses, one neutral and four negative responses. One continent responder said the approach would only work on small projects, as on large projects there are too many details to address, the other contingent responder stated that it would only work if proper alignment on requirements was achieved up front, otherwise a lot of time would be wasted on disputes. The neutral respondent stated that this approach would make it very difficult to compare bids. The negative responders raised concerns over how minimum requirements are defined and how they are agreed up front; they also said that requirements are a way of capturing the detail of what is required by the client and a risk is disputes over what is required if this approach is adopted. One positive respondent pointed out that differing stakeholder views may derail such an approach. Two other positive respondents compared this approach to value engineering conducted in reverse.

Small Focussed Teams using intuition received four positive responses, seven (>50%) contingent responses, one neutral and one negative response. The contingent responders gave several different qualifications stating that the tool is only appropriate on small risky projects, that it is only appropriate in less complex environments, that it is only appropriate to specific sectors and types of projects, that it is only appropriate for the early phases of design, that the small team must remain responsible for project success for it to work, that you need experts who may not be readily available in South Africa and that for safety and legislative reasons detail calculations would still be required. The neutral respondent was not directly involved in engineering and declined to comment on this practice. The negative responder stated that such teams could not replace detail design calculations, but would be very useful in a consulting capacity.

Six (<50%) interviewees where positive on Minimum Documentation, two gave a contingent response and five gave a negative response. The contingent responders qualified their responses by stating that such an approach would rely heavily on the skills of constructors and therefore may not be appropriate to South Africa, that the approach would only apply to specific sectors and types of projects and that a paradigm shift would be required for minimum documents to be accepted. Negative responders were concerned about documents required for commissioning and maintenance activities. One positive responder noted that the approach was acceptable in the short term, but that it would prevent repeatability by not capturing all information. One positive responder also suggested an IT based approach where deliverables are only committed to paper on demand.

No Document Review received ten (>75%) negative responses, two contingent responses and one positive response. One contingent responder stated that the approach would just work with a few very select global suppliers; the second contingent responder stated that the approach will only work if suppliers are properly managed and the emphasis is shifted away from price based competition. Eight out of ten negative responders stated that South African suppliers are not ready for such an approach; one responder stated it would be dangerous not to review documents and one stated that the approach is not appropriate as long as contracting companies remain responsible for overall engineering quality.

The use of Reputable Suppliers received twelve (>90%) positive responses, with the one neutral interviewee contending that there is no such as thing as a reputable supplier because all suppliers are driven by a profit motive.

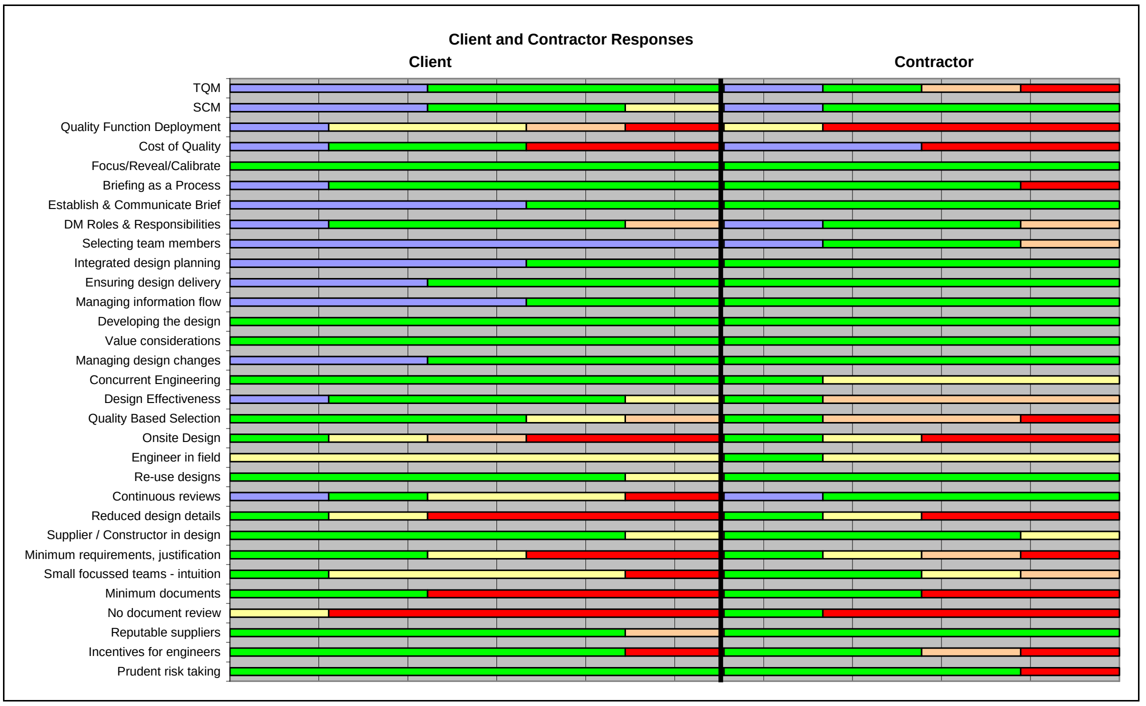
Ten (>75%) interviewees were positive on offering Incentives for Engineer, one was neutral and two gave negative responses. The neutral interviewee stated that the approach would have limited benefit and that it would be difficult to manage for the correct outcome. The negative respondents pointed towards perverse outcomes, a short term focus and the fact that professionals are motivated by other factors as reasons not to adopt the approach. The positive interviewees also had some reservations, with five out of ten stating that the objectives would have to be carefully selected to avoid perverse consequences. One positive interviewee believes that this approach will become more common as pressure to deliver increases.

Creating an environment for Prudent Risk Taking received eleven (>80%) positive responses and two negative responses. The negative interviewees stated that the approach could have adverse consequences and would not improve quality. Two positive respondents stated that the current “blame culture” in industry may prevent this approach from working, while a third commented that risks on safety should not be permitted.

The data was also categorised to see if there where any obvious differences in the way the interviewees responded to the questions. The data was categorised in terms of interviewees from client and contractor organisations (consultants excluded) and interviewees with a quality versus an engineering background to investigate for any differences between these groups.

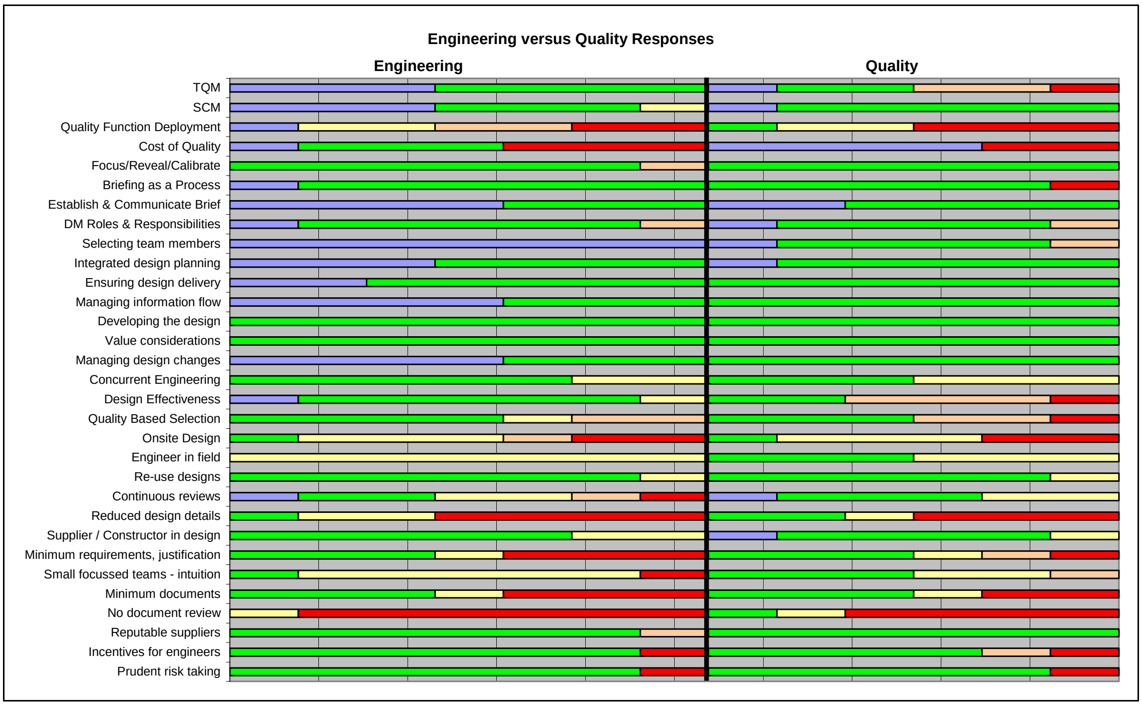
There are only a few obvious differences between the responses from client and contractor interviewees as can be seen in Figure 6. The first obvious difference is that all client interviewees were positive on TQM, with a neutral and negative response on the contractor side. Contractors were also somewhat more negative on Quality Function Deployment than clients. On Design Effectiveness several interviewees from contractors were neutral, while client interviewees were positive with one contingent response. On Quality Based Selection the client response was mostly positive, with contractor response being mostly neutral. Continuous Reviews received two contingent and one negative response from clients and only positive responses from contractors. It is also interesting to note that all client interviewees consider Selecting Team Members to be a key practice.

Figure 6 - Client and Contractor Responses



When comparing the responses of interviewees with an engineering background to those of interviewees with a quality background only a few obvious differences can be seen (see Figure 7). All the engineers were positive on TQM, while some quality practitioners were neutral and negative towards the concept. All the engineers had a positive or contingent response on Design Effectiveness, while the quality practitioners where mostly neutral or negative. All the engineers gave a contingent response on Engineers in the field, while the quality practitioners were equally split between positive and contingent responses. Finally all the engineers believed that Selecting Team Members was a key practice.

Figure 7 - Engineering and Quality Responses



6 Discussion of the Results and Recommendations

In this section of the report the results of the study are discussed and related to the literature, recommendations flowing from the research are also made. Firstly the feedback from the unstructured portion of the interviews is discussed, then aspects unique to South Africa are discussed and then the feedback from the structured portion of the interviews is discussed. Finally the results are related to the research problem, questions and propositions.

6.1 Unstructured Questions

6.1.1 General

In this section the feedback from the unstructured portion of the interviews is discussed around the thirteen themes identified during the content analysis. Recommendations pertaining to each theme are also made where appropriate.

6.1.1.1 Skills

The single most prevalent topic that arose from the unstructured portion of the interviews was skills and competence and the shortage thereof. This is not entirely surprising considering global and local trends indicating an increasing shortage of engineers abroad (Creamer, 2006b) and in South Africa (Olivier, 2005). This is supported by the academic literature in the form of Tan & Lu's (1995) model of engineering design quality (see Appendix 2) which lists qualified manpower as one of the input quality criteria for engineering design projects. Love *et al.'s* (2000c) study of rework in engineering showed that error proneness is inversely proportional to the experience of the engineering resource. A study on causal loops (see Figure 2) in the project system also showed that low skill levels have negative effects on project duration, cost and quality (Love *et al.,* 1999b).

The comment that the best systems and tools will not deliver quality if you do not have competent resources to drive them is significant. Taken in the context of the increasing construction spend planned for South Africa over the next few years, and the skills shortages mentioned above, it is clear that the construction industry will come under increasing pressure in the foreseeable future. The observation that good standards and specifications alone will not ensure quality, but that engineering judgement (i.e. competence) is required, paints an even direr picture.

The shortage of competent engineering resources can be addressed both from a supply side and a demand side. The supply side issues and recommendations will be discussed in this section, while a number of demand side aspects will be covered later in this report.

Industry wide collaboration to address the engineering skills shortage is probably warranted, and such initiatives have already been undertaken to address the shortage of skilled artisans by industry investing R 140 million in skills training (Spadavecchia, 2006). Longer term work load agreements will allow contractors to retain more permanent staff and allow more specific training of these engineers who previously rotated between organisations and received little training. Attention should also be given to increased practical training and cross discipline training. Engineers who are trained to operate across disciplines are able to see the "big picture" and therefore operate more effectively in an integrated engineering environment. A training initiative to embed Design Management (Bibby *et al.*, 2006), which received overwhelming positive response in the structured section of the interview, is also recommended.

Increased use of mentoring and coaching can have positive impacts by accelerating the pace of development of inexperienced engineers. It also has the potential of improving the productivity and effectiveness of these engineers while they are developing. In the context of the shortage of engineering skills, this practice must be seriously considered. Using retired engineers in this role, as suggested by Theunissen (2005) gives the benefit of this practice without using resources from an already strained resource pool.

Retention strategies such as training and development, remuneration, bursary and graduate programs, technical mentoring and coaching, rotation to international offices for high potential candidates and accelerated leadership development programs are important at an individual company level if the company wants to retain competent engineers. However, unless industry wide supply issues are addressed through improved training and development, such retention strategies could easily result in one-upmanship between respective companies. Driving up cost to company, but ultimately doing very little to improve the overall situation.

Given the constraint on resources, the selection of engineering team members to match project complexity becomes even more critical. This is borne out by the fact that eight out of thirteen interviewees considered Selecting Team Members to be a key practice in the structured section of the interview. This is the most positive response on all the practices tested for in the structured section of the interview. Selecting Team Members (Bibby et al., 2006) involves selecting project team members on specific quality criteria to match their specific competencies to the needs of the project. Tan and Lu's (1995) model also suggest manpower must be qualified to meet project requirements. This means not only should the most competent resources be used on the most complex projects, but that the most competent resources should not be allocated to less complex projects, as this is an inappropriate use of engineering competence which is in short supply.

The statement by an interviewee that in the current engineering resource constrained environment, the A-team and even the B-team may not be available is an important insight that requires careful consideration. The imperative will be to ensure that appropriate action is taken to allow the C-team to perform like an A-team. Approaches that may work include coaching and mentoring, substitution of members with A-team players at critical junctures, balancing team composition to compensate for lack of skills in certain areas and adopting a task force approach where teams of highly skilled engineers can consult to the C-team when needed.

6.1.1.2 Requirements

Considering that quality is often defined as conformance to customer requirements (Hassan *et al.,* 2000) the emphasis on understanding of, and alignment on requirements is appropriate. Tan and Lu's (1995) model lists conformance to client requirements and codes and standards as input quality criteria, with clarity and reasonableness of owner requirements being a primary impacting factor. Conformance to client requirements and conformance to codes and standards were ranked in the top three quality criteria by both owner and contracting firms.

The use of various forms of alignment meetings is prevalent under the parties interviewed. Tan and Lu's (1995) model lists communication and co-ordination of requirements as a primary impacting factor on engineering quality. This practice should be continued and adopted where not yet in use. A detailed review of the contract and requirements and clarification of any queries would be considered a critical part of such alignment sessions. An increased emphasis on alignment on requirements can be considered. Practices such as Focussing / Revealing and Calibrating Client Expectations (Ojasalo, 2001) and Briefing as a Process (Barrett & Stanley, 1999), which received very positive responses in the structured section of the interviews, should also be considered for adoption. The suggestion to make use of roaming quality people with a good understanding of requirements to communicate and enforce requirements can be considered as one method to adopt the Briefing as a Process concept.

Cognisance must be taken of the notion that alignment and understanding will be more difficult to obtain where the client and contractor or supplier have not previously worked together. This should be taken into account as a selection criterion during appointment of such suppliers or contractors. Additional time and resources should be allocated to allow for proper alignment in such cases.

Clients should also avoid the trap of over-specification to compensate for possible mis-interpretation and non-compliance. Efforts will be much better spent on specifying the appropriate requirements and then spending time to ensure alignment and understanding of requirements.

6.1.1.3 Schedule and Planning

Interestingly Tan and Lu's (1995) model lists conformance to schedule (and cost) requirements as one of the criteria of engineering quality, the reasonableness of the schedule is given as one of the primary factors impacting engineering quality. Love *et al*.'s (2000c) model of factors affecting error proneness during engineering also lists schedule pressure as one of the four main factors. Interviewees' comments that increasing schedule pressure is negatively impacting on engineering quality is supported by the literature. The remark that schedule is determined by the number of work fronts that can be engaged simultaneously suggests that schedule pressures will further increase when seen in the context of the skills shortage already mentioned.

The importance of planning in addressing the issue of schedule pressure is supported by the positive response by interviewees on Integrated Design Planning, with all respondents being positive, including four key responses.

A key observation by one of the interviewees is that in the modern fast track project environment, many engineering decisions are based on assumptions, this improves project schedule, but can ultimately lead to quality problems and rework. This practice is consistent with concurrent engineering (Costin, 1999) and is also captured by the inclusion of parallelism in Love *et al.*'s (2000c) model as one of the main factors affecting error proneness during engineering. In the modern project environment, engineers need to understand this phenomenon and put mechanisms in place to manage these assumptions and to minimise the negative impact of such assumptions. This would include carefully scrutinising assumptions to ensure they minimise the potential for rework, managing these assumptions through the design cycle to ensure they are all addressed, and attempting to resolve the assumptions during the engineering phases when change is relatively cheap compared to the manufacturing and construction phases.

6.1.1.4 Quality Systems

The emphasis placed by interviewees on quality systems is not surprising as both contractor and client organisations involved in the study have ISO accredited or ISO based quality systems. The importance of quality systems and processes is also suggested by the fact that most quality awards typically only allocate a 20% weighting to product quality (Toakley & Marosszeky, 2003). Tan and Lu's (1995) model lists conformance to design processes and procedures as one of the design process criteria of engineering quality, and gives the effectiveness of quality assurance and control as primary impacting factors.

The Managing Director (not one of the interviewees) of one of the contractor companies interviewed mentioned during a discussion of the research that people make mistakes; the only way to completely avoid such mistakes is to not allow engineers to work. This suggestion is supported by Love *et al.'s* (2000c) model which includes "normal error" as one of the four main factors affecting error proneness in design. The only way to address this issue of normal error is to use practices such as squad checks or peer reviews to inspect deliverables for mistakes. The use of peer reviews in addition to normal quality audits to check the content of engineering deliverables is further supported by Tan & Lu's (1995) model which includes the completeness and conformance to standards as the quality criteria for engineering output. Peer review forms an important part of the quality control of engineering deliverables (also see discipline audits discussed later).

The use of project specific quality systems is warranted by the once-off nature of projects (Smith *et al.,* 2004). Each project is unique and may have a different set of client requirements, having a customisable quality system that can be set up for each individual project allows contractors to address such client specific requirements.

Planning of quality steps is related to the Integrated Design Planning practice which forms part of Design Management (Bibby *et al.*, 2006) and which received much positive response in the structured section of the interviews. Specifically including the planning of quality steps in the planning process is strongly recommended.

The opinion of a quality consultant that the construction industry has a heavy inspection focus is supported by the Cost of Quality feedback in the structured section of the interviews where interviewees suggested that there is an excessive amount of appraisal cost as compared to prevention costs. Consideration should be given to increasing the emphasis on prevention costs.

6.1.1.5 Demand Side

As discussed above the shortage of engineering skills and competence can be addressed from a supply and a demand side. On the demand side the most discussed approach was the use of automation and productivity tools. One interviewee suggested that as the productivity frontier expands, business will continue to place pressure on the system by demanding improved schedule and cost performance. This is in line with continuous improvement which is part of TQM (Silvestro, 2001) practice and should not deter companies from continually seeking improvements. The suggestion was also made that engineers should work smarter and the use of engineers for mundane activities should be minimised. This is in line with Maister's (1993) suggestion that professional service firms have three types of worker, procedural, brain and grey hair, and that each of these types of resources should be applied where they are most effective. Automated systems allow companies to free up the time of their valuable brain and grey hair resources to focus on the critical few activities where they can add the most value. This does create a potential problem, the procedural and mechanistic work that young engineers typically did as part of their training to obtain a deeper insight in engineering falls away as automation increases. This gap must be addressed by specific training programs developed to bridge this gap and give young engineers the necessary exposure to develop their insight and judgement.

One form of such tools that is in use is intelligent systems that are able to link flow sheets, 3D models, engineering data, datasheets, isometrics and other engineering deliverables in an intelligent way; thereby ensuring engineering data is maintained in a consistent fashion at a central point and updates are reflected on all deliverables and communicated to all affected parties. A client interviewee quoted comparative figures suggesting that such a system can improve productivity by as much as 500% in specific cases. Such systems supports change management (discussed later in this section) by reflecting updates across all deliverables, but also assists in Managing Information Flow which was one of the practices that received an extremely positive response in the structured section of the interviews. These systems not only free up engineering time by taking care of mundane activities, but reduce the opportunity for human error by controlling data centrally and therefore also directly improve quality.

Not all companies can afford such complex and expensive systems. However, efforts should be made to follow the same principle to reduce the amount of mundane work that engineers have to do, and also to attempt to rationalise the amount of work needed. Some of the proposals made by interviewees included reducing engineering activities by combining engineering meetings where multiple orders are placed with the same supplier and bulk approval of documents that are repeatedly used.

Where productivity tools are available, care should be taken to provide the necessary training to ensure that engineers (old and young) are familiar with the tools and able to use them effectively.

Other demand side issued such as rationalising the amount of work planned for the future comes down to strategic business decisions and is beyond the scope of this research.

6.1.1.6 Risk Management

The emphasis on risk management was not entirely anticipated based on the literature survey conducted. However, ISO 9004:2000 (ISO, 2000a) states that quality management principles not only provides direct benefits but also makes an important contribution to managing costs and risks and that risk management considerations are important for the organisation, its customers and other interested parties. ISO (2000a) further states that risk assessment should be undertaken to assess the potential for, and the effect of, possible failures or faults in products and processes and that the results should be used to define and implement preventative actions to mitigate the identified risks. It is also suggested that management reviews be extended to include loss prevention and mitigation plans for identified risks. Seen in this context the emphasis on technical risk management is understandable. Technical risk should be identified, assessed, and mitigated as appropriate, this should be an ingoing process throughout the project lifecycle, including the engineering phases.

6.1.1.7 Teams – Relationships

Team work is considered a secondary impacting factor of input engineering quality (Tan & Lu, 1995). Team building, which can be done as part of alignment sessions, is important to create and develop teams that will work together, thereby impacting engineering quality. Teams tend to be aligned and this assists in improving mutual understanding of requirements and reduces later conflicts. The relationship between project managers and the environment they create is critical as suggested by one interviewee and supported by Tan and Lu's (1995) model which presents the project managers ability to lead and motivate the team as a factor that impacts engineering quality.

Building relationships and becoming less confrontational supports the recommendation for industry co-operation for training suggested above. It is also aligned with the Supply Chain Management concept that received a very positive response in the structured section of the interviews. The relationship aspect is in agreement with the service quality literature which suggests that the process of delivery matters (Stewart *et al.*, 1998) and that social interaction is a component of professional service quality (Woo & Ennew, 2004).

The suggestion to make more use of integrated teams is consistent with concurrent engineering (Costin, 1999) which received positive and contingent responses (due to resource intensity) in the structured section of the interviews. It is also supported by the positive feedback given in the structured section of the interview on involving suppliers and contractors in the design process (CII, 1999) where appropriate. Integrated teams also potentially improve communication and alignment between parties.

6.1.1.8 Continuous Improvement

Continuous improvement is a key part of TQM (Silvestro, 2001) and quality systems such as ISO 9000 (ISO, 2005). The use of lessons learnt and ensuring that these lessons are acted upon can play a key role in continuous improvement in the project environment. The utilisation of client feedback can also assist in continuous improvement and is consistent with customer orientation which forms part of TQM (Silvestro, 2001). Other sources of information to feed continuous improvement is non-conformance systems and knowledge management systems such as the one used by one of the contractor companies interviewed. This knowledge management system allows personnel from all their international offices to submit best practices and learnings; these are then moderated by full time subject matter experts and published for global consumption if considered best practice. Similar techniques can be use to moderate and implement project lessons learnt, even where a sophisticated global system is not available.

Measuring key indicators of parameters critical to success not only allows for monitoring and control, but trends of these indicators can be used as an input to continuous improvement.

Finally the comment that management review meetings should become more quality focussed is important, continuous improvement can have the best inputs in terms of information such as metrics and lessons learnt, but will be meaningless if not acted upon. Management reviews and other similar forums must be used to drive continuous improvement initiatives home.

6.1.1.9 Accountability

This issue of accountability and contracts was not entirely anticipated based on the literature, apart from the references to clear roles and responsibilities for the design process. However, the contract is of fundamental importance because it sets the legal basis of the relationship between the parties (Ramanujan & Jane, 2006). It forms the foundation for a sustainable relationship and the aim should be to create a collaborative environment that discourages zero-sum outcomes.

The suggestion that contracts are not always effective in allocating accountabilities and that greater reliance should be placed on relationships is consistent with the earlier discussion that the relationship between client and contractor is important and that partnerships and alliances should be considered. However, even such relationships will not achieve this end if accountabilities are not clearly and explicitly assigned. The allocation of design management roles and responsibilities, which received a positive response in the structured section of the interviews, is one method to achieve an explicit allocation of responsibilities and accountabilities.

ISO 9001:2000 (ISO, 2000b) requires that that responsibilities and authorities are defined and clearly communicated. The quality standard also requires that interfaces be managed between the different groups involved in design and development and that there is clear assignment of responsibility.

6.1.1.10 Cost

Conformance to cost requirements is one of the criteria of design process quality (Tan & Lu, 1995). Love *et al.* (2000c) lists design fee pressure as one of the main factors affecting error proneness in design. A study of causal loops in the project system also indicated that skills shortages can further place pressure on project costs (Love *et al.,* 1999b). It is therefore not surprising that interviewees suggested that cost pressures are impacting negatively on quality. This is further supported by a large proportion of the interviewees commenting in the structured section of the interviews that the industry tends to be overly cost focussed. Techniques like Quality Based Selection (FIDIC, 2003) or similar that gives more weight to quality aspect than cost should be considered for adoption. Client companies would also do well to take into account that contractors are unable to produce quality engineering if clients are not prepared to pay for fair value.

6.1.1.11 Change Management

Change management is critical to engineering quality and was discussed several times in the unstructured section of the interviews, and also received a very positive response in the structured section of the interviews. Tan and Lu's (1995) model of engineering quality refers to change and the management thereof as primary impacting factors of design process conformance, schedule conformance and cost conformance. In their causal loop diagrams of project systems Love *et al.* (1999b) show that design changes negatively impact on quality of documentation, project cost and schedule. Change therefore potentially impacts on several aspect of engineering quality and should therefore be carefully managed. The suggestion by one interviewee that companies need to understand the technical, cost and schedule impact of changes, and have clear decisions criteria for accepting changes is in line with Bibby *et al.'s* (2006) maturity model (see Appendix 5) which states that mature companies can quickly assess the impact of change.

Intelligent engineering systems make it easier to manage the impacts of change, but it still needs to be understood that changes can have adverse technical, schedule and costs impacts. These impacts become more severe as the design progresses towards the execution phase of the project.

6.1.1.12 Audits

According to ISO 9000:2005 (ISO, 2005): "*Audits are used to determine the extent to which the quality management system requirements are fulfilled. Audit findings are used to assess the effectiveness of the quality management system and to identify opportunities for improvement.*"

Audits are therefore important to determine that conformance of design processes and procedures, which is one of the quality criteria for design process quality according to Tan and Lu (1995). Internal audits are a mandatory requirement in terms of ISO 9000:2000 (2000b) and audit findings are also considered an important input to continuous improvement and one of the topics that should be discussed in management review meetings.

The suggestion of discipline audits in addition to normal audits can be considered as a form of independent peer review and can add much value in terms of checking engineering deliverable content. Quality system audits will typically only check conformance to system and procedures, while discipline audits will check the content of selected deliverables to establish conformance to requirements. Completeness and conformance of output to requirements is one of the quality criteria in Tan and Lu's (1995) model.

6.1.1.13 Constructability

Fayek *et al.* (2003) list constructability problems (see Figure 2) as one of the second tier causes of rework in construction projects. Tan and Lu (1995) state that constructability is one of the quality criteria of engineering and that both owners and contractors rate it as one of the top three criteria. Factors impacting on constructability include timeliness and completeness of supply, teamwork between engineering and construction, construction field experience of design engineers, standardisation, consideration of variation in site conditions and auditing of the design for constructability.

The suggestion that planning for construction should be addressed during engineering is consistent with the literature. Involving construction experts in design, which received a positive response in the structured section of the interviews, is a way to improve teamwork and to boost the construction field experience of the design staff. Addressing and planning for construction risk is also congruent with the aspect of taking into consideration site variations.

Constructability is the only quality criteria of the receiving system dimension of engineering quality (Tan & Lu, 1995), and therefore a key aspect of engineering quality. In this context the suggestion of the quality consultant with construction and automotive experience to place more emphasis on planning and designing for constructability makes a lot of sense. This approach would also support the recommendation made to address the construction skills shortage by focussing more on modular construction and shop fabrication.

6.1.2 South Africa

As noted in the discussion of the unstructured sections of the interviews, skills and competency is an important contributing factor to engineering quality. Therefore considering the recent reported shortages of engineering skills in South Africa (Olivier, 2005) and the planned increase in construction spend (CIDB, 2004; Hill, 2006; Venter, 2006), it is not surprising that interviewees highlighted this as one of the only unique aspects to the South African context. It must be noted that there is a global resource shortage due to increased construction spend, fuelled in part by high oil prices, but that the experts interviewed believe that the shortage is more severe in South Africa due to several factors including the “brain drain,” previously sub-standard education systems, the slowdown in construction in previous decades due to isolation (CIDB, 2004) and other factors. Special consideration of this aspect is warranted and a number of recommendations to address this problem have been made in the section discussing skills shortages above.

The suggestion that South African business often see quality systems as a marketing tool and little else is supported by research conducted in Australia which suggested that construction industry companies often fund their quality system implementation from their marketing departments (Love *et al.,* 2000b). It is important for South African client, contractor and supplier companies to understand the benefits that can result from quality systems that are correctly implemented (Mawson, 2005).

The notion that South Africa is a small player which is considered third world and that substandard products and services are dumped here could possibly be supported by anecdotal evidence, but no reference in the popular press or academic literature was found to support this notion. This does not disprove the contention, but rather raises the question how one would go about proving or disproving the idea and what one could possibly do to address this fact if it was true. This can possibly be the topic of future research.

The positive aspects raised about the attributes of South African engineers probably warrants further research to determine if there are such attributes and what they might be. Once such attributes are established, strategies for improving the competitiveness of South African engineering and construction can be developed that take these attributes into account. For example, if is can be shown that South African engineers are adept at interacting with diverse cultures, are multi-skilled and see the big picture, an approach whereby relatively cheap Indian or Chinese engineers are used for design, with South African engineers supervising and managing the interfaces may be viable.

An important conclusion from this section of the interviews is that apart from the South African engineering skills shortage that warrants special attention, internationally accepted quality systems, processes, procedures and practices are appropriate and applicable to the South African context.

6.2 Structured Questions

This section of the report draws conclusion on the feedback received from the interviewees in the structured portion of the interviews on the best practices identified in the literature. Recommendations for the adoption of these best practices are made based on the feedback from the interviewees. A summary of the conclusions and recommendations on these best practices is presented in Table 6 for ease of reference.

Table 6 - Summary of Structured Feedback Discussion

Practice	Recommend	Reason	Remark
TQM	Yes	>75% Positive	Implementation critical
SCM	Yes	>90% Positive	Involve entire value chain
QFD	Yes, selectively	>30% Contingent >35% Negative	Only for early phases of engineering
COQ	Yes	>60% Positive	At the very least use as planning tool
Focus/Reveal/ Calibrate Expectation	Yes	>90% Positive	Add a focus on soft aspect to alignment
Briefing as process	Yes	>90% Postive	Incorporate in existing practices
Design Management	Yes to all nine aspects	>97% Positive	Use Bibby et.al. training program
Concurrent Engineering	Yes	60% Positive 40% Contingent	At least use more integrated teams
Design Effectiveness	Yes	>60% Positive	
QBS	Neutral	>50% Positive	This or similar techniques required to balance cost focus
Onsite Design	Yes, only in specific cases	>45% Contingent >30% Negative	Only consider for brown field where contractor set-up allows
Engineer in Field	Yes, selectively	>75% Contingent	Resource intensive, use only in critical cases
Re-use Designs	Yes	>75% Positive	Check that design is appropriate
Continuous Reviews	Yes	>50% Positive >30% Positive	Formalise process

Reduced Design Detail	No	>50% Negative	No appropriate to SA, shortage of construction skills
Supplier / Constructor in Design	Yes	>75% Positive	Plan for and involve where needed
Minimum Requirements	No	<50% Positive >30% Negative	Practice not appropriate in isolation
Small focussed teams	Yes, only in early phases	>30% Positive >50% Contingent	Also use as "consultants" to less experienced engineers
Minimum Documents	No	<50% Positive >35% Negative	Consider rationalising documentation
No document review	No	>75% Negative	Most negative response, SA suppliers not ready
Reputable Suppliers	Yes	>90% Positive	Links to SCM
Incentives for Engineers	Yes	>75% Positive	Carefully select objectives and targets
Prudent Risk Taking	Yes	>80% Positive	Empowering employees part of TQM

More than 75% of the interviewees were positive on TQM. The two negative interviewees both said that TQM is not appropriate to South Africa. However, one of the contractor organisations interviewed indicated that their quality system based on TQM principles. Joubert (2002) has conducted research on critical success factors for implementing TQM in the South African construction industry. This research recommended further research into TQM failures in South Africa, but indicated that successful implementation is possible if critical success factors are addressed. TQM is a company wide initiative which requires several factors such as top management support for correct implementation. TQM, if correctly implemented offers many benefits to the organisation.

SCM was supported by all interviewees except one who felt it will only deliver benefit if all companies in the value chain can be aligned. One of the major laments of the construction industry is the fragmented nature of the value chain; the opinions of the experts interviewed support the notion that SCM can improve overall quality of construction outcomes.

The response to Quality Function Deployment was not very positive. There was some interest in the tool for use in the earlier phases of design, which is aligned with the CII (1993) recommendation for this tool. It is suggested that engineers involved in the feasibility and conceptual phases of design investigate this tool for use.

Cost of Quality received more than 60% positive responses. The 40% negative responders noted that monitoring these costs is difficult and costly and not justified by the benefit. However, some techniques have been developed to allow capturing of these costs as part of a normal project accounting system (CII, 1989). Given that all modern quality approaches relies on fact based decision making, and that several interviewees believe that the prevention and appraisal cost balance is not optimum, it is recommended that this approach be adopted. If there is a reluctance to invest the time and cost to do proper COQ accounting, at the very least these principles should be applied as part of planning as suggested by one of the interviewees.

In the context of the overwhelming emphasis placed on requirements and alignment thereon in the unstructured section of the interviews, it was not surprising to note greater than 90% positive responses on the two related best practices of focussing, revealing and calibrating client expectation and briefing as a process. It is recommended that focussing, revealing and calibrating client expectations be addressed by including specific time and activities in alignment meetings up front before contract placement, to ensure that the softer issues are addressed and that these issues that are perhaps not explicitly addressed in the requirements are identified, discussed and agreed upon. Briefing as a process should also be incorporated as a standard process. Several existing mechanism can be used for this such as regular communication sessions or meetings between client and contractor engineers and formal technical clarification systems where technical queries can be submitted by either party for clarification. Any such process will have to be carefully monitored and controlled to ensure that it does not result in scope growth, by for example insisting that any scope growth that may potentially arise from such clarification go through a formal scope addition screening and approval process.

Response on the design management concept was overwhelmingly positive with only three neutral responses and no contingent or negative responses out of a possible 117 responses on all nine components. It is strongly recommended that the work of Bibby *et al.* (2006) in terms of developing a comprehensive handbook and training program for embedding the design management principles in an organisation be explored and adopted if possible. The eight key responses for Selecting Team Members, ties up with and supports the emphasis placed on skills and competency during the unstructured section of the interviews. An important note is the client interviewees' contention that value considerations are mostly client driven; this must be taken into account by clients and contractors alike.

Considering the fragmented nature of the construction project environment (Smith *et al.,* 2004), concurrent engineering offers a method to bridge these gaps and 60% of interviewees support the technique. The 40% contingent responders noted that the approach is resource intensive and not warranted in all cases. It is recommended that more integrated teams be used for engineering of construction projects, thereby removing barriers and moving the methodology closer to concurrent engineering and reaping some of the benefits. Critical resources such as supplier and construction personnel can then be involved at key points in the design process.

With 60% positive responses and only one qualified negative response it is recommended that Design Effectiveness be adopted. This also ties up with the measurement aspect grouped under continuous improvement in the unstructured portion of the interviews. Many of the individual component measures for Design Effectiveness is already in place, which implies that implementation of the practice should not be difficult. This practice will support fact based decision making and continuous improvement.

Given that 60% of interviewees believe that industry is overly cost focussed, approaches like Quality Based Selection that increase the emphasis on quality based selection criteria are warranted. Considering that the cost drive ultimately comes from shareholders, Quality Based Selection may struggle to find acceptance. This is further complicated because Quality Based Selection requires that the client be able to prepare accurate estimates, and not all client organisations are able to do this. Alternatively approaches such Quality and Cost Based Selection, where cost is only one aspect of the decision criteria, with a weighting no more than 20%, should be pursued.

Given that Onsite Design is a contingent approach, the high number of contingent responses is not surprising. What is clear is that the practice is only appropriate in selected cases and should be applied as such. Considering that all companies may not be set up to do engineering at a site location, this also needs to be taken into account. Given the low number of positive responses, it is not clear that this practice should be further pursued, perhaps only in the case of highly integrated brown field projects should it be considered.

Using engineers at the construction site and at supplier location should be used, but only in selected cases as the practice is resource intensive and not warranted in all cases.

The re-use of designs where appropriate should also be used as far as possible, especially considering the current resource constrained environment.

If practical considerations such as geographical proximity and availability of the right people permit, Continuous Reviews should be considered for adoption. However, the review process will have to be formalised to ensure that review feedback is captured and acted upon and also to prevent people from developing bad habits over time.

Reduced Design Details relies on competent construction resources to implement the design, and there are serious questions over the availability of sufficient competent construction resources in South Africa. In fact, in the unstructured section of the interviews it was suggested that the design should be specified in more detail to compensate for the shortage of construction competence. More than 50% of interviewees gave negative feedback on this practice; therefore it is recommended that it not be considered for adoption.

Involving suppliers and constructers in design received no negative feedback, but it was suggested that these parties only be involved in selected cases as appropriate. Therefore it is recommended that engineers critically review the design process to identify where suppliers and contractors should be involved, and then involve them in these instances only.

The setting of minimum requirements, with justification of any additional requirements received 46% positive responses and 30% negative responses. The nature of the contingent and neutral responses, stating that it would not be appropriate to large projects, that obtaining alignment would be very difficult and that comparing bids would be difficult, tips the scales against this practice. As pointed out in the CII (1997) document, this practice is probably only appropriate in cases when the entire approach including organisational culture, procurement strategy and design philosophy is in place. Therefore this approach is not recommended at this time.

Only 30% of interviewees were positive on the use of Small Focussed Teams using intuition, but there were several contingent responses. Relying solely on intuition in lieu of detail design calculations is probably not appropriate, especially considering that there are safety and legal aspects that would require detail calculations in certain cases. However, using such teams in early design phases and as consultants in all phases is warranted. This is supported by the current resource shortages, where such teams can focus on the critical few activities where their expertise, which is in short supply, can be applied most effectively. This is very much as Maister (1993) suggests Grey Hairs should operate. Such engineers can also be used as mentors and coaches as suggested in the unstructured section of the interviews.

Considering that less than 50% of interviewees were positive on Minimum Documentation, and the several critical problems were raised, such as lack of skilled constructors, loss of repeatability and the lack of documentation for the operation and maintenance of facilities, this practice is not considered appropriate. However, several interviewees pointed out that certain client organisations require huge amounts of documentation and that there is room for rationalising the amount of documentation required.

No Document review received the most negative responses at 77%. The major objection was that South African suppliers are not ready for such an approach. Accordingly this approach is not recommended.

Apart from the one interviewee who does not believe there is such a thing as a reputable supplier, all interviewees supported the use of reputable suppliers. Therefore this practice is recommended. This approach also relates to SCM which received a very positive response from interviewees.

Considering the 77% positive responses on Incentives for Engineers, this practice is recommended. However, the concern of perverse outcomes raised by many interviewees is a real one. Careful selection of objectives and targets will be required with an inclusion of both short term and long term targets to ensure appropriate behaviour is driven. Allocation of incentives by clients directly to engineers involved on their jobs may be one way to address Drucker's (2002) statement that organisation must take responsibility for all the people whose performance the rely on, whether direct employees or not.

As noted by the negative responders, it could be argued that creating an environment for prudent risk taking will not improve quality. However, considering that empowerment of employees is a basic tenant of TQM (Silvestro, 2001), it could be claimed that such a practice would have indirect quality benefits. Considering that Risk Management is one of the themes that arose in the unstructured section of the interviews and this practice received 85% positive responses, it is recommended.

One should not read too much into the differences between client and contractor or between engineering and quality practitioner responses, because the sample is small and such differences may not be significant. However, a number of interpretations can be suggested. In the case of TQM, some of the contractor interviewees were of the opinion that TQM may not be appropriate to South Africa due to previous unsuccessful implementations. It is not believed that this is a significant difference between client and contractor point of view, rather that the interviewees with previous negative experience of TQM just happened to be from contractor companies. The difference between client and contractor responses on Design Effectiveness may point towards contractors being more concerned with productivity measures than effectiveness, as contractor companies are ultimately selling man-hours. This may be a harsh criticism as the contracting companies did seem to have some measures in place that can be considered to measure more than just productivity. The difference between client and contractor on Quality Based Selection can probably be explained by the comment from one of the interviewees who suggested that in most cases the client determines the approach selected. The difference in response on Continuous Reviews could be explained by the fact that such an approach would be more resource intensive for client organisation (therefore less positive), but would reduce contractor rework (therefore all positive responses from contractors). It is interesting to note that all client interviewees deemed Selecting Team Members as a key practice, but seeing that all respondents were positive on this practice, it does not affect any recommendations.

As in the case of client and contractor, the differences on TQM between engineering and quality practitioners are not considered meaningful. The differences on Design Effectiveness can possibly be explained by the fact that the quality practitioners will take a systems view, while the engineers who are directly involved in engineering are more likely to appreciate the benefits of the practice. The differences on Engineers in the Field between interviewees with a quality background and an engineering background (all contingent) can be explained by the fact that interviewees with an engineering background probably has a better understanding of how resource intensive the practice can be, therefore the contention that it is only appropriate in selected cases. Finally, the fact that all the engineers considered Selecting Team Members to be a key practice, probably points towards their involvement in selecting team members, while quality practitioners would possibly not be directly involved in the selection process.

6.3 Research Questions

The problem addressed in this research is the perceived lack of quality focus in the South African construction industry. The approach taken was to identify best practices to improve the quality of engineering in construction in South Africa. This was done by first establishing expert opinion on South African practices, comparing these to international best practices, determining the applicability of international best practices in South Africa and finally obtaining expert opinion on whether uniquely South African practices are required.

A number of research questions and propositions were put forward. The questions and propositions will now be discussed and related to the research results.

Q1: In expert opinion, what are the best practices for the management of quality of engineering on large construction projects executed in South Africa?

A number of best practices were identified by the interviewees in the unstructured section of the interviews. These practices were grouped around thirteen themes. The themes include skills shortages, alignment on requirements, quality systems and schedules and planning and are listed in Table 5.

Q2: How do these practices compare to international best practices as described in the literature?

P1: Most best practices suggested by experts for South Africa are aligned with international practices.

The practices raised address all seven quality criteria of the Tan and Lu (1995) model of engineering quality in construction. All four aspects contributing to error proneness in design (Love *et al.*, 2000c) were also addressed. Seven of the fourteen best practices recommended by the CII (2006) for project improvement (not just engineering) were addressed by the experts interviewed. There is strong consistency between expert opinion and the literature in terms of the broad themes covered. The consistency with the international literature suggests that these practices can be adopted to improve the quality of engineering in construction. Good alignment was also found between the best practices from the literature that were specifically tested for in the structured section of the interviews and the practices recommended by the experts interviewed.

Q3: Do experts believe selected best practices from the literature are appropriate to South Africa?

P2: Experts will consider most of the best practices from literature appropriate to South Africa.

The experts were positive on many of the best practices from the literature. Several of these practices are recommended for adoption as per Table 6. The practices that received contingent or less positive responses were the practices that the literature suggested were contingent or highly innovative and perhaps not applicable in all cases. In general there was good support from the experts on the specific best practices identified from the literature.

Q4: Do experts believe that a different approach to quality management of engineering is warranted in South Africa?

P3: Some specific local practices are required to address skills shortages, small markets and other unique attributes.

Apart from the need for special practices to address the shortage of engineering skills in South Africa, the experts interviewed were clear that no fundamentally different approaches were required and that international practices, systems and tools are appropriate to South Africa. This opinion is supported by the other findings which show strong alignment between best practices recommended by the interviewees and the literature and also strong acceptance of the best practices from the literature.

One finding that does not specifically relate to any of the research questions is that, although the literature suggests distinctly different approaches for quality in services like engineering, very little reference to service quality consideration were made by any of the experts. References to team building and relationships begin to touch upon some of the service quality aspects, but not one of the interviewees made an explicit reference to service quality aspects in the unstructured section of the interviews. This suggests that quality considerations in the construction industry in South Africa, like elsewhere, still have a very strong product focus. This is at odds with the notion that the construction industry delivers a combined product and service offering (Government Gazette, 2000).

The findings of this research make a contribution to improving the quality of construction in South Africa by providing a number of best practices suggested by South African experts that are aligned with the international literature, providing a number of recommended international best practices, that local experts believe are appropriate to South Africa and finally by concluding that experts believe, that apart from special practices needed to address skills shortages, international practices, techniques, tools and systems are applicable in South Africa. This final finding opens the door to further research into practices to address the skills shortage, but also suggests the approach that international practices should be sought out and applied in South Africa to improve the quality of engineering in construction.

7 Final Conclusions

This section of the report gives an overview of the main findings and recommendations, presents topics for further research based on the findings and the literature and gives a final overview summary of the entire research project.

7.1 Main Findings

All the experts interviewed in this study agreed that international practices for managing the quality of engineering in construction are appropriate to South Africa. The only aspect which warrants a unique focus and practices in South Africa is the shortage of engineering skills and competency, which the experts interviewed believe is worse in South Africa than elsewhere.

The issues raised by the interviewees in the unstructured section of the interviews address all seven quality criteria in Tan and Lu's (1995) model of engineering quality. Popular opinion often view cost, schedule and quality as three separate project aspects, whereas the Tan and Lu (1995) model include cost and schedule conformance as aspects of quality; this notion is supported by the interviewees raising cost and schedule, in addition to technical quality in the interviews. All four factors contributing to error proneness in engineering (Love *et al.*, 2000c) was addressed by the interviewees. The opinions of the experts interviewed are therefore corroborated by the international literature, and this also further confirms the notion that international quality practices are appropriate in the South African context. Despite this alignment with international practices, there was very little service quality focus evident from the discussions with the interviewees.

In the thematic content analysis of the unstructured section of the interviews, several themes where identified, with possible best practices suggested around each theme by the interviewees. Five themes or categories stood out, with more than half of the interviewees discussing these subjects. Theses categories were the shortage of skills, clarity of requirements and alignment thereon, the use of quality systems, schedule pressures and planning and the use of demand side practices to mitigate skill shortages. Detail discussions of the findings and recommendations on these and the other themes identified are given above.

The structured section of the interviews provided feedback on several potential best practices from the literature that could be considered for adoption to improve the quality of engineering in the construction industry. A number of practices stood out, with more than 75% of interviewees (ten out of thirteen) being positive that these practices would improve the quality of engineering in construction. These practices were Focussing / Revealing and Calibrating client expectations, Briefing as a Process, Design Management (all nine components), Engineer in the Field, Re-use of Designs, involving Supplier / Constructor in Design, using Reputable Suppliers, using Incentives for Engineers and creating an environment for Prudent Risk Taking. These practices are all discussed and references detailing the practices and giving guidance on their application are given in this report. Design Management is specifically noteworthy; this practice consisting of nine elements received a positive response in excess of 97%. In addition the two approaches of TQM and SCM, which are not only applicable to engineering, but has a much wider focus, also received a greater that 75% positive response from interviewees.

It must be added that this research has focussed specifically on large projects in the industrial sector of the construction industry. The degree to which these findings can be generalised to smaller projects and other sectors of the industry was not investigated. Generalisation of these findings must be done with care. The projects considered in the study where large and technically complex. Some of the tools and best practices recommended for this environment may be too complex and costly for application on smaller projects in less complex environments. Other practices such as addressing skills shortages and embedding the principles of design management may be more easily translatable.

7.2 Summary of Recommendations

The opinion of the experts interviewed is that international practices for the quality management of engineering are appropriate to South Africa, with special attention needed to address the shortage of engineering skills. This means that the practices recommended in this study should be considered for adoption in South Africa where not yet the case, but also that the South African construction industry must continue to search the international arena for new best practices and adopt such practices as appropriate.

The shortage of engineering skills and competency can be addressed from both a supply and a demand side. On the supply side, industry collaboration to train and develop a pool of engineering resources that will provide sufficient capacity to deliver on the construction aspirations of the public and private sector in South Africa over the next decade is required. On the demand side approaches to automate certain aspects of engineering work and use tools to gain productivity improvements should also be considered. It was recommended that engineers work smarter and apply critical engineering resources where they add the most value. It was noted that although retention strategies may be an imperative at the company level to retain critical resources for the company to function, it is at best a short term tactical approach. Such strategies can easily devolve into one-upmanship in terms of salaries and benefits, increasing cost to company and the industry without addressing the underlying fundamental shortage of skills.

Ensuring clarity and alignment on requirements is critical to ensuring the quality of engineering. Making use of several forms of alignment meetings featured strongly and is recommended as a best practice. In additions it is recommended that focussing, revealing and calibrating customer expectations and using briefing as a continual process rather than a single event be added to the repertoire of tools used to address understanding and alignment of requirements. Special attention is needed to make the focus of alignment wider than just a product focus, but to consider the more intangible aspects of the engineering service delivery process.

Quality systems such as ISO 9000 should be implemented, but with a specific focus on improving client satisfaction through improved business processes. A mechanistic application of such systems purely for the purposes of accreditation will add little value. Based on the positive feedback from the interviewees, the adoption of TQM principles is also recommended with the caveat that careful implementation will be required to realise the expected benefits. Several resources providing guidelines for the implementation of TQM in the engineering and construction industry are supplied. SCM is also recommended to address the fragmented nature of the construction industry.

Considering the negative impact that schedule constraints can have on engineering quality and that skills shortages may increase these pressures, careful consideration must be given to reducing these pressures trough detailed planning and matching realistic schedules to the available resources. In addition the cost or man hours allowed for engineering should be adequate to allow for quality engineering to be conducted.

It is recommended that all the practices from the literature that received more than 75% positive response from the experts interviewed be considered for adoption taking into account the appropriateness of the practice to the specific context. It is strongly recommended that organisations use the Design Management Maturity Assessment Model (Bibby *et al.,* 2006) attached in Appendix 5 to assess their maturity in terms of design management. Where shortcomings are identified, it is suggested that the training program developed by Bibby *et al.* (2006) be adopted to entrench these practices in the organisation.

This summary has only discussed high level recommendations on those themes from the unstructured interviews raised by more than 50% of interviewees and the best practices from the structured interviews supported by more than 75% of the respondents. More detailed discussions of these and all other recommendations are included earlier in this report. It is suggested that interested parties review all recommendations to determine which are most appropriate to their applications. For ease of reference Table 6 gives a summary of all the recommendations regarding the best practices from the literature discussed in the structured section of the interviews.

7.3 Further Research

This research was exploratory in nature; therefore several topics for further research can be suggested.

Research on methods to address the shortage of engineering skills and competency is warranted, this is the topic that received the most attention from all the experts interviewed. Research can be conducted on supply and demand side remedies for the skills shortage.

From this research it is also clear that international best practices are applicable to South Africa. Research to develop a comprehensive guide listing all best practices and giving guidelines on the implementation and use of such practices will add much value to the industry and is aligned with the mandate of the CIDB (Government Gazette, 2000).

This research has only determined that international practices to improve engineering quality are applicable to the South African construction industry. It is very likely that international practices to improve quality across the entire construction value chain are applicable to South Africa. This proposition should be tested by research and, if found true, further research to develop a comprehensive guide for quality improvement practices across the entire project value chain should be conducted.

This research has relied on international academic literature and the local press to formulate the assumption that there is a lack of quality focus in the South African industry. Formal research to test this assumption and do a comparative study on the extent of quality focus and problems between different sectors in the construction industry will be beneficial in confirming the assumption (or not) and determining where quality improvement efforts are most needed.

No research has been conducted on the cost of rework in the South African industry. It is recommended that research be conducted to determine rework cost per sector in the construction industry. Such information would be valuable in informing stakeholders of the actual cost of quality problems, and will assist in motivating and focussing quality improvements in the industry. Such improvement will have benefits for the industry itself, but also the economy as a whole.

This research has found that there is a lack of service quality focus in engineering in the construction industry. Research to quantitatively confirm this finding and determine to what extent an increased service quality focus will improve construction quality is recommended.

The limitations of this research were that it was exploratory in nature, relied on a small sample size and focussed on a very specific sector of the construction industry. Further research to determine to what extent these findings can be generalised to other sectors of the construction industry is warranted. Specific sectors where delivery problems currently exist, which may warrant further attention, include low cost housing and public infrastructure spending.

The experts interviewed suggested that the shortage of construction skills may be even more severe than the shortage of engineering skills. A study to determine engineering approaches such as shop fabrication and modular construction to address this perceived lack of construction expertise and competence in South Africa will add value.

Research to test the proposition that South African engineers have unique attributes and to determine what these attributes are will be beneficial. This research can be taken a step further by determining strategies to best utilise these attributes for competitive advantage.

The suggestion that South Africa is considered a third world dumping ground for inferior services and products can also be tested. This will only add value if the suggestion is in fact true and remedies to correct the problem can be found.

Research around the main themes other than skills shortages identified from the unstructured interviews can be contemplated. However, considering expert opinion which suggests that international best practices are applicable in these fields, efforts would be better spent in collecting such best practices and making them available in South Africa as recommended above.

7.4 Integrative Summary

This starting point of this research was the international academic literature and South African press reports and a limited number of studies suggesting a lack of quality focus in the construction industry. The literature suggested that engineering or design is often the single largest contributor to quality problems in the construction industry. The research focussed on best practices for managing the quality of engineering on construction projects.

The research approach was to obtain expert opinion on the best practices for managing the quality of engineering in the South African construction industry, comparing these practices to international best practices and determining if the experts believe fundamentally unique practices are required by the South African environment. The research focussed on large projects in the industrial sector where engineering is complex and multi-disciplinary, because it was believed that the likelihood of finding best practices for improving the quality of engineering would be greatest in this sector.

The literature was reviewed to obtain an understanding of quality concepts, the improvement that quality approaches can bring about, the unique aspects of quality in services such as engineering and quality in the construction environment. A number of best practices specific to the quality management of engineering were also identified and discussed.

Thirteen experts where interviewed using a semi-structured interview approach. Open ended questions were used to determine expert opinion on best practices for South Africa and aspects unique to South Africa. Structured questions were used to obtain expert opinion on the applicability to South Africa of specific best practices from the literature. The transcripts of the interviews were analysed using thematic content analysis to identify the common themes that arose.

A strong consistency between the opinions of experts and the literature on the best practices for the management of quality in engineering was found, lending credibility to these opinions. Several themes arose from these interviews, of which the shortage of engineering skills was the most predominant. The shortage of engineering skills was also the only aspect requiring practices unique to South Africa. Recommendations to address these skills shortages from a supply and a demand side were made. The other themes included alignment on requirements, the use of quality systems and the use of planning to address increasing schedule pressures. Recommendations addressing each of the themes identified were also forthcoming from the interviews. Experts were also positive on the applicability to South Africa of many of the best practices identified from the literature; recommendations for the adoption of some of these practices were also made based on the expert feedback. Details of these practices and their implementation are referenced in the literature study.

The research was exploratory in nature, therefore several avenues of further research were also proposed. These include determining to what extent the findings of the research can be generalised to other sectors of the construction industry, research to determine approaches to address the shortage of engineering resources and research to develop a comprehensive best practices selection and implementation guide.

An important conclusion from the study, based on the consistency between the experts and the international literature and the positive response on most of the best practices from the literature, is that international tools, techniques, practices and systems for the improvement of engineering quality in construction is applicable to South Africa. The only aspect that warrants special consideration and practices is the shortage of engineering skills, which is considered by the experts interviewed to be worse in South Africa than elsewhere. The importance of this conclusion is that the construction industry must continue to seek out best practices for improving the quality of engineering from all sources, and implement these practices to improve quality where appropriate.

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9 Appendix 1

Influence Diagrams from Love *et al.* (2000c)

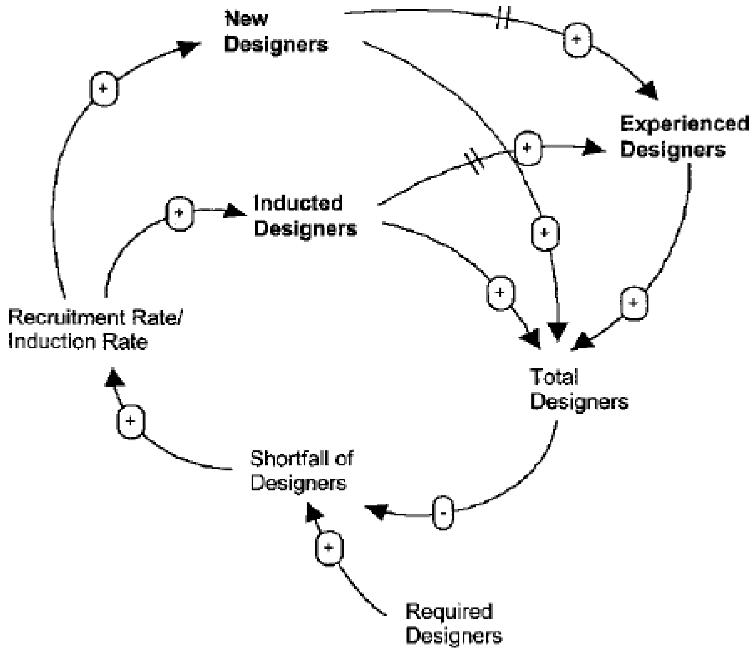


Figure 1 The process of inducting/recruiting design staff

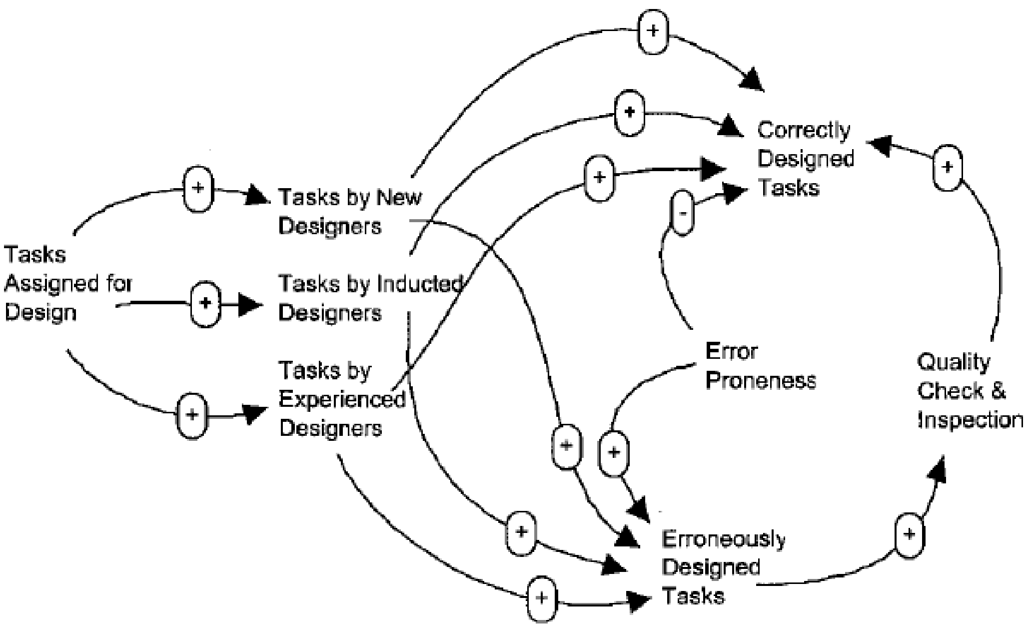


Figure 2 The process of designing tasks

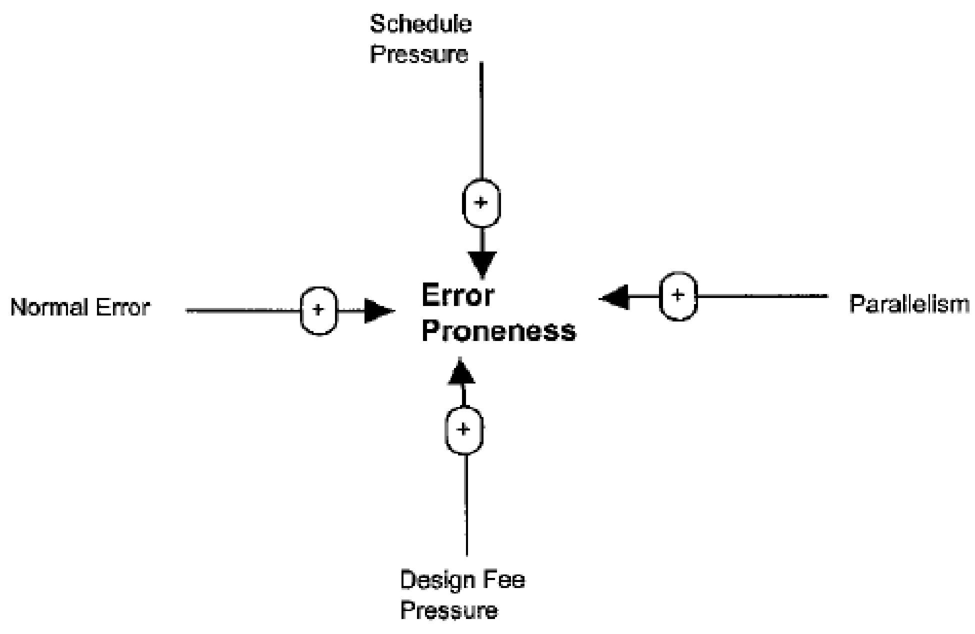


Figure 3 Factors affecting error proneness during design

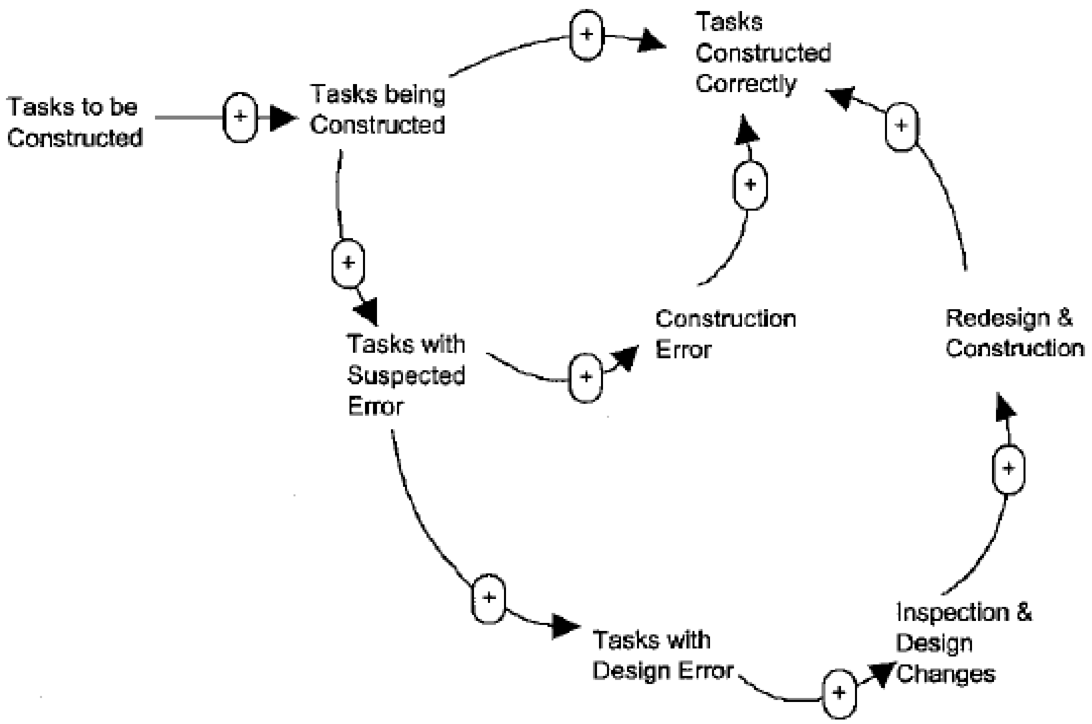
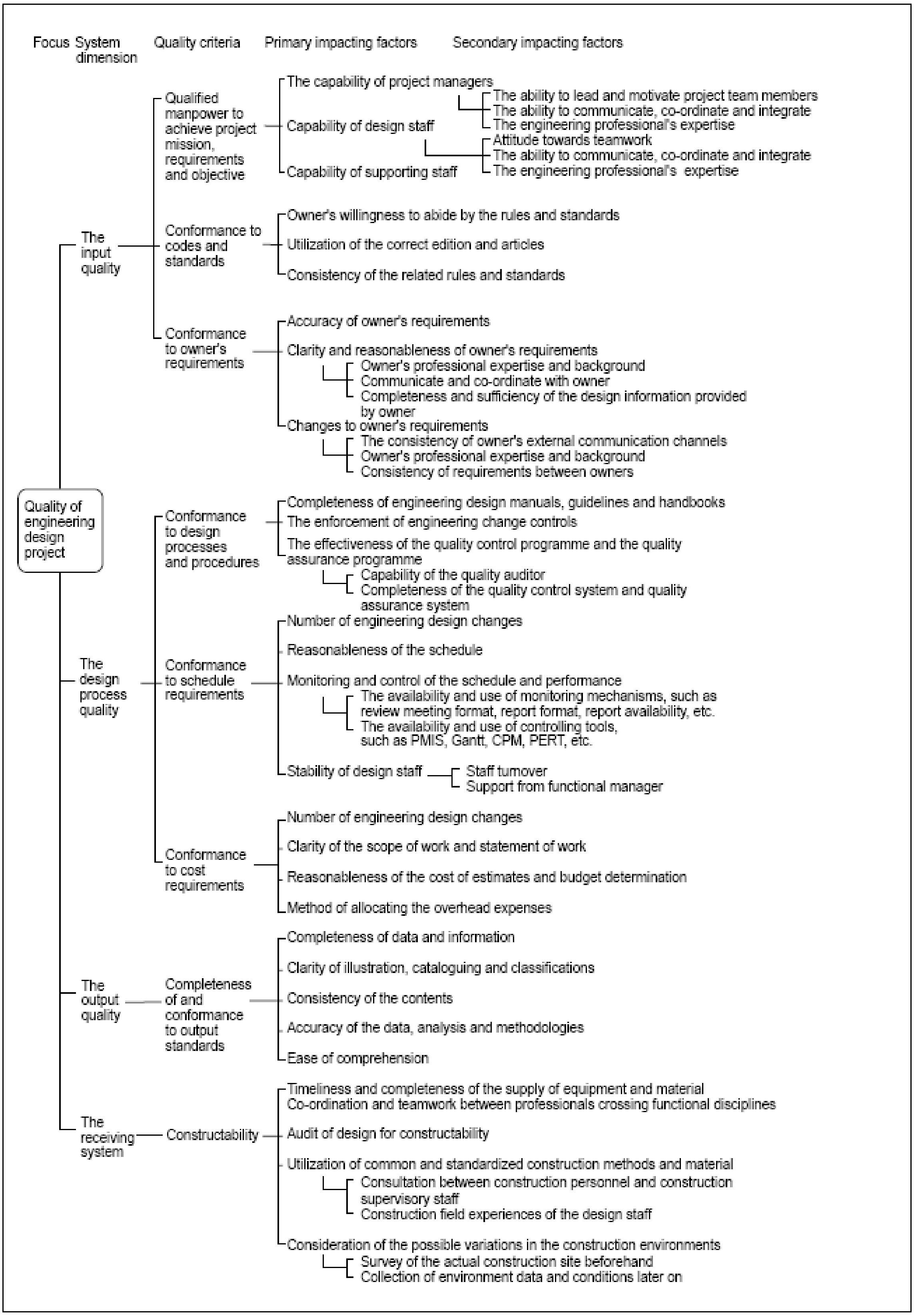


Figure 4 The process of re-designing design tasks

10 Appendix 2

Engineering design project quality system and its impacting factors (Tan & Lu, 1995)



11 Appendix 3

Detail causes of Engineering and Review problems (Fayek *et al.*, 2003)

A. Late Design Changes	
A1	Insufficient time between engineering and construction activities
A2	Incomplete Client design review
A3	Inadequate constructability reviews
A4	Inadequate execution plan
A5	Process and instrumentation drawings are incomplete
A6	Drawings not issued for construction (incomplete)
A7	Drawings not issued for construction (in review)
A8	Drawings not issued for construction (revisions required)
A9	Document presentation of poor quality (missing details)
A10	Document presentation of poor quality (missing drawings)
A11	Scope changes
A12	Errors & Omissions
A13	Late Owner input

B. Poor Document Control	
B1	Inadequate Revision Control
B2	Document delivery delay
B3	Improper drawing log
B4	Incorrect numbering on drawings
B5	Incorrect work package numbering/contents
B6	Inadequate vendor data control
B7	Inadequate or insufficient resources for document control
B8	Inconsistent treatment/comments on vendor drawings
B9	Inconsistent/conflicting numbering on alliance jobs
B10	Request for Information (RFI's) not responded to in a timely fashion
B11	Incorrect distribution of documents
B12	Drawings not available
B13	Lack of internal document tracking

C. Scope Changes	
C1	Process tinkering (fine tuning of end product)
C2	Client scope changes
C3	Bad process assumptions
C4	Client operating changes
C5	Inadequate design change control
C6	Scope gaps between Contractors/Client
C7	Utilities, off-sites, and site integration
C8	Technology changes
C9	Unknown conditions (undergrounds, field checks)
C10	Licensor changes
C11	Incorrect initial vendor data
C12	Specification changes
C13	Inadequate prototype design
C14	Constructability issues
C15	Request by Fabricator/Supplier

D. Errors & Omissions	
D1	Inadequate discipline coordination
D2	PM deviates from process
D3	Inadequate field verification by designer
D4	Changes in personnel (small project)
D5	High turnover (resulting in quality issues)
D6	Conflicting project demands
D7	High work load taxing capability
D8	Lack of skills
D9	Incomplete engineering
D10	Complex specifications
D11	Consistency not ensured before Issued For Construction (IFC)
D12	Original design/specification was incorrect
D13	As-built error (for retrofit)
D14	As-built error (for interface)
D15	Lack of attention to (critical) details
D16	Insufficient details
D17	Inexperience
D18	Poor assumption during the design

12 Appendix 4

Interview guide: To ensure consistency between interviews the following guide was complied to guide the interviewer through the process.

Introduction: Interviewee must be put at ease and ensured that all responses will be anonymous. The following must be explained:

1. All questions are asked in the context of the construction industry
2. The aim of the interview will be establish the interviewee's opinion on the practices / activities / methods for the management of quality of engineering
3. Both practices that are in use and practices that are not, but that the interviewee believes should be, are of interest, interviewees to note which is which.

Unstructured Questions:

- Ask the interviewee about their opinion on the best practices, techniques and tools in use in industry for the quality management of engineering. Continue probing until this line of questioning seems exhausted.

Use questions such as:

- In your opinion what are the top three practices / methods / activities that are in use or can be used to manage the quality of engineering?
- If you could only do three things to improve the quality of engineering, what would they be?
- If you could add two more, what would they be?
- What are the other key practices / methods / activities the will add value that we have not yet discussed?

Structured Questions:

Total Quality Management

The intent here is to test the interviewees understanding of what TQM entails and establish whether it is considered important for the industry. Therefore the concept is not explained, but rather is pointed out that some schools of thought believe TQM and SCM are two key ingredients to improve quality in construction. Interviewees are then asked whether they think TQM is important and what they understand under the concept of TQM. An understanding of TQM as a holistic view of the organisation aimed at improving quality through a systematic approach shows a sufficient high level understanding of the concept.

Supply Chain Management

Supply Chain Management is explained as an attempt to manage all the companies involved in the construction value chain from a holistic point of view, i.e. manage the entire supply chain as a single entity. Interviewees are then asked if they agree that SCM is appropriate to the construction industry.

Quality Function Deployment

QFD or House of Quality is explained as a technique where client requirements are mapped against the engineering firms' ability to deliver certain technical aspects. This has the advantage of ranking customer's requirements, but also prioritising engineering activities to meet these requirements. Interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Cost of Quality

Cost of quality is explained as a technique to measure the cost impacts of quality to improve decision making. Typically COQ can be divided between cost of prevention, appraisal and failure, or alternatively cost of conformance and cost of non-conformance. Interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Managing Client Expectation

Focus/Reveal/Calibrate Expectations

It is explained that the way service quality is measured depends heavily on client expectation and the gap between client expectation and the actual service experience. This is even more true in the professional services environment where client expectation can be fuzzy, implicit and unrealistic. In such cases time should be taken to focus the fuzzy, reveal the implicit and calibrate the unrealistic expectations. Interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Briefing as a Process

In addition is explained that some schools of though argue that the briefing process is not a single event, but an ongoing process whereby the contractor engages with the client continually to clarify and reconfirm the brief. Interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Design Management

Each design management aspect is explained and interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Establish and Communicate the brief.

This is the process whereby client requirements and determined and clarified and communicated.

Design Management Roles and Responsibilities

This is the process whereby the responsibilities of all parties involved in the design process is clearly established and clarified before the design process commences.

Selecting Team Members

This is where team members are selected based on specific criteria to ensure that the team members have the necessary skills and competencies to execute the work.

Integrated Design Planning

This is where the complex design process with all its interactions is planned in advance with the involvement of all parties responsible for the design process.

Ensuring Design Delivery

This is where specific management tools and techniques are used to ensure the design is produced and delivered as planned.

Managing the Information Flow

This is where the flow of information required and produced in the design process is controlled and directed at the appropriate parties.

Developing the Design

This relies on the degree of collaboration and integration of the design team developing the design. Individual engineering working in isolation at one end of the scale with fully integrated task teams at the other end.

Value Considerations

Specific actions are taken to improve the value proposition of the design.

Managing Design Changes

Controlling design changes to ensure the impact of changes is assessed before implementation and that the necessary impacts are communicated to all and reflected in all design deliverables.

<u>Concurrent Engineering</u>

This is where multi-disciplinary design teams are used throughout the design process. By multi-disciplinary, reference is not only made to the traditional engineering disciplines, but also to representatives from construction, marketing, operations, maintenance and suppliers. Often under these circumstances activities can be performed in a non-sequential fashion. Interviewees are then asked whether this approach is appropriate to engineering in the construction industry.

Design Effectiveness

Most engineering houses make use of productivity measures to monitor engineering, design effectiveness is a multi-component measure which includes productivity but looks at measures to assess the effectiveness of the entire process. Design effectiveness considers aspect of the inputs, the process itself and the outputs of the design process. Interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Quality Based Selection

QBS is a process where selection is not made on cost alone. Cost is a qualifying element only, and bidders are given an expected cost range based on a previously prepared estimate of the value of the job. All bidders who fall within this cost range qualify to be evaluated. Evaluation is based on specific weighted criteria which were provided to the bidders. The who has qualified for evaluation who scores the highest on the criteria is awarded the job. Interviewees are then asked whether this technique is appropriate to engineering in the construction industry. Interviewees opinions on the balance of the South African industry on cost versus quality based selection is also asked, a distinction between the appointment of contractors and suppliers is also made is deemed necessary.

Onsite Design

This is a technique whereby, based on the unique attributes of the project, certain design activities are executed at the construction site. This does not refer to typical “Field Engineering” but rather actual design work at site.

Exceptional Projects

This is explained as a collection of techniques used on projects executed under extreme pressure due to external forces such as a fire repair or extreme market drivers. Typically these projects are executed with a 10% to 90% schedule reduction, 50% of them with lower cost and all of them with comparable quality to a control sample of projects. Only techniques related to design are discussed. Each technique is explained and interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Engineer in Field

This is more than the onsite design concept earlier discussed. Engineers are not only sent to site, but also to suppliers locations to be resident during the fabrication of equipment.

Re-use of Design

In this case existing design are extensively re-used without modification or update.

Continuous Reviews

This is where design are reviewed on a continual basis in an informal way, rather than relying on periodic formal reviews.

Reduced Design Details

This is where final detailing of deign is not specified, but left to the construction contractor to complete during installation. A typical example is where cable rack routing is not given, but left to the construction contractor to finalise.

Supplier / Constructor in Design

This has been touched upon under concurrent engineering, but is where representatives of the construction contractor and suppliers are involved in the design process to ensure their inputs are captured.

2% Engineering

This explained as a set of highly innovative techniques which are implemented as part of a highly integrated initiative involving company culture, contracting strategy and design philosophy. Only the design aspects are touched upon. Each technique is explained and interviewees are then asked whether this technique is appropriate to engineering in the construction industry.

Minimum Requirements

Under this technique absolute bare minimum requirements are specified, any additions are only allowed with clear justification.

Small Focussed Teams

This is where rather than rely on complex design calculation, a small select group of very experienced engineers are used to develop the design relying heavily on their judgment and intuition rather than design calculations.

Minimum Documents

Under this approach only the bare minimum of documents required for construction is produced.

No Document Reviews

It is pointed out that this technique is only implemented together with the next one, reputable suppliers. In such cases owners rely on a very short list of reputable suppliers to produce designs; these documents are then not reviewed based on the reputation of the suppliers.

Reputable Suppliers

Only a short list of very reputable suppliers is used.

Incentives for Engineers

This is where engineers and project managers are offered financial awards based on their project meeting very specific targets and goals.

Prudent risk taking

For all these techniques to work, a culture of prudent risk taking is encouraged. In this culture if an engineer has taken a prudent risk, and the risk realises, the engineer is not punished.

Questions on Uniquely South African aspects:

Finally interviewees are asked about their international project experience. Once this is noted, it is explained that the reason for this question is to determine whether in their opinion there are aspect that are unique to the South African construction industry that warrant a fundamentally different approach to the quality management of engineering. This subject is explored until no further feedback is forthcoming.

13 Appendix 5

Design Management Maturity Assessment Model (Bibby *et al., 2006)*

	Level 1 Haven't thought about it	Level 2 Thinking of doing something about it	Level 3 Beginning to do something about it	Level 4 Doing it as normal business	Level 5 Advanced practices developed
establishing and communicating design briefs	no process to establish and communicate project design briefs	inconsistent approach to establishing and communicating project design briefs	collaboratively ensure all stakeholders needs are articulated, captured and understood before phase begins	consistently establish and communicate work scope and delivery details for whole project	consistently establish and communicate work scope and delivery details for whole project and individual disciplines
design management roles and responsibilities	no consideration given to defining the roles and responsibilities of a design manager	ad-hoc approach to defining roles and responsibilities of a design manager	roles and responsibilities of a design manager defined	roles and responsibilities of design manager and the involvement of other parties in design management defined	all parties aware of their potential contribution to and involvement in design management
selecting team members	no selection process used to identify suitable design team members	inconsistent approach to assessing and selecting potential design team members	structured means to identify and assess consultant's skills	structured means to differentiate assessed skills of consultants to select a preferred consultant	performance data used to assess consultant skills and determine selection
integrated design planning	design is planned separately from the procurement and construction processes	major design activities planned with consideration of construction requirements	major design, procurement and construction activities linked and integrated	individual design activities of all disciplines integrated with each other and construction activities	resource allocation considered on integrated project programmes
ensuring design delivery	no effort to manage the distribution of design deliverables	document management recognised as a major task that must be improved	inconsistent management of the production and issue of design deliverables	consistent management of the production and issue of design deliverables	range of approaches to manage the production and issue of design deliverables to all parties
managing information flow	design information distributed to all parties without consideration of needs	recognised overload of information flow and need to improve practices	information distributed based on issuers perception of recipient needs	information needs of each party understood with parties able to access essential information	fully co-ordinated needs expressed, specific information requirements and why each is needed
developing the design	design development undertaken in uncontrolled manner and designers working in isolation	inconsistent design development but designers collaborating on major issues	structured approach to design development and designers collaborating on most issues	structured approach to design development and designers collaborating where necessary	design team operating within fully integrated and collaborative design environment
value consideration in design process	no consideration of value in design development process	aware that can and should be considering value in the design process	inconsistent approach using value analysis techniques in the design process	phased set of value analysis activities structured into the design process	value generation process undertaken as an intrinsic part of the design development process
managing design changes	design changes implemented by instruction	inconsistent approach to the assessment of design change proposal	consider design changes proposals by identifying and assessing significant impacts	design proposals assessed consistently using structured process to identify and assess time, cost and quality impacts	ability to quickly and effectively explore potential design change options

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