Quality Function Deployment (QFD)

in the UK Construction Industry

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Abstract

In the face of increasing competition, striving for a competitive edge is a necessity for any commercial organisation to survive in the global market. To remain competitive an organisation must be able to develop high quality products more economically and faster than its competitors. This global competition is not limited to only the manufacturing industry, but also exists in the construction industry.

Whereas the manufacturing and service industries have invested in advanced technology such as CIM, CAD/CAM, and various management techniques such as TQM, JIT, MRPII, which have brought improvements in product quality and customer-focused operations, the UK construction industry has been slow to adopt these techniques. Several Governmental reports have shown that there is the need for improvement in the performance of the construction industry. These reports highlighted issues such as fragmentation and client dissatisfaction. Other publications also indicated that:

1. There is often little integration and co-ordination between the different functional groups involved in a construction project, resulting in poor quality and conflicts between project participants

2. Although the performance of each stage/phase in the construction process affects the quality of the project, the most critical phase, construction planning and design, is often poorly managed.

In the light of the above issues this thesis focused on the evaluation of a well-established technique in manufacturing systems, namely Quality Function Deployment (QFD), in a construction environment. QFD is a team-based technique that provides a means of identifying and translating customers' requirements into technical specifications for product planning, design, processes and production. The nature of QFD allows product-development teams to design quality into the product. Trade-offs are made where there is possible conflict and hence reducing mid-course changes and rework. It also enhances collaboration between project participants.

QFD was chosen as the technique for investigation because its very nature indicates that it has the potential of combating the problems highlighted above. However the literature on QFD also showed that QFD matrices could become difficult to handle when projects become large and complex. To overcome this weakness, a novel tool in the form of a software has been developed to aid its implementation in the construction industry.

In order to test the reliability of the software, three practical cases have been used as samples and the results presented. Even though the software developed proved to be versatile in terms of computational speed, and allowed changes to be made quickly it was found out that some improvements could be made in the QFD technique such as components and materials planning, and construction process planning. In addition, the integration of techniques such the Analytical Hierarchy Process (AHP) and Analytical Neural Networks (ANN) will make it even more powerful in terms of information processing. Further research in these areas is therefore encouraged.

It is envisaged that the outcome of the research will enhance the performance of the construction industry, bring it up-to-date in best practices and guide it towards strategic exploitation and delivery of quality, responsiveness and customer service. It will also serve as a proof-of-concept and as a case example for the implementation of QFD in construction. In addition it will benefit a wide spectrum of the construction industry in achieving optimal interactions in the supply chain.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The increasing global competition, rapid technological advance, disappearance of niche markets, and proliferation of both expert and practitioner driven solutions are the realities of current business environment. The future of any business is shaped by the interactions of these realities. Businesses are made or marred as they encounter them. With the introduction of the Euro, and the likelihood of subscription by the UK, its construction industry is at the threshold of a new competitive game plan. Already, homebuyers in the UK can take out mortgages in Euro. Soon more construction firms, encouraged by the elimination of currency transaction difficulties (as a result of common currency across the European Union), will enter the UK construction markets, and thereby increase the competitive pressure. In order to have a competitive edge, construction firms must be able to deliver on high quality, low cost, better responsiveness and customer service (Yusuf and Little, 1998).

Although the capability of the UK construction industry to deliver the most difficult and innovative projects can match any other construction industry in the world (Powell, 1995), there is still deep concern that the industry as a whole is underachieving (Phillips 1950; Banwell 1964; Latham, 1994; Egan 1998). For instance, in the Egan report, the growing level of dissatisfaction amongst both private and public sector clients was highlighted as an evidence of the underachievement in the construction industry. Projects were widely seen as unpredictable in terms of delivery on time, within budget and to the standards of quality expected. This perception was supported by a survey which concluded that:

- more than a third of major clients are dissatisfied with contractors' performance in keeping to the quoted price and to time, resolving defects, and delivering a final product of the required quality

- more than a third of major clients are dissatisfied with consultants' performance in co-ordinating teams, in design and innovation, in providing a speedy and reliable service and in providing value for money

- clients want greater value from their buildings by achieving a clearer focus on meeting functional business needs

- clients' immediate priorities are to reduce capital costs and improve the quality of new buildings

- clients believe that in a longer-term, the more important issue is reducing running-costs and improving the standard of existing buildings

- clients believe that significant value improvement and cost reduction can be gained by the integration of design and construction.

It is evident from the Egan report that clients need better value for their investments. In order to achieve this objective at reasonable profits, and thus assure the long-term future of construction companies, the industry will need to improve upon its performance.

Egan also suggested that the construction industry could improve upon efficiency by learning from the experiences of other industries, notably the manufacturing industry. This was based on the fact that the manufacturing industry, stimulated by the advances in technology and customer needs, have over the past twenty years adopted new working practices which have brought improvements in product quality and customer-focused operations.

According to Latham:

> *Patronage should emphasise not only on the external appearance – important though that is – but also that the project should be effective for the purpose for which it is intended. A well-designed building need not be to a high level of specification. Evidence to the review has suggested that some UK buildings are over specified and thus unnecessarily costly. A well-designed project will impact upon the satisfaction, comfort and well being of its occupants, and if it is a commercial building, upon their productivity and performance. ...Quality should be the overriding consideration.*

Alden (1994) echoed Latham's view by identifying two main areas which could provide useful savings:

- Waste – which, according to the Building Research Establishment figures, accounts for more than £1bn a year of clients' costs.

- Over Design – over-design and over-specifications add up to 50% of construction costs.

Other publications (Powell, 1995; Gunasekaran and Love, 1998; Kagioglu et al, 1998; Crowley, 1998; Howell, 1999) have also argued that manufacturing management techniques such as Total Quality Management (TQM), Just In Time (JIT), Concurrent Engineering (CE), Teamworking and Benchmarking are quite applicable to construction. Since these publications, some construction firms in the UK have started using some of these techniques (Roy and Chochrane, 1999)

Although these tools may have potential impact, the construction industry still lacks adequate ability to accurately determine its clients' requirements and successfully transform them into planning and design specifications (Abdul-Raman et al, 1999). In addition, the construction industry needs to improve in the area of bringing together multifunctional teams. There is, therefore, the need for a methodology which provides a framework for the identification, structuring, analysis, and translation of clients' requirements. Such a methodology should be holistic enough to draw on all the conceivable sources likely to affect the final product, and be able to nurture a strong integrating mechanism and allegiance to the project objective (Pheng and Ke-Wei, 1996). One positive approach is the Quality Function Deployment (QFD) methodology, which is part of the TQM philosophy.

The QFD methodology advocates a multidisciplinary team approach to product design by encouraging collaborative decision-making based upon team co-ordination and information sharing. The successful implementation of QFD is reflected in a number of publications such as Vonderembse and Raghunathan (1997), Tsuda (1997) and Natarajan et al (1999), which address the concept, application, and limitations of the methodology. The benefits derived from QFD implementations include enhanced product quality and customer satisfaction, reduced production costs and reduced time-to-market (Glen, et al, 1996; Pitman et al, 1996, Ghobadian and Terry 1998, Radharamanan and Godoy, 1996; Barnett and Raja, 1995, Tan et al, 1998). For example Vonderembse and Raghunathan (1997), investigated the impact of QFD on product development and resource consumption, and concluded that QFD implementation can enhance customer satisfaction, product quality, cost reduction and time-to-market.

QFD is used extensively by many companies in Japan, USA and by some companies in the UK. Companies which have successfully implemented QFD include Toyota, Ford Motor Company and GEC-Marconi (Hauser and Clausing, 1988, Johnston and Burrows, 1995). Due to many reported benefits (Bossart, 1991; Hauser and Clausing, 1988; Lockamy and Khurana, 1995; Sullivan, 1988; Vonderebse and Ragunathan, 1997), more and more companies are now investigating the use of QFD (Kathawala and Motworani, 1994). For example, Tsuda (1997) compared two QFD models, a '2-storied quality chart' and a parallel flow quality chart with case studies on a Japanese automobile company to prove the validity of the two models as good management tools. Delano et al (2000) also reported the application of QFD and Decision Analysis in the selection of the design for a new cargo/passenger aircraft. Hochman and O'Connell (1993) used the case of a portable telephone to show how customer environmental concern can be integrated into QFD.

Traditionally, QFD applications have tended to be focused on manufacturing. However, it is now employed in wide ranging areas. Maddux et al (1991) reported the use of QFD as a strategic planning tool in the formulation of a strategy to successfully implement and manage a program called Production Engineering Tools. He contends that QFD can be successfully applied as a strategic planning tool for the design of intangible products such as program or activity. In the same vein Crowe et al (1996) described how to use QFD in manufacturing strategic planning whilst Philips et al (1994) described the use of QFD in Policy Formulation (Sullivan, 1988) using a case study as an example. Ghobadian and Terry (1998) also examined how Alitalia, the airliner, successfully used QFD to design a new business class. QFD has also been applied successfully in the educational and health sectors (Einspruch et al, 1996, Pitman et al, 1996, Lim and Tang, 2000, Wiklund et al, 1999).

Although QFD has been extensively used in both the manufacturing and service industries, its application in construction is not very widespread. The main reason would seem to be the traditional conservatism of the construction industry and the (mis)conception of the "uniqueness" of construction. Although the uniqueness of construction is often pointed out in literature as barriers for implementation, there is a lack of empirical evidence to support or dispute this theory, and therefore this argument has prevailed so far. Koskela (1992) observes that construction professionals' propensity to perceive uniqueness is, ironically, not unique to construction. Many manufacturing plants claim uniqueness which could be indicative of a psychological need to perceive one's own system as unique.

Several publications give some indication of the relevance of QFD in the construction industry. Countries like Finland (Antti et al, 1995), Japan (Akao, 1988) and Malaysia (Abdul-Rahman et al 1999) have applied the QFD technique in construction with some level of success, but they failed to take into consideration the peculiarities (e.g. Construction procurement methods) of the construction industry. In order to take advantage of the full benefits of QFD, the unique characteristics of construction, such as the adhoc manner in which project teams are brought together, must be taken into consideration. QFD's success is mostly based on the level of interaction between project participants, and thus the way construction project is procured must be taken into consideration.

Although majority of the available literature give account of the successful implementation of QFD, experiences from other QFD projects have shown that companies very often encounter some problems at the initiation stage (Herzwurm et. al., 1998). Most of these problems encountered usually arise as a result of inadequate preparation and lack of commitment (Pfeifer et. al., 1996; Dickinson, 1995). Most practitioners are of the opinion that companies which are applying QFD for the first time, should start with small projects, as these are more manageable and more likely to succeed. Although a matrix size of about twenty to thirty requirements (Laurikka et al, 1996) is considered reasonable by many authors, others (Griffin and Hauser, 1993) believe that it is important to get as many as possible.

Considering the diversified applications and versatility of QFD, this study is intended to evaluate its application in the UK construction industry and how it could enhance the performance of the industry and guide it towards strategic exploitation and delivery of quality, responsiveness and customer service.

1.2 Aim and Objectives of the Study

As already highlighted, the UK construction industry has been underachieving and could benefit from some manufacturing management techniques. Even though some of the construction companies have started using techniques such as TQM and JIT, the industry lacks the necessary tools for full implementation of these techniques. Therefore the main aim of the research is to evaluate QFD as a decision support tool for design and planning purposes in the construction industry.

In the light of the main aim, the specific objectives are;

1. to assess the impact of manufacturing techniques in the construction industry
2. to examine the principle and practice of QFD in the context of construction projects.
3. to develop a framework for the application of QFD in construction industry.
4. to develop an interactive computer software that will aid QFD implementation as a form of decision support tool.
5. to assess and evaluate the use of the software as a construction management tool.

This research focuses on achieving the set objectives. The reason relates to the fundamental exploration of QFD in the construction industry for which very little empirical evidence exists. However, this fact will not restrain the fulfilment of the research objectives. The achievement of the objectives will serve as a proof-of-concept and as a case example for the implementation of QFD in the construction industry. In addition it will benefit a wide spectrum of the construction industry in achieving optimal interactions in the supply chain.

1.3 Research Methodology

Research methodologies are the philosophical assumptions underlying the research process. Research methods are the means of data collection and analysis. The results, conclusions, values and validity hinge on a well-designed research methodology. Thus an understanding of the philosophical assumptions is very important. Easterby-Smith et al (2003) identifies three reasons why the exploration of research philosophy may be significant with particular reference to research methodology:

- Firstly, it can help the researcher to refine and specify the research methods to be used in a study, that is, to clarify the overall research strategy to be used. This would include the type of evidence gathered and its origin, the way in which such evidence is interpreted, and how it helps to answer the research questions posed.

- Secondly, knowledge of research philosophy will enable and assist the researcher to evaluate different methodologies and methods and avoid inappropriate use and unnecessary work by identifying the limitations of particular approaches at an early stage.

- Thirdly, it may help the researcher to be creative and innovative in either selection or adaptation of methods that were previously outside his or her experience.

This section therefore explains the importance and relevance of understanding the research philosophies and paradigms that underpin any empirical research.

1.3.1 The Two Philosophical Traditions

According to Clarke (1998), research methods can be classified at different levels, with the most basic being the philosophical level. The methodological distinctions most commonly used focus on the differences between quantitative research, which is generally associated with the philosophical traditions of positivism, and qualitative research, generally associated with interpretivism and constructivism (Bryman 2004).

Positivism

The basic reasoning of positivism, more recently called Logical Positivism or empiricism, assumes that an objective reality exists which is independent of human behaviour and is therefore not a creation of the human mind. That is, all real knowledge should be derived from human observation of objective reality. The senses are used to accumulate data that are objective, discernible and measurable; anything other than that should be rejected as transcendental (Easterby-Smith et al, 2003).

In practical terms positivists make several assumptions. The first of these is that the observer is independent of what is being studied, and has no measurable effect upon its behaviour. Secondly, what needs to be studied can and should be derived from the application of select research criteria. The objective of research is to construct a model by hypothesising behaviour and testing the accuracy of these hypotheses by empirical observation. Such a model should be able to retain its validity when applied to all instances of the phenomenon. Hence, for example, Newton's Laws of Motion will have equal validity wherever they are applied. If they do not apply in the same way everywhere, then there should be a clear way of understanding how they vary in different circumstances. Thus Einstein was able to explain why, under certain circumstances, Newton's Laws of Motion appear not to work, and his Theory of Relativity is able to account for variations in these Laws and predict the behaviour of bodies when they are moving at velocities near to the speed of light.

The general elements of positivist philosophy have a number of implications for social research based on this approach. These implications, adapted from Easterby-Smith et al (2004), and Hughes (1994) are:

Independence: the role of the researcher is independent of the subject under examination

Value-freedom: the choice of what to study, and how to study it, should be determined by objective criteria rather than by human beliefs and interests

Causality: the aim should be to identify causal explanations and fundamental laws that explain human behaviour

Hypothesis and deduction: science proceeds through a process of hypothesising fundamental laws and then deducing what kinds of observations will demonstrate the truth or falsity of these hypotheses

Operationalisation: concepts need to be operationalised in a way that enables facts to be measured quantitatively

Reductionism: problems are better understood if they are reduced to the simplest possible elements.

Generalisation: in order to be able to generalise about regularities in human and social behaviour it is necessary to select samples of sufficient size, from which inferences may be drawn about the wider population

Cross-sectional analysis: such regularities can most easily be identified by making comparisons of variations across samples.

Methodological: all research should be quantitative, and that only research which is quantitative can be the basis for valid generalisations and laws

Interpretivism and Constructivism

Interpretivism/Constructivism, which was developed largely in reaction to the application of positivism to the social sciences, stems from the view that 'reality' is not objective and exterior, but is socially constructed and given meaning by people. Therefore the task of the social scientist should be to appreciate the different constructions and meanings that people place upon their experiences, and not to gather facts and measure how often certain patterns occur (Easterby-Smith et al, 2004).

The main idea of Interpretivism/Constructivism focuses on the way that people make sense of the world, especially through sharing their experiences with others via the medium of language.

1.3.2 Methodology Adopted for the Research

Whilst quantitative research methods (positivist philosophies) and qualitative methods (interpretivist/constructivist philosophies) are often seen as opposing views they are frequently used in conjunction. Clark (1998) emphasises this point:

> *"Though some distinction between methods is well placed... it is being acknowledged that philosophically the qualitative and quantitative paradigms are not as diverse or mutually incompatible as often conveyed."*

A recent trend in the social sciences and more so in the business and management research has been to adopt a middle-ground between the two philosophies. This mixed method, known as triangulation is advocated because it can provide more than one perspective of the problem, and the different forms of evidence collected can reinforce each other to improve the richness of results (Carson et al, 2001). Thus the use of a combination of qualitative and quantitative methods was considered to be the most appropriate approach for this investigation as the study is neither a physical science or purely observational in nature. The methods used include, literature reviews, a questionnaire survey, Software development and evaluation (desktop and field evaluation involving an interview). Below is a description of the methods employed.

Literature review

Available literature related to QFD has been reviewed. The review examined the concept, development and implementation of QFD. It also examined the nature of the construction industry and the potential for its adoption of QFD. Various sources search as Books, Journals, Conference Papers, Theses, Internet, Indexes/Abstracts, Government publications and Electronic Databases were used in the search for literature.

Questionnaire Survey

In order to gain the depth of understanding necessary for the development of a decision support tool, a survey by questionnaire was conducted. The questionnaire constructed for the survey was also used to determine the impact of manufacturing techniques and the relevance of QFD in the construction industry.

Software Development

Based on the analysis of the literature review and the questionnaire, software incorporating the House of Quality has been developed. The programme was written using the visual C++ language. The visual C++ language was used because of its unique advantages over other languages such as Visual Basic. Whilst both development languages are readily available, the object oriented nature of Visual C++ makes it a more attractive choice, considering the complexity of the task. An object oriented language allows data to be grouped in classes, of which various instances could be used to represent a segment of the QFD chart. In addition, the C++ is fast and able to handle complex calculations better than Visual Basic.

Software evaluation

In order to determine the effectiveness of the QFD software developed, available data from literature and other research papers were used to evaluate the software. Further testing was done by using a real life case. The data for the real life case was obtained through a face to face interview.

1.4 Structure of Thesis

This thesis has been structured under ten main chapters with each chapter supported with comprehensive references where necessary.

Chapter Two – This chapter deals with the review and analysis of the literature pertaining to the construction industry. The nature of the construction industry, its significance to the economy, and construction procurement methods and related problems are highlighted.

Chapter Three – This chapter deals with the various aspects of Quality Management including its evolution. The tools and techniques employed in quality management have also been presented in this chapter.

Chapter Four – This chapter relates to the concept of "Construction as a Manufacturing Process". Prior research in the implementation of QFD and other manufacturing techniques in the construction industry are also discussed.

Chapter Five – The first part of this chapter explains the importance and relevance of understanding the research philosophy and paradigms that underpin any empirical research project and QFD research in particular. On this basis, alternative research methods are compared and contrasted, and the choice of Questionnaires as the research instruments justified. The second part deals with the actual analysis of the questionnaire survey conducted. The survey seeks to determine the impact of manufacturing techniques on the construction industry.

Chapter Six – This chapter focuses on the development of QFD and the basic methodology of the technique. The strengths and weaknesses of the technique have been presented and the methods to overcome the perceived weaknesses discussed.

Chapter Seven – This chapter describes the framework developed for the application of QFD in the construction industry and goes on to describe the architecture of the software component of the framework.

Chapter Eight – This chapter deals with the development of the software and its evaluation. The rationale behind the development of the software and the language of choice is also given. The results of the software evaluation are also presented in this chapter.

Chapter Nine – The conclusions drawn from the research and recommendations are presented in this chapter. This chapter also highlights the limitations of the present study and makes suggestions in areas for further research.

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CHAPTER TWO

THE UK CONSTRUCTION INDUSTRY

2.1 Introduction

This chapter presents the review of the literature pertaining to the UK construction industry. The chapter begins with the analysis of the nature of the UK construction industry and its significance to the economy. The processes through which construction products are realised (i.e. construction procurement systems) have also being analysed. In addition, the current move to view construction as a manufacturing process has also been looked at.

2.2 Nature of the Industry

The construction industry is one of the few industries able to produce goods that increase in value over time. The structure of the industry is complex in the large range of types of contractors and professional firms connected with it. Its activities, which generally comprises both civil and building works, plays a crucial role in creating assets and hence, wealth of the country (Harvey and Ashworth, 1993). The term construction is general used to describe the process of building physical infrastructure, superstructure and related activities. These activities include the planning, regulation, design, manufacture, construction and maintenance of buildings and other structures. According to Turner (1990), construction is

> *"...an act of boldness even for the simplest building. For modern, complex buildings it involves the commissioning, management, design and assembly of huge amount of raw materials and the use of considerable labour recourses over a long period of time..."*

Although the above view is expressed in the context of building projects, the construction industry is much more diverse. The industry embraces the sectors of building and civil engineering and also includes the process plant industry. The physical nature of construction products as well as the wide geographical spread of demand for them, and the fluctuations in the demand have together moulded the structure of the industry, and determined the process of creating a construction product from the client's requirements to the production site.

The construction industry has some characteristics that separate it from all other industries (Wells, 1986; Harvey and Ashworth, 1993). The physical nature of construction products tends to be large and expensive and often represents a client's largest single capital outlay. In addition the finished products of construction are generally permanent in the particular location where their construction takes place. Consequently, the final process of construction must be in-situ. Construction products are generally produced after demand. Consequently each product of construction is unique and built to the individual needs of the client. However there are several notable exceptions to the custom of not producing product of construction before demand. For example, repetitive and speculative housing may be produced in advance of demand because their demand may be consolidated, continuous and anticipated. Apart from these exceptions, continuity of production in the construction industry depends upon the maintenance of continuity of demand (Wells, 1986).

The construction industry is also different from other industry in the sense that, a large part of its output consists of capital or investment goods. These refer to products required for the production of other goods or services in an economy. Construction therefore, is liable to be affected by the variations in the level of activity in the economy (Wells 1986).

2.3 The UK Construction Industry and the economy

The relationship between the construction industry and the UK economy is very important. It provides over half the fixed capital investments in the UK. Historically, the government has been the major client in the construction industry, but is now shrinking due to the large number of departments being privatised. Nevertheless, the government is still an important player in the industry as it affects demand indirectly by acting on the overall demand in the economy, on taxation, on interest rates, and the supply of credit, and directly by determining the level of public sector spending on construction.

The construction industry is featured as one of the sectors of the analysis of Gross Domestic Product (GDP). The share of construction to the GDP is the difference between the value of sales at market prices and the market value of all current purchases. It excludes the value of purchased building materials and components, fuel, transport, professional services, insurance and legal fees (Wells, 1986) and other goods and services which the contracting industry purchases from other parts of the economy. In its widest sense the UK construction industry accounts for about 8% of Gross Domestic Product (Fairclough, 2002).

The construction industry is also a major employer and plays a critical role in the social and environmental development of the UK. The industry directly employs about 1.5 million people (Morton 2002). There are also a large number of others who are employed indirectly with materials and component manufacturers, plant and vehicle builders and repairers. The number of people employed in the repair and maintenance sector alone is considerably greater than those in agriculture, mining, shipbuilding and many of the other traditional industries (Harvey and Ashworth, 1993).

The output of the construction industry ebbs and flows as a key indicator of the economy. However it does rely to a large extent on the good fortune of other industries or sectors for much of it work. The effects of changes in output, employment, incomes or demand in the construction industry have repercussions in other sectors of the economy through a knock on effect. Thus a decline in construction will have an adverse effect upon other activities and industries in a market economy. With the government being the major client of the construction industry, it is tempting to suggest that the industry may be used as a regulator to control the economy. The government may defer or cancel construction projects for other reasons, such as to reduce the public sector borrowing requirement which in turn may create a knock-on effect. Cuts in public expenditure sometimes have a high construction consequence, but these are often accompanied by other measures, so it is debatable whether this can be cited as an example of regulation.

2.4 Construction Procurement Systems

Since the publication of the Emmerson (1992) report, construction procurement has attracted much attention amongst researchers. This has led to the proliferation of many construction procurement systems in an attempt to find a way to reduce the time for building construction from inception to completion, and to provide value for money for clients. According to Hibberd (1991), although there has been a proliferation of construction procurement systems in recent years, no standard definitions or classification approaches have become generally accepted.

In a detailed analysis of the UK construction procurement systems, he found that UK practitioners identified with the following eight paths, despite the fact that some of them share a significant number of characteristics: Convention or Traditional, Management Contracting, Design and Build, Two Stage Conventional, Construction Management, British Federation System, Prime Cost, and Develop and Construct. Nahapiet and Nahapiet (1985) also identified five distinct groups of procurement systems: Lump Sum Contracts, Negotiated Contracts, Construction Management Contracts, Managing Contracting Contracts and, Design and Build Contracts. However, they referred to such systems as contractual arrangements rather than procurement systems. Walker and Hampson (2003) using a cost risk/relationship risk perspective also identified seven options: Traditional, Total Package, Design and Construct, Construction Management (Management Contract), Sequential Negotiated Work Package, Guaranteed Maximum Price, and Full Cost Reimbursement.

The construction procurement concept has been defined in many ways (Nahapiet and Nahapiet, 1985; Masterman, 1989; Hibberd, 1991). The definition of the procurement process developed by the International Commission on Building (CIB W92) during its 1997 meeting was:

...a strategy to satisfy client's development and/or operational needs with respect to the provision of constructed facilities for a discrete life cycle.

This sought to emphasise that the procurement strategy must cover all of the processes in which the client has an interest (Rowlinson and McDermott, 1999). Masterman (2002), in a detailed analysis of construction procurement systems defined it as:

"The organisational structure adopted by the client for the implementation, and at times the eventual operation, of a project". (Masterman, 2002)

In order to classify the various methods of procurements available Masterman (2002) adopted a method which is based on the way in which the interaction between the construction and the design, and sometimes the funding operation, is managed. This classification is most suitable when considering the application of QFD in the construction industry and will therefore be used in this thesis. The main reason being that the success of QFD is largely based on the level of interaction and co-operation between team members. Although QFD initiates a method by which client's requirements are explicitly defined and the supplier (in this case the design and production team) seeks to arrange itself in such a way as to fully meet the requirements, communication and contractual links created by the various procurement methods often dictates how the various professions interact. Below is an outline of the classification by Masterman:

- Separated procurement systems – where the main elements of the project implementation process, i.e. the design and construction, is carried out by separate organisations. This category includes the Conventional or Traditional system.

- Integrated procurement systems – where one organisation or contractor, usually but not exclusively, takes responsibility for the design and construction of the project. Examples are Design and Build, and Develop and Construct.

- Management Oriented procurement systems – where the management of the project is carried out by an organisation working with the designer and other consultants to produce the design and manage the physical operations which are carried out by contractors. This category includes Management Contracting and Construction Management.

- Discretionary systems – where the client lays down a framework for the overall administration of the project within which he/she has the discretion to use the most appropriate procurement system. Examples of this category include Partnering and the British Property Federation systems.

A brief description of the various systems under the different categories is presented below

2.4.1. Separated Procurement Systems

The unique characteristic of this category is the separation of the responsibility for design of the project from that of its construction. The only procurement system in this category is The Traditional or Conventional Procurement System (Figure 2.1).

a) The Traditional Procurement method

In this method the client organisation appoints a design team led by the architect who also undertakes the overall management of the project. Other specialist design consultants are appointed if necessary and a quantity surveyor is appointed to advise on costs. The client organisation also appoints a contracting organisation to carry out the construction work under separate contract from the design team.

This method separates the design from the construction process and is sequential in nature as the client takes the scheme design to an advanced stage with the design team before the appointment of the contractor, although their contribution would be invaluable. It tends to create a "them and us attitude" between parties resulting in adversarial relationships with associated contractual disputes. This situation can result in lack of teamwork, which is crucial if the success and benefits of a QFD project is to be realised.

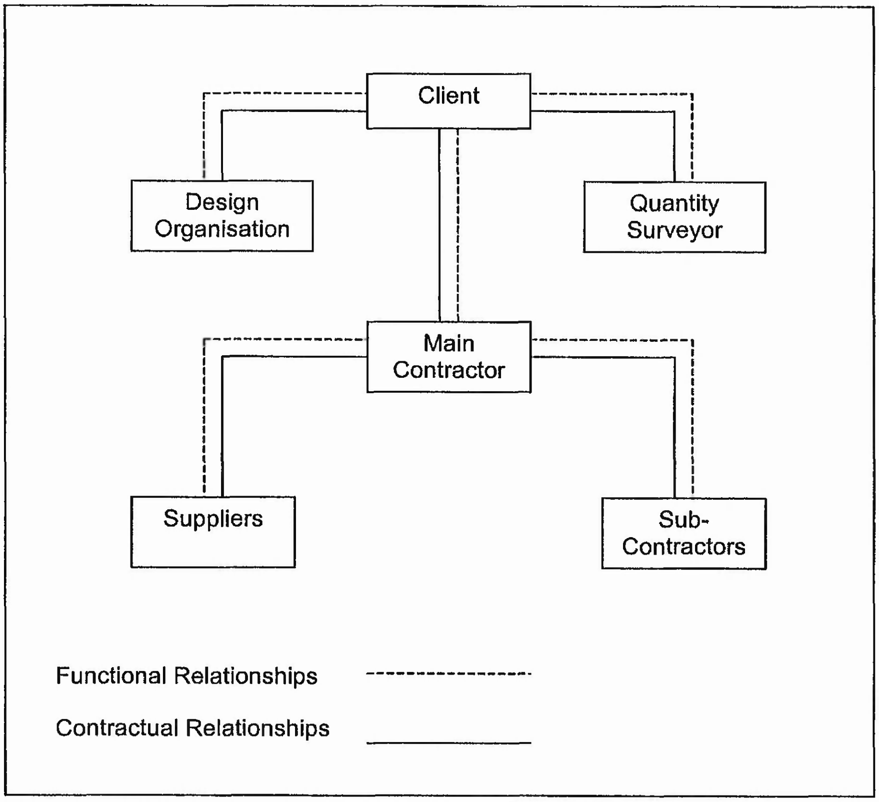

Figure 2.1 – The Traditional Procurement System

The advantages and disadvantages of the traditional procurement system is as follows:

Advantages

1. The system ensures lower costs for the client and proper competition if the design has been fully developed and uncertainties eliminated.

2. It allows time and freedom for architects to develop designs fully, in consultation with clients, quantity surveyors and engineers.

3. The existence of a priced bill of quantities enables interim valuation to be assessed easily variations to be quickly and accurately valued by means of prearranged rates.

4. It provides a higher degree of certainty that quality and functional standards will be met than when using other systems.

5. The design team retains control of the way the design intentions are realised. Although it is the contractor who manages the actual construction process, his activities are subject to instructions from the client normally acting through the architect.

6. The system is well established and well understood by architects, contractors, subcontractors and clients.

Disadvantages

1. The sequential and confrontational nature of this system can result in lengthy design and construction periods, poor communication between client and project team members and problems of buildability.

2. While the facility to respond to late demands for change, by introducing variations, can result in satisfied customers, such actions have been identified as one of the main causes of delays, and increased cost, and can lead to a permissive attitude to design changes.

3. Where tenders are obtained on the basis of incomplete designs, the bids obtained can only be considered as indicative of the final cost and the client is thus vulnerable to claims for additional financial reimbursement from the contractor.

4. The contractor has no input into the design or initial estimating procedure; the contractor's knowledge of his own methods of working, the skills available to him and the current market conditions of materials put him in a better position than the architect to judge some aspects of the buildability of a design.

5. The tendering process is complex and expensive, and where too many contractors are allowed to bid the total costs involved can be very high.

It can be seen that the traditional method of procurement does not readily facilitate the use of the QFD methodology. The main reason being the separation of the design and construction teams.

2.4.2. Integrated Procurement Systems

This category of procurement systems includes all the systems for which the management of the design and construction are integrated and become the responsibility of one organisation. The main member of this group is Design and Build, however other variants of the design and build also exist.

a) Design and Build

This procurement method has increased significantly over the recent years. In this method the client enters into a contract with a single party who is then responsible for the design and construction of the project (Figure 2.2). The contractor carries most of the risks, and as a result the client has very little control over the project. This system allows for overlap of design and construction and hence reduces the time for the completion of a project. In addition there is opportunity to improve teamwork and communications, and buildability/constructability. The integrated nature of this procurement system makes it very suitable for QFD implementation

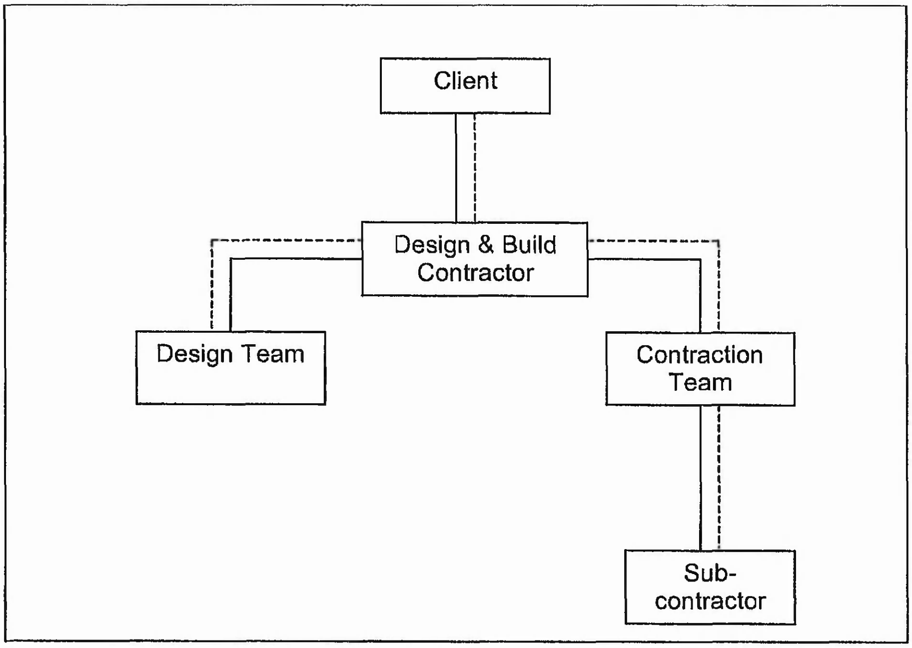

Figure 2.2 – The Design and Build Procurement System

The advantages and disadvantages of this system is outlined below:

Advantages

1. The client has the advantage of dealing with one organisation that is responsible for all aspect of the project.

2. Provided that the client's requirements are accurately specified, certainty of final project cost can be achieved, and this cost is usually less than when other types of procurement systems are being used.

3. This system results in improved communication being established between the client and the contractor, and thus enabling shorter, overall project periods to be achieved and project management efficiency to be improved.

Disadvantages

1. Great difficulties can be experienced in evaluating proposals and if the client's brief is ambiguous.

2. Although well-designed and aesthetically pleasing buildings can be obtained when using this system, the client has very little control over the project as compared to other procurement systems.

The design and build procurement route offers a greater potential for the implementation of QFD due to the integration of both the design and construction teams.

2.4.3. Management-Oriented Procurement Systems

This category includes two systems of procurement which are usually treated as "non-traditional" but which are really developments of the traditional system, in that they are designer led. These are Managing Contracting and Construction Management. In this system the contractor is elevated to the status of a consultant and special emphasis is placed on the integration of the management of both design and construction. Thus, they are also sometimes referred to as fast track methods because by allowing the design and construction stages to overlap, actual building work can be started earlier than under the pure traditional system.

These systems are mainly used by large organisations such as the big retail chains which have major construction programmes and considerable experience. However, it has remained a very small proportion of total contracts (Morton, 2002). Below is a description of the systems that make up this category.

a) Management contracting

This involves the addition of management contractors to the client's professional team. The management contractor employs the trade contractors who carry out the actual work. This management contractor has an increased involvement in the decision making process thus improving the management input. The client has much greater control of the project and also the method allows for overlap of design and construction (Figure 2.3).

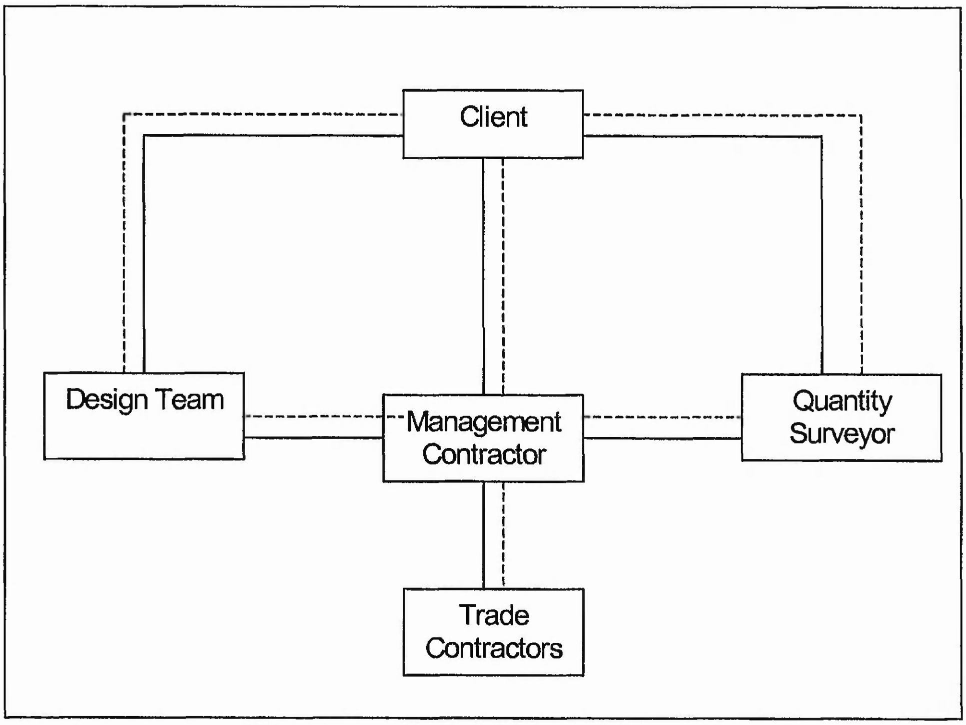

Figure 2.3 – Management contracting

b) Construction management

In this method the client employs trade contractors directly. The construction manager is appointed very early in the process and is of equal status to the other consultants. He holds very little risk as the majority of the risk is born by the client (Figure 2.4).

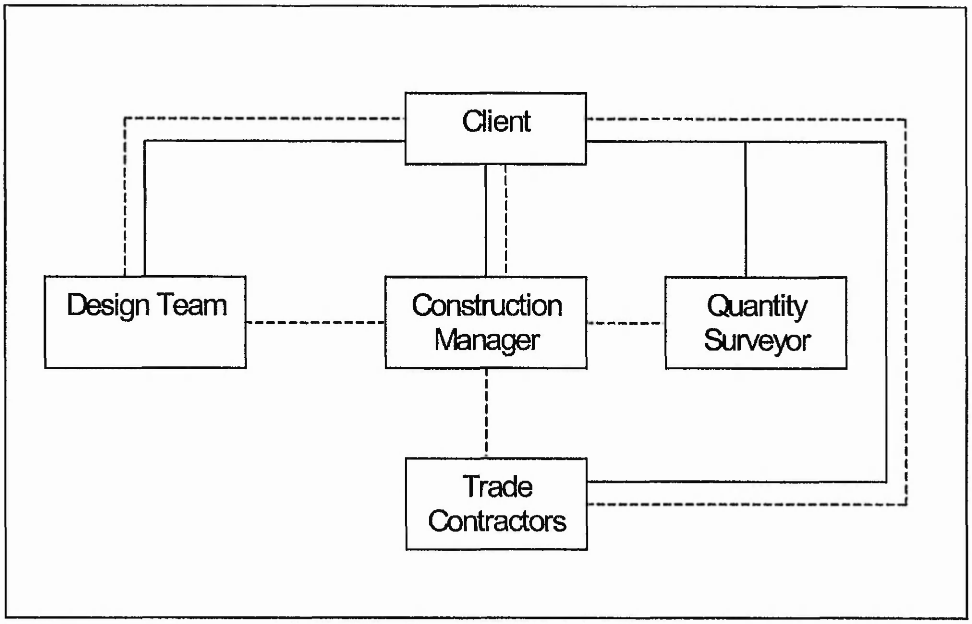

Figure 2.4 – Construction Management

The advantages and disadvantages of the management-oriented procurement systems are highlighted below:

Advantages

1. This system enables the commencement of the project to be accelerated, which in turn, should enable earlier completion to be achieved than the separated procurement systems

2. Early advice can be obtained from the contractor/manager on design, buildability, programming, and materials availability, together with general construction expertise.

3. This systems in this category have a high degree of flexibility to allow for delays, variations and rescheduling of works packages

Disadvantages

1. The client bears a major part of the risk involved and can be particularly burdensome where works package contractors fail to perform.

2. Although the contractor/manager is responsible for supervising construction and ensuring that work is built to the standards identified by the design team, the fact that his obligations are limited to his management performance implies that the client is liable for the cost of remedying any defects resulting from the substandard performance of any works contractor who is unwilling or unable to rectify his own faults.

3. The issue of maintaining quality control is problematic when systems within this category are employed, and the client may therefore need to appoint additional site supervision to avoid difficulties in determining the responsibilities for defects and to ensure that the specified quality standard is achieved.

Management oriented procurement systems are very much client oriented. In addition teamwork is an inherent characteristic of the system. Although, the system maintains separate design team, there is the advantage of inputs from the contractor. Thus this system also lends itself to the implementation of QFD.

2.4.4. Discretionary Procurement Systems

The discretionary system of procurement is an administrative and cultural framework into which any procurement system(s) can be incorporated, thus allowing the client to carry out the project by imposing a very specific management style, or company culture, while at the same time enabling him to use the most suitable of all the available procurement systems (Masterman, 2003). This system includes the British Property Federation (BPF) and Partnering.

a) British Property Federation (BPF)

This system was developed because:

Members of the British Property Federation have become increasingly concerned about problems in building which occur far too frequently, particularly those of poor design, inadequate supervision and insufficient choice of material. Many contract methods cause delays, by their nature are inefficient and can substantially increase costs. (British Property Federation, 1983).

In this system the design team still provides the design function but their management role is curtailed. A client's representative and a design leader are appointed to take over this role.

b) Partnering

Partnering is a system which relies on trust and collaboration and has at its core a philosophy of real co-operation, partnership and equality among all the members of the project team, thus engendering a mutual desire to fulfil the projects objectives. This is a means of administering and establishing and environment within which a project is implemented using any of the available procurement systems. Successful partnering can only be achieved if all the participating organisations are prepared to trust each other. This trust can be generated through the implementation of techniques such as QFD.

2.5 Discussion

This chapter has looked at the UK construction industry, its characteristics and its significance to the economy. It was gathered that construction industry has been under criticism for its less than optimal performance. Governmental reports and other publications agree in their conclusions that the industry has much to learn from the manufacturing industry. As a result of these publications a number of practitioners and researchers have turned to manufacturing as a point of reference.

The chapter has also examined the development and practice of different procurement methods and contractual relationships between clients, designers and contractors. The various procurement routes determine how the construction procurement process itself is managed. It has generally been agued that some routes lead to a more efficient construction process than others. The traditional procurement system has often been cited as being particularly prone to the creation of delays and excessive costs. However, there seem to be very little empirical evidence to support any general assumption that well managed schemes under the traditional systems cannot be built as efficiently as under any procurement system (Masterman, 2002).

Comparisons between these systems are often made without reference to design quality. However, regardless of the form of procurement system, the quality of design greatly influences the quality of the construction project. Since the quality of the output of any given process depends, to a large extent, on the inputs, it is of utmost importance that the inputs, are as accurately determined as possible. In the case of construction projects the inputs are the clients' requirements. If the client's requirements are not properly analysed and understood, the project team could apply the best of procurement methods and techniques, but the end result will be a product that does not conform to the actual specifications of the client. There is therefore the need for a methodology to aid the design team in capturing and processing clients' requirements.

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CHAPTER THREE

THE EVOLUTION OF QUALITY MANAGEMENT

3.1 Introduction

The issue of product quality is not new. Throughout history quality assurance has been an important aspect of production operations. An example of the issue of product quality in the ancient world can be seen in the pyramids of Egypt. Apart from their massive scale, the complexity of their internal features and the precision of their construction, these structures have survived to this present day. There seems little doubt that these ancient craftsmen used well-developed methods to help the ancient Egyptians in the control of quality while building the pyramids. One just has to consider these mighty structures to appreciate the quality planning involved in their construction.

The concept of quality can be confusing, partly because people view quality in relation to differing criteria, and partly because the meaning of quality has evolved as the quality profession has grown (Evans and Lindsay, 1999). According to the seventeenth century economist, Nicholas Barbon,

> *"The Qualities of Wares are known by their colour, sound, smell, taste, make, or shape. The difference in the qualities of wares are very difficultly distinguished; those organs that are the proper judges of those differences, do very much disagree; some men have clearer eyes, some more distinguishing ears, and other nicer noses and tastes; and every man having a good opinion of his own faculties, it is hard to find a judge to determine which is best."*

Thus the quality in this era was transcendental and as such cannot be defined precisely – you just know it when you see it (Evans and Lindsay, 1999; Gavin, 1988). Thus the consumer was responsible for assuring the quality of the goods they purchased. This is the essence of the *caveat emptor:* Let the buyer beware. The principle of caveat emptor works quite well with simple products. For more complex products it loses its feasibility for complex products as customers or consumers may not be able to observe the quality prior to purchase. In order to safeguard the interests of the consumer against unscrupulous tradesmen punitive measures were instituted. For example King Hammurabi of Babylon introduced the concept of quality and liability into the Babylonian building industry of that time by declaring:

> *"...if a building falls into pieces and the owner is killed then the builder shall also be put to death. If the owner's children are killed then the builder's children shall also be put to death."* (Kehoe, 1996)

Just as modern day industrialists were driven towards quality by the harsh realities of competition, so the ancient craftsmen, often little better than slaves were motivated towards excellence, not only by pride in their trade but also by the fear of instant death.

The second method used in the early days to ensure quality was trademarks. This ensured that poor quality products can be traced and punitive measures administered. However, as time moved on, these trademarks became more than just tracers; they also became a source of pride.

The development of quality assurance and management to the state as we know it today has gone through several stages (Gavin, 1988; Feigenbaum, 1991). Feigenbaum identified five stages in the evolution of quality control and management:

1. Operator (Craftsman) Quality Control
2. Foreman Quality Control
3. Inspection Quality Control
4. Statistical Quality Control
5. Total Quality Control

The last level, which is the current stage of quality management, was identified by Gavin, i.e.:

6. Strategic Quality Management

Below is a brief description of the various stages.

a) *Operator (Craftsman) Quality Control*

Operator Quality Control was inherent in manufacturing up to the end of the nineteenth century. Under that system one worker, or at least a very small number of craftsmen were responsible for the manufacturing of a complete product, and each exclusively controlled the quality of his work. Since these craftsmen and the buyers of their products usually live in the same village, they (craftsmen) are subject to scrutiny and character evaluation. With his livelihood closely tied to his reputation as a competent and honest craftsman, every effort is made to ensure that quality is built into the final product. It was considered that a well-performing product is the natural outgrowth of reliance on a skilled craftsman for all aspect of design, manufacturing and service.

During those times goods were produced in small batches and parts matched to one another by hand. The finished product is then inspected to ensure high quality. In this wise the craftsmen served both as producer and quality inspector. Another factor, which made it possible for the craftsmen to ensure that quality is being built into the product, was that they had direct communication with the consumers. The direct contact between producer and consumer/customer began to diminish with the advent of the industrial revolution and the concept of division of labour. Under the division of labour system a group of craftsmen performing similar tasks were grouped together and supervised by a foreman, who then assumed the responsibility of the quality of their work.

b) *Foreman Quality Control*

The development of power driven machinery and sources of mechanical power ushered in the industrial revolution and with it, the factory system together with the concept of division of labour. The factory system usually subdivided former trades into multiple specialised tasks. Although this resulted in increased productivity it also brought in new quality problems. With the craft tasks divided between many workers, the responsibility of those workers were no longer that of satisfying the customer, but rather the responsibility became one of "making it like the sample" (Juran, 1995). In addition, products that consisted of the assembly of bits and pieces demanded that those pieces be interchangeable. This also brought in the problem of variation, requiring a greater precision in machinery, tools and measurements.

c) Inspection Quality Control

The development of jigs and fixtures solved the problem to some extent. In theory, since every part that is worked on is held in place in the same way, a high degree of interchangeability is expected. Nevertheless, parts could still deviate from one another due to improper mounting, defects in materials or worn tools. With very little understanding of the nature of process variation and the resulting product variation coupled with limitations of quality planning during those times, a lot of defective products were produced during manufacturing. In order to minimise problems at assembly a system of gauges were developed. These gauges ensured a more accurate inspection than would have been possible with the eye. Thus with the help of the gauges defective goods were fished out by hired inspectors. Hence the main quality-related activity was post-operation inspection.

In the early 1900s Frederick Taylor formulated the "Principle of Scientific Management". His concept was to separate the planning function from the execution function. Managers and Engineers were given the task of planning; supervisors and workers the task of execution. However, the focus on productivity had an effect on quality, and to restore the balance quality inspection departments were created. This artificial separation of production workers from the responsibility for quality assurance led to an indifference to quality among both workers and their managers. Top managers showed very little interest in quality improvement or prevention of defects and errors, relying instead on mass inspection. With this method of quality control manufacturers were able to ship defect-free products but at a great cost.

Although the quality control in this era was mostly limited to such activities as grading and post operation inspection, work conducted by Walter Shewhart and a team at Western Electric in the 1920s shifted the focus to identifying and removing the problems that cause defects. This ushered in the era of Statistical Quality Control.

d) Statistical Quality Control (SQC)

SQC is the application of statistical tools and methods for controlling quality. Tools like control charts were used to identify quality problems in production processes and to ensure a consistent output. Shewhart recognised that variability cannot be totally eliminated, although it could be understood using principles of probability and statistics. He recognised that, even the same part produced by a single operator on a single machine was likely to show variation over time. The issue, therefore, is how to distinguish between acceptable variations from fluctuations that indicate trouble. The entire analysis grew out of Shewhart's concept of statistical control:

> *"A phenomenon will be said to be controlled when, through the use of past experience, we can predict, at least within limits, how the phenomenon may be expected to vary in the future. Here it is understood that prediction means that we can state, at least approximately, the probability that the observed phenomenon will fall within limits."* (Shewhart, 1986)

Shewhart then developed statistical techniques to determine these limits.

The next stage in statistical quality control was started from the premise that 100% inspection was an inefficient way of sorting good products from bad. This led to the development of sampling techniques, where a number of items in a production lot were inspected to decide whether the whole lot should be accepted or rejected. Useful as this method was, it entailed the risk of accepting a production lot that actually contain a lot of defective items. This is because sampling is never fully representative. A related risk is to reject a production lot which is actually good. In order to overcome this limitation, a new concept known as the "Outgoing Quality Limit" was developed. It indicated the maximum number of defective items that a process would produce under two conditions:

1. Sampling inspection by lots
2. Individual separation of good items from bad from all lots that have been rejected on the basis of sampling.

Although these breakthroughs brought improvements in quality, there was little use of these techniques in manufacturing companies outside of the Bell Laboratories until the advent of the Second World War. During that time, Japan's industrial system was virtually destroyed, and it had a reputation for cheap imitation products with poor quality. The Japanese recognised these problems and set about solving them with the help of some quality gurus, notably, Deming, Juran and Feigenbaum. The Japanese quality control revolution ushered in Quality Assurance.

e) Total Quality Control

Japanese manufacturers during the 1960s changed the emphasis from a quality control approach to a quality assurance approach. Quality Assurance involves a set of activities designed to ensure that the development and/or maintenance process is adequate to ensure that a system will meet its objectives, whilst quality control is a set of activities designed to evaluate a developed work or product. Thus the emphasis moved from that of product oriented to a process oriented. This required more of the business functions of the organisation to be involved in the management of quality. This finally led to a 'total' approach to quality management whereby everyone in the organisation is involved in developing an improvement and prevention orientation which focuses upon the customer through teamwork. This enabled Japanese companies to make significant penetrations into western markets. Although many factors account for the dominance of Japanese industries over western industries, the achievement of high product quality was the most significant. At first sight, there is no obvious reason to explain why a Japanese car, for example, should have fewer defects than a car made by the European or American manufacturer, yet there was a common acceptance that this was the case, with the best European and American manufacturers matching the standards of the Japanese.

Quality, cost, timeliness, and productivity are often viewed as conflicting elements that require trade-offs. The Japanese, however, have learnt to optimise these apparently conflicting objectives whilst making minimal trade-offs. This can be seen in the quality and cost of their products. Whilst their products are consistently rated above average, their costs are often rated below average. In a large part, the achievement of this strong competitive advantage has been due to the way the Japanese view quality. Although there are many definitions for quality, the Japanese view quality as 'satisfying the requirements of the customer'. These requirements may include availability, delivery, reliability, maintainability, and cost effectiveness.

In spite of all these changes, approaches to quality still remained largely defensive. The main objective of the quality department was still prevention of defects. Even though a proactive approach was now being used, quality was still not seen as a possible basis for competition. That view finally changed in the 1970s and 1980s when the strategic aspects of quality were recognised and embraced (Gavin, 1988) as a result of increased competition.

f) Strategic (Total) Quality Management

In the face of intense global competitive pressure a new vision towards quality began to emerge. For the first time top managers at the level of chief executives and presidents began to link it with competitive advantage and profitability. Quality was now defined from the customers' point of view and linked to the company's strategic planning process. Thus quality was no longer an isolated, independent function, dominated by technical experts. This new approach to quality management incorporates elements of the first quality eras, but goes a step further by linking it with competitive success. Market research on quality, pressures for continuous improvements and high levels of communication and participation are now required in order to succeed in the competition.

Currently Strategic/Total Quality Management is the capstone of quality management. In its original incarnation, quality was the responsibility of the manufacturing department; today it has emerged from the factory and entered the boardroom.

3.2 Total Quality Management Tools

In the never-ending quest for improvement a thorough data gathering, recording and presentation is essential. In addition to the basic elements of a quality system, there exists a set of methods known as the seven basic tools, which offer a means collecting, presenting and analysing data.

a) Check sheets or tally sheet

This is a data-gathering tool useful for recording direct observations and helping to gather in facts rather than opinion about a process. The objective of the data collection determines the design of the record sheet used. The results obtained from tally sheets give the frequency distribution of the parameters concerned.

b) Histogram

These are used to show in a pictorial way the frequency with which a certain value or groups of values occur. These can be used to display both attribute and variable data. A diagram of a histogram is shown in Figure 3.1.

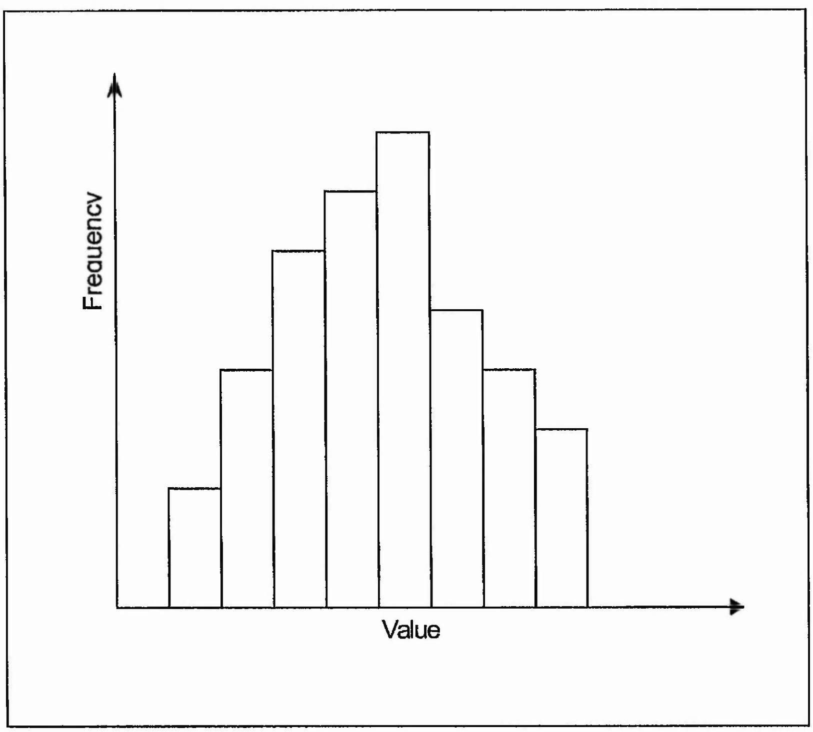

Figure 3.1 – Histogram

c) Scatter diagrams

These are used to establish relationships between parameters or factors (Figure 3.2). It is generated by a simple X-Y plot of the two sets of data. The resulting grouping of points will show whether there is a strong, positive/negative, or weak relationship between the parameters.

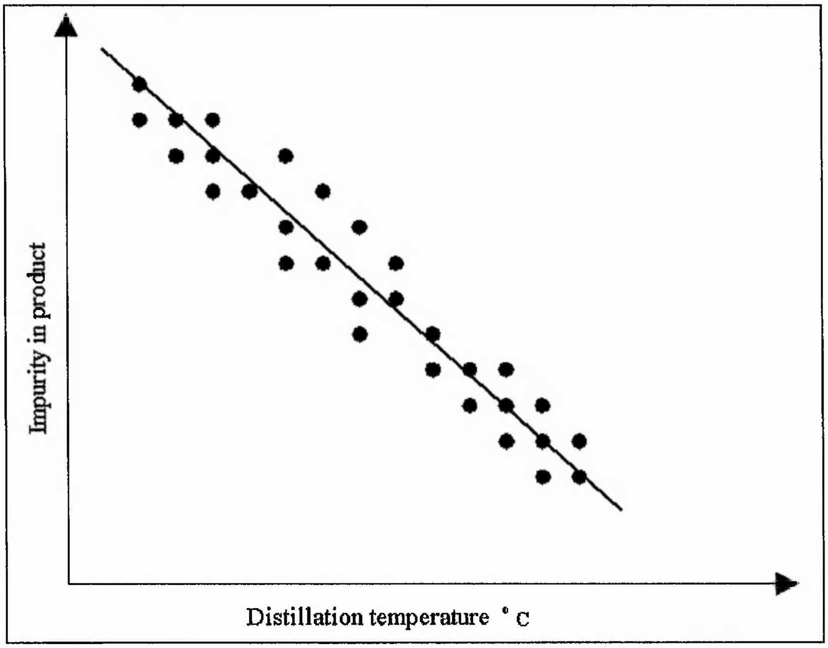

Figure 3.2 – Scatter Diagram

d) Stratification

This is the method of dividing data into meaningful groups and can be used to great effects with other techniques.

e) Pareto analysis

This is the analysis of data to identify the major problem areas. Without an analysis of this sort it is very easy to devote resources to addressing one symptom only because its cause seems immediately apparent.

f) Cause and effects analysis

This is a way of mapping inputs that affects quality. It is usually presented in a diagram known as the fishbone diagram (Figure 3.3). The effect being investigated is shown at the end of a horizontal arrow. Potential causes are then shown as labelled arrows entering the main cause arrow. Each arrow may have other arrows entering it as they are reduced to sub-causes.

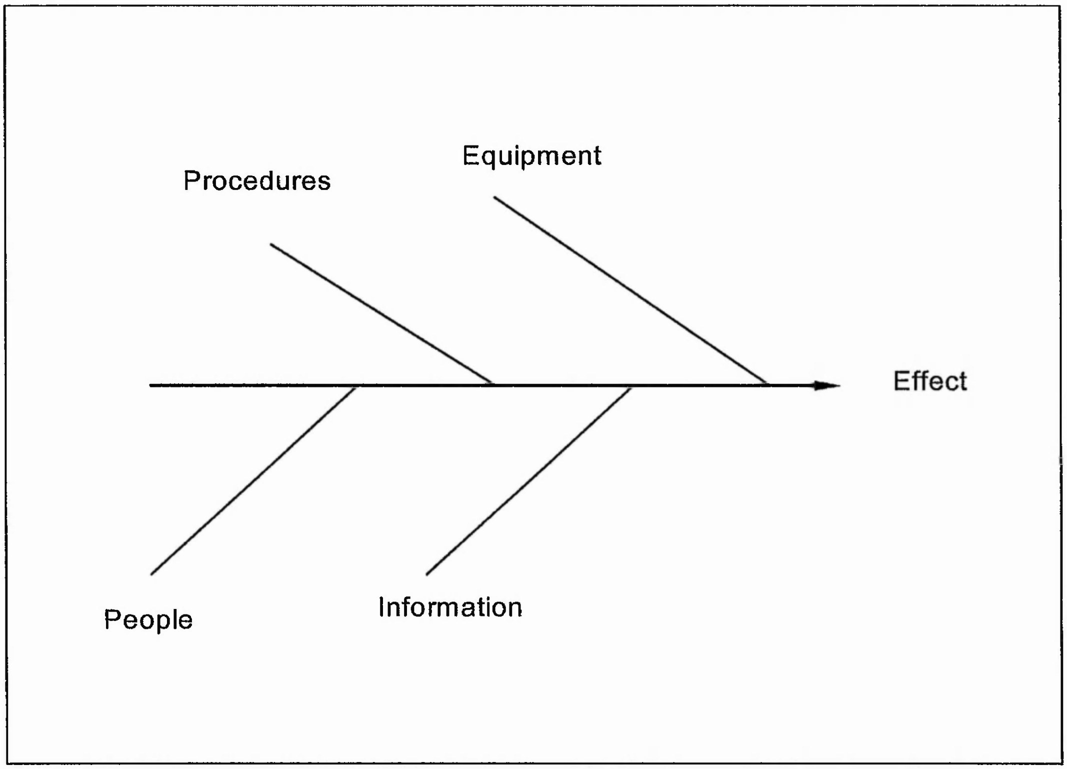

Figure 3.3 – Fishbone diagram

g) Force field analysis

This is a technique used to identify the forces that will either obstruct or help a change that needs to be made. The process begins with a team describing the desired change and defining the solution. After brainstorming to identify the favourable and unfavourable they are placed on opposite sides of the force diagram, and their potential influence on the ease of implementation is rated. The results are evaluated and an action plan to overcome some of the restraining forces and increase the driving forces is prepared.

h) Control chart

This is a graphical approach to monitoring the behaviour of the process by comparing the ongoing variation with warning and action limits derived from the normal distribution.

i) Statistical Process Control (SPC)

In terms of improving the quality in any transformation process within an organisation, SPC can assist the operators of the process to:

- Know whether the process is capable of meeting the requirements.
- Know whether the process is meeting the requirements at any point in time.
- Make correct adjustments to the process or its inputs when it is not meeting the requirements.

With the knowledge of the inputs and outputs of a process, and also the customer requirements, SPC methods can be used to monitor and control the quality of the process. SPC is a strategy for reducing variability, which is the cause of most quality problems.

In addition to the seven basic tools there are also a set of tools known as the Seven New Tools for quality design. These are systems and documentation methods used to achieve success in design by identifying objectives and intermediate steps in the finest details. They are particularly useful in structuring unstructured ideas, making strategic plans and organising and controlling large and complex projects. The seven new tools are:

1 Affinity diagram.
2 Interrelationship diagraph.
3 Tree diagram.
4 Matrix diagram or quality table.
5 Matrix data analysis.
6 Process decision programme chart (PDPC).
7 Arrow diagram.

j) Affinity diagram

This is used to collect large amount of qualitative data and efficiently organise them into groupings based on similarities or relationships between them (Figure 3.4). Its aim is to simplify complex problems through systematic grouping of the many ideas generated during brainstorming.

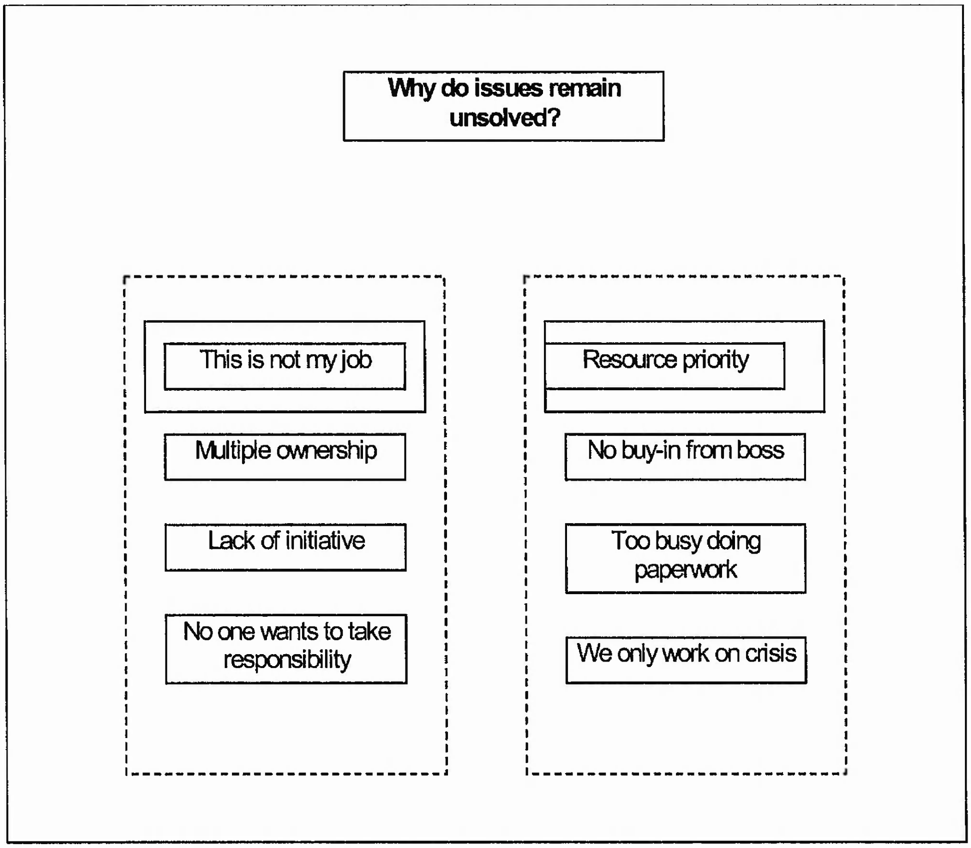

Figure 3.4 – An Affinity Diagram

First a broad statement of the problem to be considered is made, and then each member generates as many ideas as possible relating to the problem. These ideas are written on small cards or post it notes and then arranged randomly on a table or in the case of post it notes, stuck on wall or chart. The cards are sorted together based on similar attributes and later aggregated into larger piles that represent a general theme. A title card representing the theme for each pile is then created. These title cards can further be aggregated to form a three to four level hierarchy.

k) Interrelationship diagraph

The interrelationship diagraph identifies and describes the logical links among related concepts or ideas. By focusing upon a particular idea, the interrelationship diagraph brings logical structure and relationships to the ideas. The nomenclature used describes processes, causes and results.

l) Tree Diagram

The Tree diagram (Figure 3.5), like the affinity diagram, is also a hierarchical structure of ideas. It is constructed by arranging the clusters from the affinity diagram horizontally. Since the construction of the tree diagram is based on logic and analytical skills, it is possible to discover new groupings and branches and also missing ones. Tree diagrams assist the team in understanding the sequence of events which either causes the problem or are required to effect a solution.

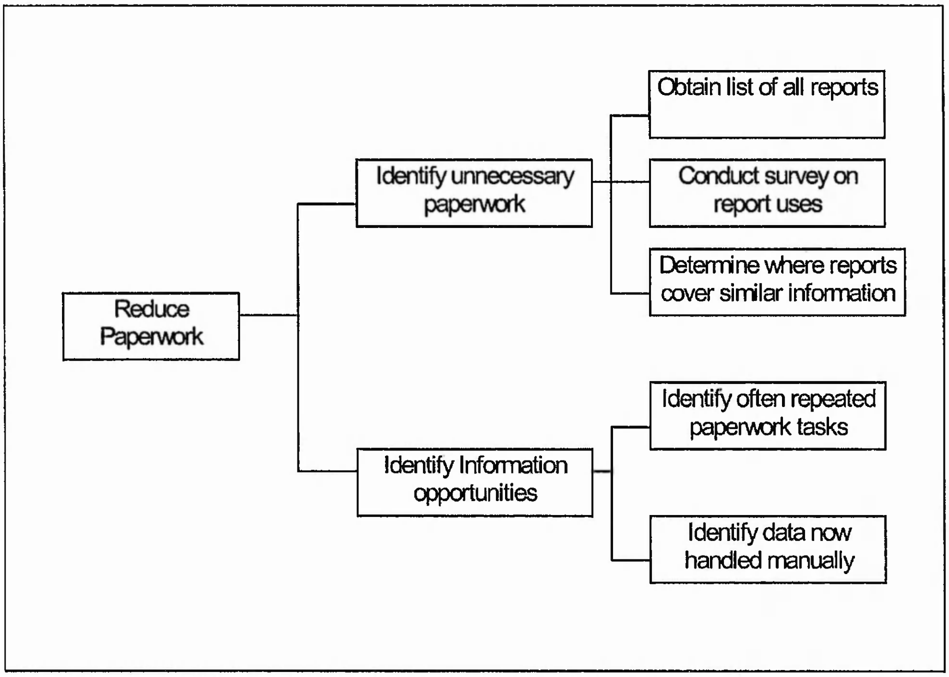

Figure 3.5 – A Tree Diagram

m) Matrix diagram

As shown in figure 3.6, this is a two dimensional array that displays relationships between ideas, activities or other dimensions in such a way as to provide logical connecting points between each item. Numeric values or symbols representing numeric values are used to indicate the strength of the correlation between them. The usual symbols used are:

1 A solid circle (●) which usually has a value of 9 and indicates a strong tendency of the product feature to satisfy that customer need.

2 A circle (O), with a value of 3 or 5, and indicating a moderate tendency of the product feature to satisfy that customer need (Cohen, 1995).

3 A triangle (Δ) with a value of 1 and indicating a weak tendency of the product feature to satisfy that customer need.

A blank cell indicates that there is no relationship between the two items.

	A1	**A2**	**A3**	**A4**	**A5**
B1	●	O	Δ	Δ	●
B2	Δ	O	●		Δ
B3	O		Δ	O	●
B4	Δ	●		O	
B5	O		O		●

Figure 3.6 – Matrix Diagram

n) Matrix data analysis

This technique is used to evaluate the numerical weighting of the relationships identified in the matrix diagram. The technique employs factor analysis to prioritise the respective correlations between the relationships. This is useful in identifying product or service factors in terms of their preference by customers in the market place.

o) Process decision programme chart (PDPC)

This is a method of mapping out all the stages and contingencies in going from the problem statement to the problem solution. It is used to anticipate the unexpected and then plan for it. It is an attempt to be proactive in the analysis of failure and to construct on paper, a run of the process on paper so that the check part of the improvement cycle could be defined in advance.

p) Arrow diagram

This is used to systematically plan or schedule a task. It is basically a diagramming method for illustrating the sequence, precedence and the duration of events.

3.3 Discussion

Under this chapter the evolution and tools of quality management have been reviewed. The chapter traced the development of quality management from an era of Quality Control through Quality Assurance to Total Quality Management.

The review showed that in order for companies to remain competitive quality must not only be limited to quality professionals, but must run through the whole organisation and be linked to the company's strategic planning process. The reason being that, every part and activity in the organisation affects and is affected by others. Failure to meet the requirements of the customer or client in one part or area creates problems elsewhere, leading to more errors and yet more problems.

The issue of quality is such that it is always in a state or evolution. This is because for companies to have competitive edge, they must continuously improve upon their previous standards. Without continuous improvement, the playing ground becomes level and competitive edge may be lost.

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CHAPTER FOUR

MANUFACTURING TECHNIQUES IN CONSTRUCTION INDUSTRY

4.1 Introduction

In the UK, USA, and Japan, the manufacturing industry has been relatively successful in implementing techniques such as Total Quality Management, Quality Function Deployment, and Concurrent Engineering since the 1980s. The construction industry is presently at the point where the manufacturing industry was in 1980 (with regards to the implementation of these techniques), with not much experience to draw from, and little concrete results in the form of case studies. However, the lessons and theories pertaining to manufacturing techniques can be applied to the construction industry in a rational and systematic fashion (Crowley, 1995; Gunasekaran and Love, 1998; Powell, 1995)

As discussed in Chapter One, the Egan report was not the first to highlight the inefficiencies in the UK construction industry, and neither was it also the first to suggest that the industry should take the manufacturing industry as a model for change. Egan vehemently rejects the claim that construction is in some special way different from the rest of the industry:

> *We have repeatedly heard the claim that construction is different from manufacturing because every product is unique. We do not agree. Not only are many buildings, such as houses, essentially repeat products which can be continually improved but, more importantly, the process of construction is itself repeated in its essentials from project to project.*

Although there exists some fundamental differences between construction and manufacturing, the Egan Report rejects the idea that these should justify the industry's failure to adopt manufacturing techniques. It is certainly true that a concept like mass production might not yet be conceivable in construction itself, some of the important generators of efficiency common in other industries can be adopted. In many respects they have in fact been adopted already. For example, Gunasekaran and Love published a paper addressing the concept of concurrent engineering and its application in construction. The paper introduced the concept of concurrent engineering and methods for integrating the flow of information during the design phase. In the same vein, the "Construction as a Manufacturing Process" sector of the "Innovative Manufacturing Initiative (IMI)", by analysing the design and construction process and drawing from proven manufacturing principles, created The Generic Design and Construction Process Protocol (GDCPP) model (Lee et al, 1999). This model is a process map which supports and encourages integration and co-ordination between the various participants or stakeholders of a construction project. Other techniques like industrialisation (i.e. pre-fabrication and modularisation), computer integrated construction, process modelling, Lean, JIT and robotics and automated construction (Koskela, 1992, Love and Gunasekaran, 1996; Crowley 1998) have also been implemented in the construction industry. This chapter is a review of some of the manufacturing techniques employed in the construction industry.

4.2 Just In Time (JIT)

Just In Time is a philosophy that defines the manner in which a production system should be managed. Unlike other inventory control systems JIT attacks problems from the root. The essential objectives of JIT are:

1. Eliminate waste – waste, in this context means anything that does not add value to a product. Examples of processes that do not add value to a product are inspection, transportation, storage and setup. Taking the case of inspection for example, the traditional approach is to strategically place inspectors to examine parts and if necessary fail them. This has a number of disadvantages, including the time it takes for the parts to go through the inspection process and the fact that the inspectors often discover faults only after a whole batch has been manufactured. This could necessitate a whole batch to be scrapped or reworked, either of which will be expensive. Therefore the JIT approach is to eliminate inspection by "making it right the first time".

2. Strive for simplicity – The JIT philosophy stresses the desirability of simplicity on the grounds that simple approaches are most likely to lead to a more efficient management. The primary thrust for simplicity covers two areas: Material flow and Control. The simple approach to material flow aim

to eliminate complex route paths by moving towards more direct, if possible unidirectional flow lines.

3. Device systems to identify problems – Under JIT, any system which brings out problems is considered beneficial. One example is the use of statistical quality control to help identify the sources of problems.

Unlike other inventory control philosophies, JIT is less expensive to implement. What is required is a reorientation of people towards their tasks. Thus any costs involved are mainly costs of education.

4.3 Lean Manufacturing

Lean Manufacturing is an integrated set of principles and methods that enables companies to identify and eliminate waste from their processes, thereby dramatically increasing their competitiveness and profitability. It is commonly believed that lean started in Japan, but Henry Ford of USA had been using parts of lean as early as the 1920s (Kilpatrick, 2003), as evidenced by the following quote:

"One of the most noteworthy accomplishments in keeping the price of Ford products low is the gradual shortening of the production cycle. The longer an article is in the process of manufacture and the more it is moved about, the greater is its ultimate cost." Henry Ford 1926

However, its development to the present state of art was through the works of Taiichi Ohno at the Toyota Automobile Company. Thus Lean Manufacturing is also known as the Toyota Production System. Ohno's work was based on Henry Ford's pioneer work in assembly-line flow.

The Lean principle classifies work in three basic categories:

- ***Value Added*** – This is what the customer is prepared to pay for.
- ***Non-value Added*** – This is what the customer is not prepared to pay for, but is an integral part of the production process. An example is maintenance.
- ***Waste*** – This is what the customer will not pay for in the production process.

The waste noted above are known to Lean practitioners as the Eight Wastes. Ohno suggests that these account for up to 95% of all costs in non-Lean Manufacturing environments. The eight wastes are:

a) Transport
b) Overproduction
c) Inventory
d) Motion
e) Waiting
f) Overprocessing
g) Defects
h) Underutilised people

Below is a description of the eight wastes:

a) Transportation

This type of waste comes about as a result of unnecessary movements of materials due to poor layout. Instead of raw materials being shipped from the vendor to a receiving location, processed, moved into a warehouse, and then transported to the assembly line, Lean demands that the material be shipped directly from the vendor to the location in the assembly line where it will be used. The Lean term for this technique is called *point-of-use-storage* (POUS).

b) Overproduction

Producing goods at a faster rate than the customer actually requires. The Lean principle is to manufacture goods based upon a pull system, or producing products just as customers order them. Anything produced beyond this (buffer or safety stocks, work-in-process inventories, etc.) ties up valuable labour and material resources that might otherwise be used to respond to customer demand.

c) Inventory

Related to Overproduction, inventory beyond that needed to meet customer demands negatively impacts cash flow and uses valuable floor space.

d) Waiting

This includes waiting for material, information, equipment, tools, etc. Lean demands that all resources are provided on a *just-in-time* (JIT) basis.

e) Motion

Unnecessary motion is caused by poor workflow, poor layout, housekeeping, and inconsistent or undocumented work methods. *Value Stream Mapping* (see above) is also used to identify this type of waste.

f) Defects

Production defects waste resources in four ways. First, materials are consumed. Second, the labour used to produce the part (or provide the service) the first time cannot be recovered. Third, labour is required to rework the product. Fourth, labour is required to address any forthcoming customer complaints.

g) Overprocessing

Processing to a standard that exceeds the requirements of the customer.

h) Underutilized People

This includes underutilization of mental, creative, *and* physical skills and abilities, where *non-Lean* environments only recognize underutilization of physical attributes. Some of the more common causes for this waste include – poor workflow, organizational culture, inadequate hiring practices, poor or non-existent training, and high employee turnover.

In order to reduce or eliminate the above wastes, Lean practitioners utilize many tools or Lean Building Blocks. It is recognised that, although most of these may be implemented as stand-alone programs, few have significant impact when used alone. Additionally, the sequence of implementation affects the overall impact, and implementing some out of order may actually produce negative results. Below is a description of these blocks.

Pull System – The technique for producing parts at customer demand. Service organisations operate this way by their very nature. Manufacturers, on the other hand, have historically operated by a Push System, building products to stock (per sales forecast), without firm customer orders.

Kanban – A method for maintaining an orderly flow of material. Kanban cards are used to indicate material order points, how much material is needed, from where the material is ordered, and to where it should be delivered.

Work Cells – This is the technique of arranging operations and/or people in a cell (U-shaped, etc.) rather than in a traditional straight assembly line. Among other things, the cellular concept allows for better utilization of people and improves communication.

Total Productive Maintenance – TPM capitalises on proactive and progressive maintenance methodologies and calls upon the knowledge and cooperation of operators, equipment vendors, engineering, and support personnel to optimize machine performance. Results of this optimized performance include; elimination of breakdowns, reduction of unscheduled and scheduled downtime, improved utilization, higher throughput, and better product quality. Bottom-line results include; lower operating costs, longer equipment life, and lower overall maintenance costs.

Total Quality Management – Total Quality Management is a management system used to continuously improve all areas of a company's operation. TQM is applicable to every operation in the company and recognizes the strength of employee involvement.

Quick Changeover – The technique of reducing the amount of time to change a process from running one specific type of product to another. The purpose for reducing changeover time is to allow for more frequent changeovers in order to increase production flexibility. Quicker changeovers allow for smaller batch sizes.

Batch Size Reduction – Historically, manufacturing companies have operated with large batch sizes in order to maximize machine utilization, assuming that changeover times were "fixed" and could not be reduced. Because Lean calls for the production of parts to customer demand, the ideal batch size is one. However, a batch size of one is not always practical, so the goal is to practice continuous improvement to reduce the batch size as low as possible. Reducing batch sizes reduces the amount of work-in-process inventory (WIP). Not only does this reduce inventory-carrying costs, but also production lead-time or cycle time is approximately directly proportional to the amount of WIP. Therefore, smaller batch sizes shorten the overall production cycle, enabling companies to deliver more quickly and to invoice

Workplace Organization – This tool is a systematic method for organising and standardising the workplace. It's one of the simplest Lean tools to implement, provides immediate return on investment, crosses all industry boundaries, and is applicable to every function with an organization.

Visual Controls – These are simple signals that provide an immediate and readily apparent understanding of a condition or situation. Visual controls enable someone to walk into the workplace and know within a short period of time (usually thirty seconds) what's happening with regards to production schedule, backlog, workflow, inventory levels, resource utilization, and quality.

Concurrent Engineering – This is a technique of using cross-functional teams (rather than sequential departmental assignments) to develop and bring new products to market faster. In many instances, implementing concurrent engineering has reduced time-to-market by 50%. Time-to-market is one of the most important tools for capturing and maintaining market share.

4.4 Agile Manufacturing

Agility is the ability to thrive and prosper in an environment of constant and unpredictable change. Agility is not only to accommodate change but to relish the opportunities inherent within a turbulent environment. Agility has been expressed as having four underlying principles (Goldman et al, 1995):

- Delivering value to the customer
- Master change
- Mobilise resources
- Forming virtual partnerships

Of these, the first three can be found within the operating philosophies Lean Manufacturing. The fourth principle is different. In fact, Agile and Lean take quite different attitudes toward partnerships, and supply chain management. Companies like Toyota stress how long it takes to develop effective partnerships for procurement of complex automotive assemblies. In the world of agility, where such partnerships are predicted to be of dramatically shorter duration, extra attention is paid to the launching and maintaining supplier relations.

Customer-supplier partnerships dominate the landscape of organizational forms for product realization of complex manufactured items. Companies seek partners because the product's complexity generally precludes any one company having all the marketing, design, or manufacturing skills to make them (Goldman et al, 1995). In some cases the company will need to seek out specific partners with special skills or attributes and create a virtual corporation from several parties to focus on meeting the needs of a customer or a market. These virtual corporations are opportunistic alliances of core competencies across several firms to provide focused services and products to meet the customers highly focused needs. With the advent of the information revolution, these various companies can readily communicate and cooperate across long distances and provide products and services that are widely scattered geographically and politically. The beginnings of the information age has made possible the ability to create widely diverse virtual corporations that can quickly and effectively address the needs of the customers and the marketplace.

The following table (Table 4.1) presents the mission and top level strategies that make an organisation agile.

Table 4.1 mission and top level strategies that make an organisation agile

Agile Principles	**Deliver value to the customer**	**Master change**	**Mobilise resources**	**Forming virtual partnership**
Agile Mission	Provide solutions that customers value	Be ready to respond to any change in the business environment	Make every asset add value to the bottom line	Make partnering a strategy of choice
Top-level Agile Strategies	• Customized, niche solutions, not mass-market products • Customer collaboration	• Change proficiency • Reconfigurable operations and infrastructure • Information transparency • Flexible operations Rapid response	• Entrepreneurial environment • Empowered people • Virtual teamwork • Knowledge management	Proficiency in partnering Virtual organisations

4.5 Value Management

Value Management is a style of management particularly dedicated to motivating people, developing skills and promoting synergies and innovation, with the aim of maximizing the overall performance of an organization. It is a strategic approach to achieving maximum value in a project consistent with the organisation's broad business goals (BRE, 1998). The structured team approach of value management to problem solving can be applied to the objective setting, concept, design and construction stages and the ongoing management of buildings. A value management exercise aims to attain optimum value by providing the necessary functions at the least cost without prejudice to the specified quality and performance. The focus of value management is on function and optimum value for money.

Value Management has evolved out of previous methods based on the concept of Value and Functional Analysis. Initially Value Analysis (VA) was used principally to identify and eliminate unnecessary costs and thus to improve value in existing products However it is equally effective in increasing performance and addressing resources other than cost. As it evolved the application of VA widened beyond products into services, projects and administrative procedures. The Value Management Approach involves three root principles:

- a continuous awareness of value for the organization, establishing measures or estimates of value, monitoring and controlling them;
- a focus on the objectives and targets before seeking solutions;
- a focus on function, providing the key to maximize innovative and practical outcomes.

The concept of Value relies on the relationship between the satisfaction of many differing needs and the resources used in doing so. The fewer the resources used or the greater the satisfaction of needs, the greater the value. Stakeholders, internal and external customers may all hold differing views of what represents value. The aim of Value Management is to reconcile these differences and enable an organization to achieve the greatest progress towards its stated goals with the use of minimum resources.

The most visible benefits arising out of the application of VM include:

- improved products and services to external customers by clearly understanding, and giving due priority to their real needs;
- enhanced competitiveness by facilitating technical and organizational innovation;
- a common value culture, thus enhancing every member's understanding of the organization's goals;
- improved internal communication and common knowledge of the main success factors for the organization;
- simultaneously enhanced communication and efficiency by developing multidisciplinary and multitask teamwork;

4.6 Discussion

Whilst it will be possible to identify useful ideas from manufacturing, it will require a change of attitude of mind towards system thinking based upon a better understanding of the integration of clients' wants and needs, resulting in an uncompromising focus on quality and production (Powell, 1995).

Although the perception of a lack of applicability of manufacturing techniques could be an implementation hindrance, recent publications give some indication of the relevance of manufacturing techniques in construction. From the review above it can be seen that Lean embraces many of the innovations in manufacturing (particularly TQM and JIT). The nature of Lean and JIT makes them suitable for the actual construction stage of a project, whilst agile principles will enhance greater cooperation between project participants. However as illustrated by the previous chapters, the greatest savings could be made during the front-end activities such as client requirements processing.

It is arguable that the quality of design can greatly influence the quality of the construction project. Since the quality of the output of any given process depends, to a large extent, on the inputs, it is of utmost importance that the inputs are as accurate as possible. For a construction project, the inputs are the client's requirements. If the client's requirements are not properly analysed and understood, the project team could apply the best of techniques, but the end result will be a product that does not conform to the actual specifications of the client.

From the above review it can be seen that the Lean and JIT, Agile and Value management techniques do not have an integrated mechanism for eliciting clients' requirements. There is, therefore, the need for a methodology which provides a framework for the identification, structuring, analysis, and translation of clients' requirements into plans and specifications. Such a methodology should be holistic enough to draw on all the conceivable sources likely to affect the final product, and be able to nurture a strong integrating mechanism and allegiance to the project objective (Pheng and Ke-Wei, 1996). Such a methodology is QFD, which is part of the TQM philosophy.

Although there are differences between the two industries (which have been discussed in Chapter Two) that can affect the successful implementation of QFD in construction, if these differences are taken into consideration, the benefits of QFD can be realised in construction. Having said that, certain characteristics of the construction industry actually favour the implementation of QFD. For example, the active participation of the client in the construction process and the current move to more integrated forms of procurement such as Design and Build provides a good groundwork for successful implementation of QFD. In addition, the current move of some of the construction industry into entering strategic partnerships will encourage teamwork which is critical for a QFD project. The problem of the huge volumes of information required during the QFD implementation can be reduced by using a software incorporating the House of Quality.

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CHAPTER FIVE

QUESTIONNAIR SURVEY AND ANALYSIS

5.1 Introduction

This chapter provides a description of the primary data collection for the research. This includes the survey technique, questionnaire design, methods of Analysis and results. The chapter begins with the justification for the choice of the postal questionnaire technique, its unique advantages, and relevance to the research. The questionnaire content is also discussed by stating the reasons for each section of the questionnaire, and the value and significance of the data expected from them. The survey seeks to determine the impact of manufacturing techniques on the performance of the construction industry. The results and analysis of the questionnaire are presented and a comparative analysis of both the construction and manufacturing industries was made.

5.2 The Questionnaire Survey Technique

Questionnaire by mail has certain advantages that make it attractive and a good choice in certain situations. These advantages were seen as relevant to the nature and circumstances of the investigation. In order to get a statistically representative sample, a large amount of data must be gathered across a range of firms. Such firms are often located in different geographical regions. Survey interviews of a large number of companies as would be required would be expensive in cost, time and effort. However, a questionnaire by mail is comparatively less expensive and can cover widely spread geographical areas within a short period of time.

Questionnaires are also easy to analyse. The data entry and tabulation for nearly all questionnaire surveys can be done easily with statistical software packages such as the Statistical Package for Social Scientist (SPSS). Unlike interviews, questionnaires are relatively standardised, as their presentation and appearance do not vary from one case to another. It therefore enhances the validity for broad-based generalisation. The absence of an interviewer also ensures anonymity. The supply of personal details like names and addresses of respondents were indicated as optional on the questionnaire to enhance this degree of anonymity. Anonymity does not only tend to increase the response rate, but genuine responses are more likely to be given when respondents are shielded from the possibility of future reference. Questionnaires also tend to be less intrusive than face to face or telephone interviews. When a respondent receives a questionnaire, he is free to complete it at his own pace.

Mail questionnaires are not without weaknesses. In mail questionnaires, all the questions are presented to the respondents at the same time and the investigator has no control over the order in which the questions are answered as in an interview situation. In addition, the interview affords greater flexibility, terms can be clarified, and more details can be obtained. In mail questionnaires only simple questions can be asked. The degree of detailed investigation carried out in case studies is unattainable in a mail questionnaire, and because of this, case studies are often resorted to in explanatory research to provide answers to "Why" and "How" questions. The mail questionnaire has limited applicability in answering these questions but is completely suitable for answering "What" questions (Yin, 1988).

Another major disadvantage is that the response rate of mail questionnaires is generally lower than that of other survey methods such as interviews (Nachmias and Nachmias, 1992). There is also no control over who completes the questionnaire. Since the researcher has no control over the environment of the respondent, he cannot be sure that the appropriate person completed the questionnaire.

5.3 Questionnaire Design

In designing the questionnaire, attention was paid to the types, format, sequence, and clarity of the questions. The questionnaire is divided into three sections namely company background, the use of manufacturing techniques, and the use of QFD in particular. The company background includes information on the name and address of the company, the age of the firm, estimates of the number of employees and annual turnover of the firm.

The second section of the questionnaire was used to determine the extent of use of manufacturing techniques in both the construction and manufacturing industries. In this section, questions were asked to elicit responses on the manufacturing techniques being employed by the firms. Below is a description of the questions. The third part of the questionnaire was focused on companies implementing QFD. A sample of the questionnaire is shown in Appendix 1.

5.4 Limitations of the Survey

The researcher is critical of several issues that may affect the quality of the data gathered through the postal questionnaire survey. Some of these issues are inherent in the postal questionnaire technique and has been discussed in section 5.2. Another issue is that the questionnaires were mailed to companies whose addresses were available on the yellow pages, and thus no proper sampling was done. The reason for using addresses from the yellow pages website was to achieve a national representative cross-section of the sample that could provide a construction industry-wide perspective of the issues being investigated.

5.5 Survey Results

Table 5.1 shows a summary of the responses from 29 construction and 24 manufacturing industries.

Table 5.1 – Summary of Results

	Construction	**Manufacturing**
Number of Employees		
Less than 50	17	6
51 - 250	8	7
251 - 500	2	0
501 - 1000	1	7
Over 2000	1	4
Annual Turn Over		
Less than £5m	17	9
£5m - £10m	3	0
£11m - £20m	2	3
£21m - £50m	3	1
£51m - £100m	1	5
Over £100m	3	6
Use of Manufacturing tools		
CIM	4	3
QFD	2	2
LEAN	0	7
TQM	14	8
JIT	2	4
OTHER	7	0
Reasons for Not using QFD		
Never heard of it	22	1
Not profitable	1	0
Too costly to implement	2	0
No resources to implement	3	0

5.6 Method of Analysis

The Personal Computer version of the Statistical Package for Social Scientist (SPSS) was used to analyse the responses received. In order to use the SPSS package effectively, the data type held by each question must be determined. There are four possible data types discussed in the literature (Nachmias and Nachmias, 1992), namely nominal, ordinal, ratio and interval data, and each of these determine the type of statistical operations that can be performed. A set of data is said to be nominal if the values/observations belonging to it can be assigned a code in the form of a number where the numbers are simply labels. Because of the nature of nominal data, only frequencies may be computed on it. Ordinal data are ranked with or without equally spaced intervals. When the space between the intervals is approximately the same, it is sound to calculate averages. An interval scale is a scale of measurement where the distance between any two adjacent units of measurement (or 'intervals') is the same but the zero point is arbitrary. Scores on an interval scale can be added and subtracted but cannot be meaningfully multiplied or divided. The difference between an interval and a ratio data is that the latter has a true zero value. In the questionnaire, nominal, ordinal and interval data have been used where appropriate. For example, nominal data can be derived from questions 7, 13 and 14, whilst data from questions 8, 11 and 15 are ordinal. The next section is a presentation of the descriptive statistical analysis of the results.

5.7 Descriptive Analysis

The presentation of the descriptive analysis begins with the demographic characteristics of the respondents. These characteristics include the distribution of the number of employees, and the annual turnover of the companies. Figures 5.1 and 5.2 show the distribution of the number of employees for the construction and manufacturing companies respectively. The results show that about 58.6% of the responding firms have less than 50 employees as compared with 25% for the manufacturing industry. This confirms available publications that the construction industry is dominated by small-scale industries. The manufacturing industry is however fairly split between companies with less than 250 employees, i.e. small-medium scale enterprises (SMEs) and over 500 employees i.e. large companies.

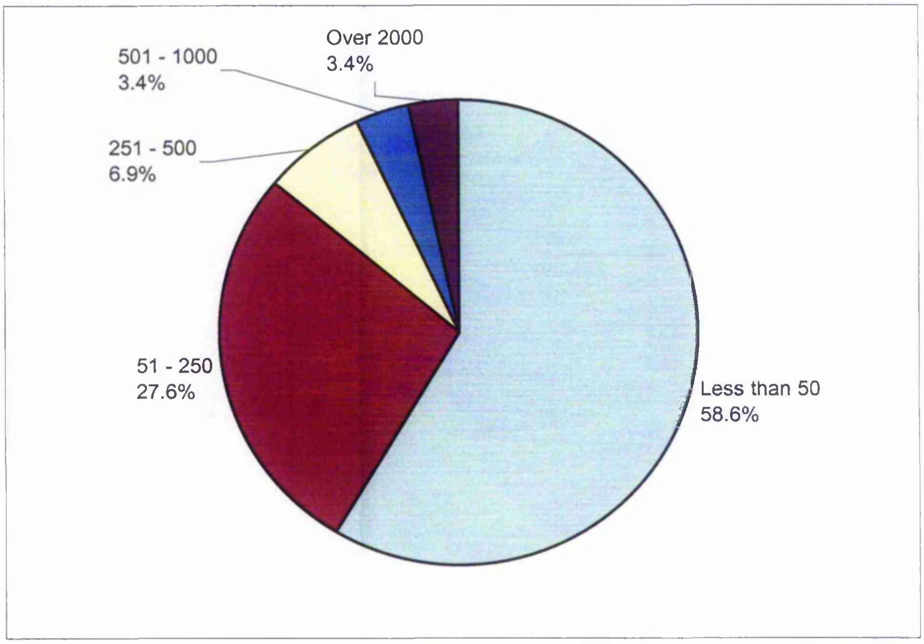

Figure 5.1 – Distribution of Number of employees (Construction Industry)

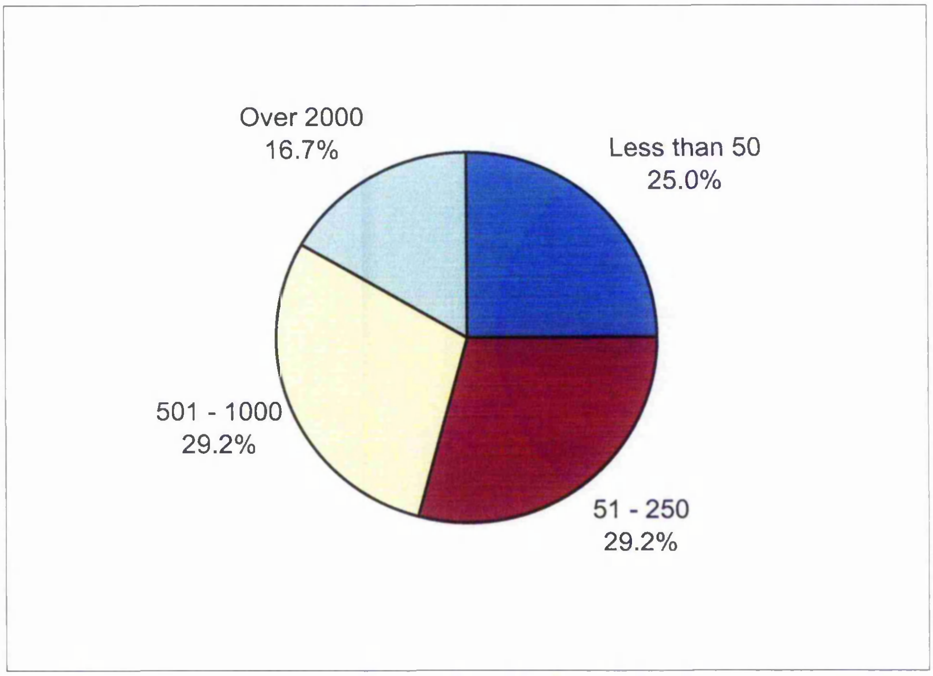

Figure 5.2 – Distribution of Number of employees (Manufacturing Industry)

The annual turnover for both the construction and manufacturing companies are shown in Figures 5.3 and 5.4 respectively. The results show that about 58.6% of the construction companies have an annual turnover of less than £5m with the rest fairly split between companies with annual turnover more than £10m – over 100m. The distribution for the manufacturing industry however shows a less skewed distribution, with the highest percentage being 37.5% for companies with less than £5m.

Figures 5.5 and 5.6 show the distribution of manufacturing techniques employed by the responding firms. The figures show that TQM is the most popular technique employed by both industries. This may be due to the fact that TQM has been more popularised than the other techniques. In addition most of the major quality and performance models (e.g. The European Foundation for Quality Management model) are based on the TQM philosophy.

The questionnaire also sought to determine the extent to which QFD is known. As shown in Figure 5.7, 78.6% of the respondents from the construction industry were not aware of the technique. With regards to the manufacturing companies only 4.5% stated that they have not heard of the QFD technique as illustrated in Figure 5.8.

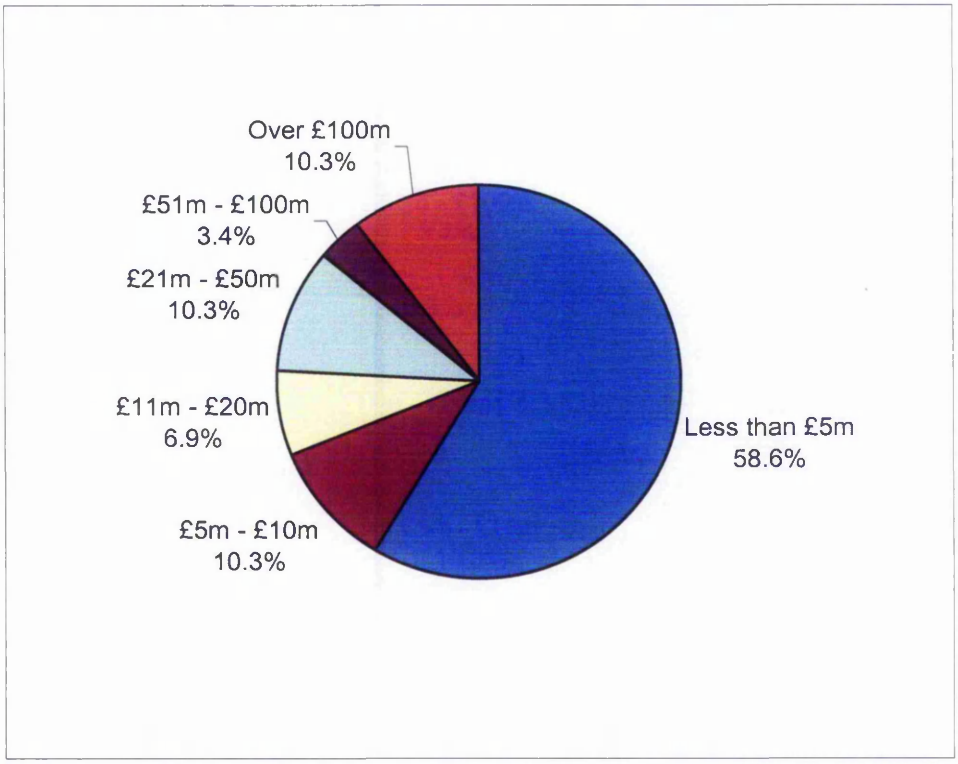

Figure 5.3 – Distribution of Annual Turnover (Construction Industry)

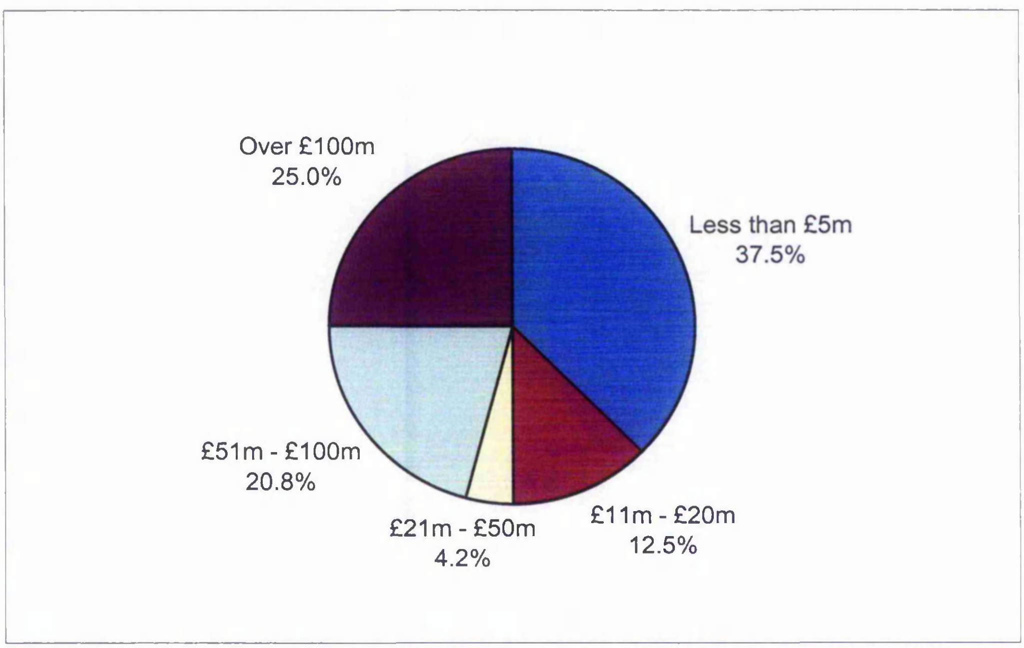

Figure 5.4 – Distribution of Annual Turnover (Manufacturing Industry)

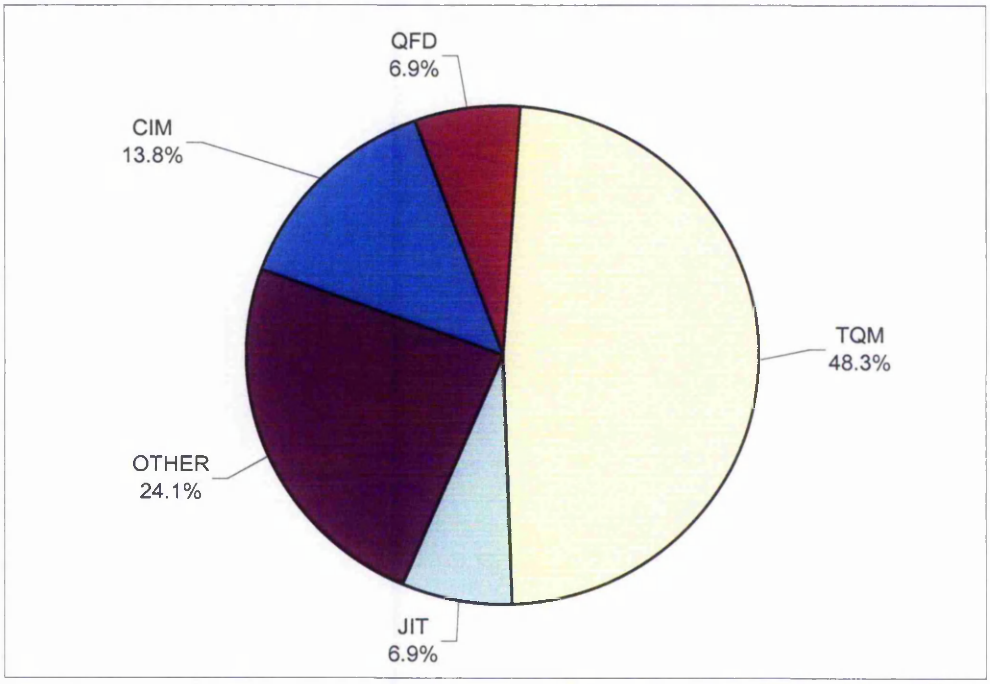

Figure 5.5 – Use of Manufacturing Techniques (Construction Industry)

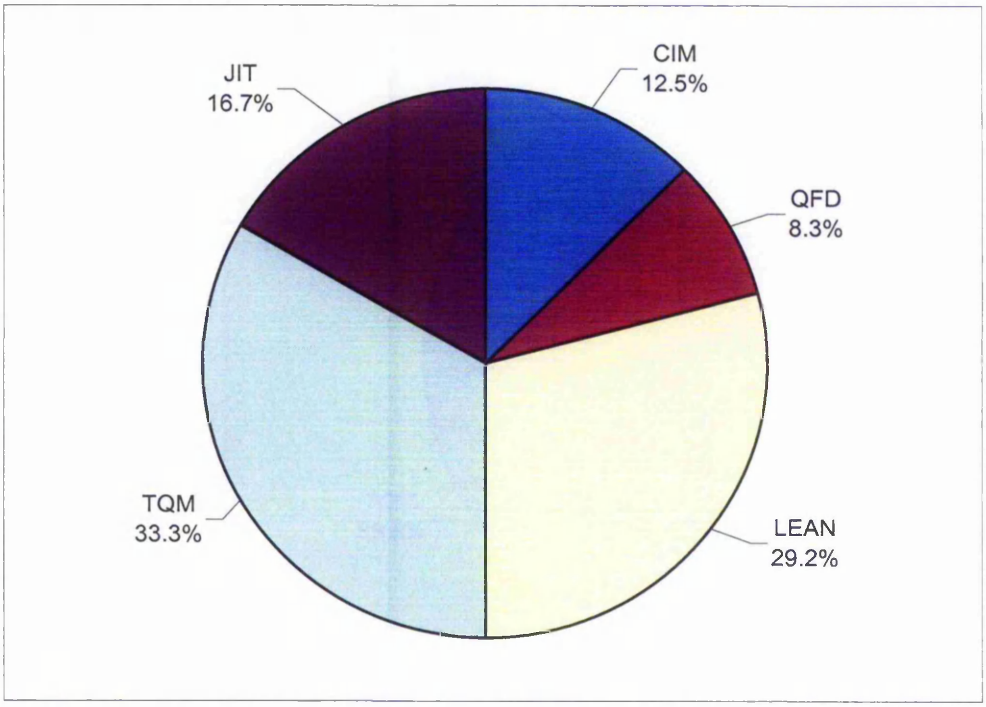

Figure 5.6 – Use of Manufacturing Techniques (Manufacturing Industry)

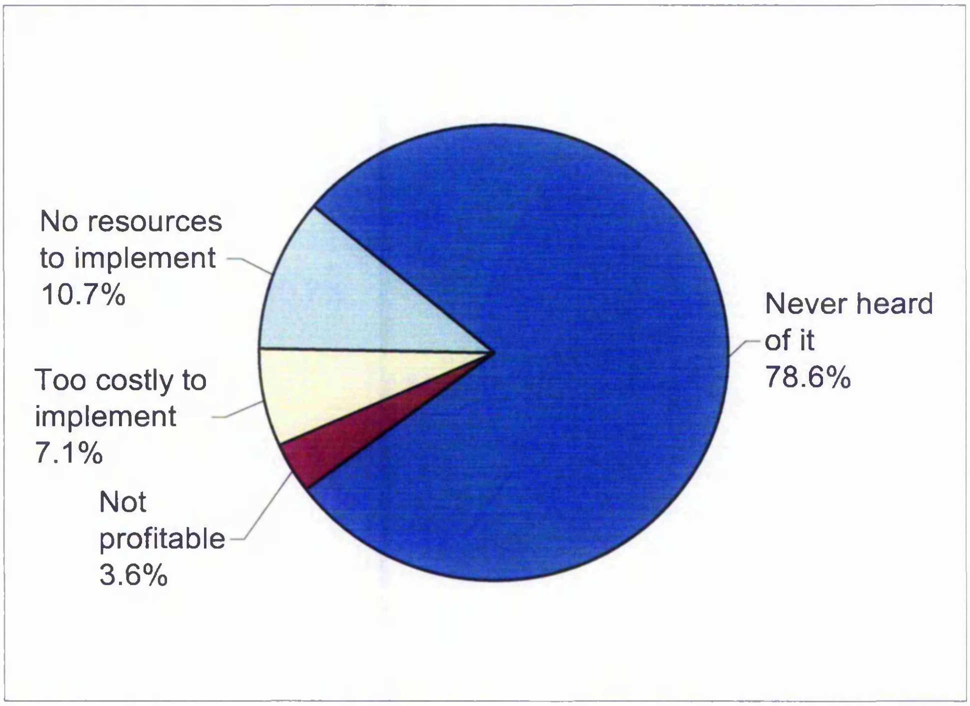

Figure 5.7 – Reasons for not using QFD (Construction Industry)

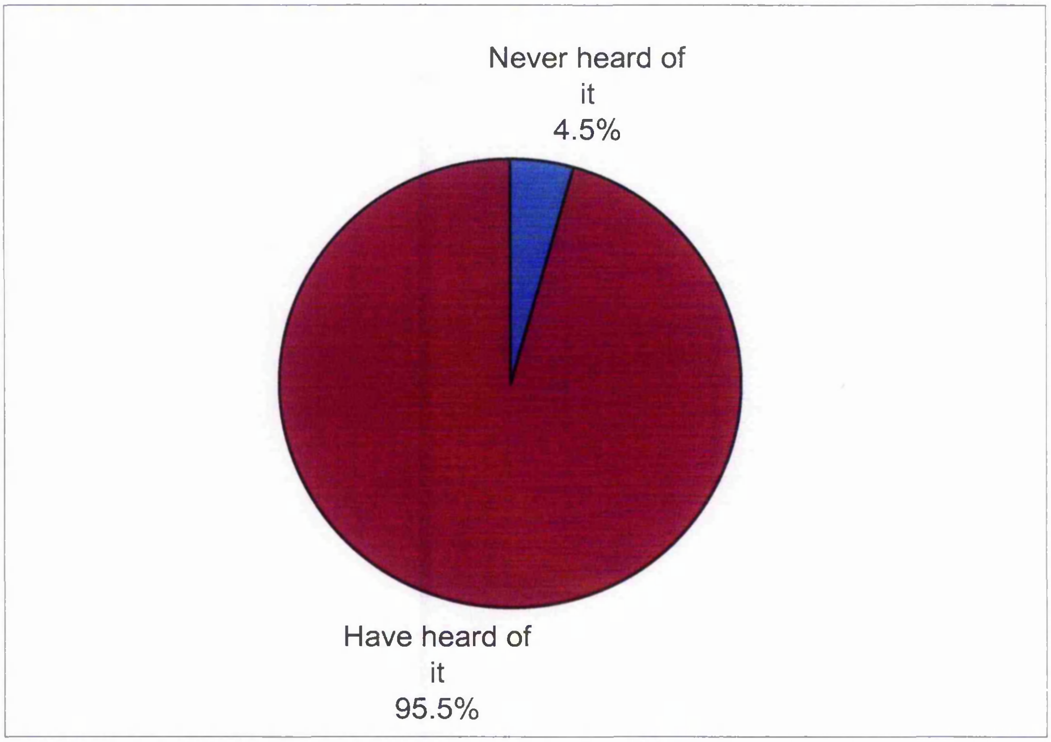

Figure 5.8 – Reasons for not using QFD (Manufacturing Industry)

In order to determine the impact of the manufacturing techniques on the performance of the firms, the respondents were asked to choose from a scale of 1 – 5 (where 1 implies no benefit and 5 implies a significantly high benefit). The mean values for the benefits are shown in Table 5.2. A mean value above 2.5 was taken to indicate that the techniques had a positive impact on the given variable. The values from Table 2 suggest that the implementation of the manufacturing techniques had a positive impact on almost all the variables. The exceptions were the variables relating to time. The next section of this chapter is the inferential analysis of the results.

Table 5.2: Mean values of Derived Benefits (Construction Industry)

Variable	Mean
Products meets customer requirement	3.70
Product right the first time	3.96
Customer focused	3.54
Competitive advantage	3.22
Reduction in mid-course changes	2.75
Reduction in new product introduction lead time	2.20
Reduction in new product development time	2.25
Reduction in cost	3.68
Reduction in waste and rework	3.56
Product quality improvements	3.68
Improved methods of working	3.61
Improved profitability	3.77
Better understanding of customer/client preferences	3.23
Better communications between stakeholders	2.68
Better understanding and control over business processes	3.23
Better co-ordination of activities	3.43

5.8 Inferential Analysis

In order to perform parametric tests on the data obtained, its validity and the normality must be established. The next subsection describes how the validity and normality of the data was established.

5.8.1. Validity and Reliability

The validity and reliability of an instrument used to measure a particular phenomenon is important because it serves as an initial indicator as to whether one is actually measuring what is intended to be measured. They also determine the quality of the research being undertaken. According to Cresswell (1994), the calculated statistical reliability of a questionnaire demonstrates the validity of the constructs. In this research therefore the reliability obtained from the SPSS Reliability procedure was used as a basis for assumption of the validity of the constructs. The results in Table 3 shows that the alpha values for the Reasons construct and the Entire questionnaire were low. The low value for the entire questionnaire can be attributed to the fact that the constructs are not unidimensional.

Table 5.3: Reliability test results

Focus of Test	Cronbach's alpha	Number of items
Reasons construct	.4898	7
Benefits construct	.7573	16
Barriers to implementation of tools	.8333	6
Entire Questionnaire	.5122	34

In order to check the dimensionality of the "Reasons and Benefits constructs", Factor Analysis was conducted. The factor analysis done on the Reasons Construct resulted in the extraction of three components (table 5.4), indicating the multidimensionality of the construct. The SPSS reliability procedure was then conducted on the three components. The result of the test is shown in table 5.5.

Table 5.4: Results of Factor Analysis for the Reasons Construct

Variables	Component		
	1	2	3
To be more customer focused	-6.925E-02	-2.325E-02	.901
Reduction in cost	.752	-5.855E-02	3.096E-02
Gain competitive advantage	.772	.435	-.144
To increase profitability	.874	-1.211E-03	-8.254E-02
Improved product specification	.335	.438	.527
Better co-ordination of activities	-.356	.827	-8.917E-02
Improved performance	-.170	.854	-8.390E-02

Table 5.5: Reliability Analysis (Reasons Construct) after extraction of components

Focus of Test	Cronbach's alpha	Number of items
First component	.7576	3
Second Component	.7866	2
Third Component	.2869	2

It can be seen that except for the third component, the reliabilities of the first two components are well above 0.7. The results of the factor analysis conducted for the benefits construct is shown in table 5.6. The analysis resulted in the extraction of four components. The reliability tests for the components (Table 5.7) were all above 0.7 and higher than their combined reliability.

Table 5.6: Results of the Factor Analysis for the "Benefits Construct"

Variables	Component			
	1	2	3	4
Products meets customer requirements	.242	-3.681E-03	.832	2.289E-02
Product right the first time	.662	9.306E-02	7.795E-02	-.416
Customer focused	.682	-.186	.173	-8.793E-02
Competitive advantage	.684	-.328	-.301	-5.282E-02
Reduction in mid-course changes	.161	.411	-.211	.581
Reduction in new product introduction lead time	.517	.295	-.429	.486
Reduction in new product development time	.478	.475	.118	.334
Reduction in cost	.518	-.513	-.486	-9.815E-02
Reduction in waste and rework	.580	-.183	-.209	.326
Product quality improvements	.443	-3.665E-03	.763	.177
Improved methods of working	.608	.202	.239	6.516E-02
Improved profitability	.583	-.633	-.247	-.217
Better understanding of customer/client preferences	.407	.187	.451	-.177
Better communications between stakeholders	-8.531E-02	.680	-.255	-.181
Better understanding and tighter control over business processes	.254	.669	-.194	-.560
Better co-ordination of activities	.364	.758	-.243	-.191

Table 5.7: Reliability Analysis (Benefits construct) after extraction of components

Focus of Test	Cronbach's alpha	Number of items
First component	.8000	9
Second Component	.8353	3
Third Component	.7028	3

The hypothesis that the data was obtained from a normal distribution was tested by obtaining the normal probability plot. This plot is obtained by plotting the observed values against the expected values. The expected values are the estimated values of a normal distribution. These values are based on the number of cases and the rank order of the cases in the sample. The normal probability plot obtained for a normal distribution more or less falls on a straight line passing through the origin. It can be seen from Figure 5.9 that the points form a straight line.

Although normal probability plots provide a visual basis for checking normality, it is often desirable to compute a statistical test of the hypothesis that the data comes from a normal distribution (Norusis, 1993). Two commonly used tests are the Kolmogorv-Smirnov (with Lilliefors correction) and Shapiro-Wilk tests. Table 5.7 shows the test results obtained for the variable "Reduction in Cost". The Lilliefors significant value is greater than .200 if the data is from a normal distribution. The Shapiro-Wilks significant value in Table 5.8 is within the region of acceptance (> = 0.01) that the data comes from a normal distribution.

Not all the tests showed significance values greater than 0.2 and 0.01 for both the Lilliefors and Shapiro-Wilks respectively. However the assumption of normality is not violated. According to Norusis (1993), any goodness-of-fit test is likely to result in the rejection of the null hypothesis if the size of the data is large. Thus, for a large data set the magnitude of departure from normality should also be looked at. The magnitude of departure from normality is observed from the normal probability plot. If the data come from a normal distribution, they will lie close to a straight line. It can be seen from Figure 5.9 that the data is derived from a fairly normal sample.

Table 5.8 – Test of Normality for Better understanding of customer/client preferences

Variable	Kolmogorov-Smirnov (With Lilliefors Correction)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Reduction in Costs	.178	37	.005	.850	37	.010

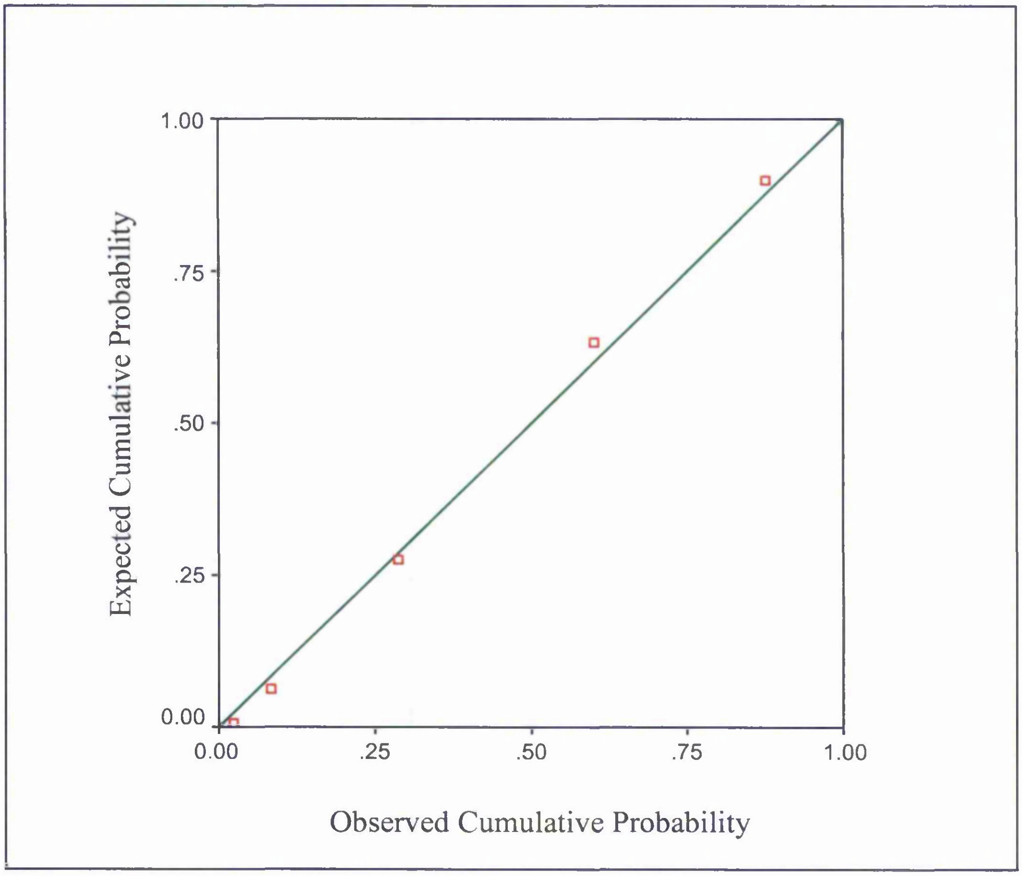

Figure 5.9 – Normal Probability Plot for Reduction in Costs

It can be seen from the above discussion that the validity of the questionnaire instrument and the reliability of the constructs have been verified. It has also been observed that the data is free from error. Finally it has been demonstrated that the normality assumptions are not violated. The data can therefore be analysed using parametric statistical techniques where necessary.

5.8.2. Parametric Statistical Tests

One of the major benefits attributed to the implementation of Innovative Manufacturing techniques is shorter development time. However, the mean values shown in Table 5.2 do not support this view. This could be explained by the inexperience of the firms in implementing the techniques. The implementation of the manufacturing techniques require a change in the way organisations go about their business, thus development times could actually be lengthened as personnel learn to implement them.

In order to assess the argument of considering construction as a manufacturing process, a further level of statistical analysis was conducted. The assessment was made based on the impact of the manufacturing techniques on the performance of both the construction and manufacturing firms. If construction is to be considered as a manufacturing process, then one expects the impact of the techniques to be similar in the two industries. One the other hand, if the techniques are not applicable, then their impact on the performance of the construction firms should be significantly lower than that of the manufacturing companies.

The MEANS procedure in SPSS was used to compare the mean values of the benefits derived obtained as a result of the implementation of the techniques. The output is shown in Table 5.9. An examination of the result shows that the mean values of the benefits obtained are higher for the construction firms. A t-test was then conducted to determine the significance of the differences between the mean values. This gives an indication of the applicability of the techniques to the construction industry. The hypothesis for the test is stated as follows:

$$H_0 : \mu_c = \mu_m \text{ ----------- } (1)$$

$$H_1 : \mu_c \neq \mu_m \text{ ----------- } (2)$$

Where H_0, H_1, μ_c, and μ_m are the null hypothesis, alternate hypothesis, mean value of construction and mean for manufacturing respectively.

Table 5.9 – Comparison of the mean values of the Benefits obtained

Variable	Mean Value	
	Construction Industry (μ_c)	**Manufacturing Industry(μ_m)**
Products meets customer requirements	3.70	3.48
Product right the first time	3.96	3.38
Customer focused	3.54	2.61
Competitive advantage	3.22	2.96
Reduction in mid-course changes	2.75	2.17
Reduction in new product introduction lead time	2.20	2.63
Reduction in new product development time	2.25	2.36
Reduction in cost	3.68	3.58
Reduction in waste and rework	3.56	3.88
Product quality improvements	3.68	3.17
Improved methods of working	3.61	3.00
Improved profitability	3.77	3.46
Better understanding of customer/client preferences	3.23	2.50
Better communications between stakeholders	2.68	2.05
Better understanding and tighter control over business processes	3.23	2.68
Better co-ordination of activities	3.43	2.83

The results from the t-test (Table 5.10) show that the differences in the mean values obtained are not statistically significant. Thus according to the results, despite the perceived differences in the two industries the manufacturing techniques had quite the same impact on both of them. Although the variables used are by no means exhaustive, the results obtained support the view that manufacturing techniques are quite applicable in the construction industry.

Table 5.10: t-test statistics for the benefits realised.

Variable	t-test for Equality of Mean Values			
	t	df	Sig. (2-tailed)	Mean Diff
Products meets customer requirements	.531	46.593	.598	.23
Product right the first time	1.527	44.525	.134	.58
Customer focused	2.749	46.679	.008	.93
Competitive advantage	.725	42.184	.472	.26
Reduction in mid-course changes	1.664	44.330	.103	.58
Reduction in new product introduction lead time	-1.047	41.645	.301	-.42
Reduction in new product development time	-.275	39.649	.785	-.11
Reduction in cost	.309	39.787	.759	9.67E-02
Reduction in waste and rework	-.966	46.934	.339	-.32
Product quality improvements	1.382	43.049	.174	.51
Improved methods of working	1.709	47.519	.094	.61
Improved profitability	.861	43.559	.394	.31
Better understanding of customer/client preferences	1.746	47.347	.087	.73
Better communications between stakeholders	1.673	40.720	.102	.63
Better understanding and tighter control over business processes	1.569	41.767	.124	.55
Better co-ordination of activities	1.613	40.938	.115	.60

5.9 Discussion

Firms invest in quality improvement techniques with the hope to realise the benefits that can result from their implementation. Some of the most important benefits are customer satisfaction, reduction in product introduction time, and reduction in costs. Over the years the use of these quality improvement techniques have almost exclusively been restricted to the manufacturing industry. Other industries like the service and software have taken advantage of the experiences of the manufacturing industry and implemented these techniques. These techniques have had limited implementation in the construction industry due to the misconception that they are not applicable to the construction industry. However, the results of the questionnaire survey indicate that the techniques are relevant in the construction industry (Tables 5.9 and 5.10). Generally, most of the mean values for the derived benefits are above 3.50. This shows that the implementation of the techniques brought a level of improvements in the performance of the companies. In addition the t-test conducted to test the differences between both industries seem to support the view that construction could be considered as a manufacturing process. This gives an indication of the relevance of the implementation of manufacturing techniques into the construction industry.

The areas with the lowest mean values for benefits derived relate to communication, and new product introduction and development time. These two areas can contribute to most problems associated with product improvement or development. This is an area where QFD implementation could prove beneficial to the companies, as QFD facilitates communication and improves product development time. Proponents of QFD argue that QFD is able to help companies develop products which satisfies the customer. The results show that the variable *"Product satisfies customer requirements"* was one of the highest benefits derived, although QFD was one of the least used techniques. This may give an indication that the techniques or techniques employed may be adequate for accurately specifying customer requirements. However, it is arguable that customer specifications could be satisfied (even zero tolerance) after a lot of rework and waste.

Although QFD seems to be popular in the USA and Japan, the uptake in the UK is very low with only a few scattered cases of companies experimenting with the method. This may be due to the fact that the data captured and the decisions made using QFD usually relate to future product plans and are therefore sensitive and proprietary, hence companies are usually reluctant to admit the usage of QFD. However, it was gathered from the questionnaire responses that QFD did have a significant impact on their performance. Although this result cannot be generalised, evidence from related techniques like TQM indicates that the assumption that QFD can improve construction cannot be rejected.

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CHAPTER SIX

QUALITY FUNCTION DEPLOYMENT

6.1 Introduction

Quality Function Deployment (QFD) is a methodology for translating customer-required quality characteristics into appropriate product or service features (Ranky, 1994). The underlying philosophy of QFD is a focus on satisfying the customer (Akao, 1988; Ghobadian and Terry, 1995). Through the use of an integrated set of tools, QFD ensures that the customers' requirements translate into accurate technical requirements and actions throughout each stage of product development. In addition the QFD process facilitates multidisciplinary teamwork, and ensures that priority is given to the aspects of the design with the most potential for improving customer satisfaction and competitive advantage. Because QFD allows developers to evaluate all design decisions at the beginning of a proposed project, mid-course changes are minimized and hence reducing waste and time to market. The technique has attracted a lot of attention since its inception in Japan at Mitsubishi's Kobe shipyard in 1972, as evidenced in the volume of related articles in publication (Ghobadian and Terry, 1995; Nicols and Flanagan, 1994; Prasad, 1998).

There are several definitions for QFD (Cohen, 1995; Shillito, 1994). Akao (1990), defined quality function deployment as:

> *"Converting the customers' demands (whats) into quality characteristics (hows) and developing a designing quality for the finished product by systematically deploying the relationships between the demands and the characteristic, starting with the quality of each functional component and extending the deployment to the quality of each part and process".*

The concept of QFD was conceived by the Japanese in the late 1960s (Akao, 1990). This was during an era when Japanese industries broke from their post-World War II mode of product development through imitation and copying and moved to product development based on originality. The purpose was to develop a quality assurance method that would design customer satisfaction into a product before it was manufactured. The first large scale application was presented by Kiyotaka Oshiumi of Bridgestone Tire, which used a fishbone diagram to identify each customer requirement (effect) and to identify the design substitute quality characteristics and process factors (causes) needed to control and measure it.

The technique generated very little interest until 1972 when the Kobe Shipyards, guided by both Shigeru Mizuno and Yasushi Furukawa (Akao, 1997), developed a table for the design of their super-tankers that "systematised" the true quality (customers' needs) in terms of functions, then showed the relationship between these functions and the quality characteristics. Akao called the new approach Quality Deployment (QD). At about the same time, Value Engineering principles were linked to what later became known as "narrowly defined QFD". Mizuno (1978) described narrowly defined QFD as " step-by-step deployment of a job function or operation that embodies quality, into their details through systematization of targets and means". The combination of QD and narrowly defined QFD gave rise to broadly defined QFD.

The introduction of QFD in the USA and Europe began with the publication of an article by Akao (1983). Subsequent efforts by Larry Sullivan of the American Supplier Institute and Bob King of GOAL/QPC have led to the establishment of on-going QFD seminar programs throughout the United States ever since. The use of QFD in the US spans a broad range of industries, with particular extensive use in the automobile industry. In the USA the first serious exponents of QFD were the 'big three' automotive manufacturers in the 1980's, and a few leading companies in other sectors such as electronics. However, the uptake of QFD in the Western world appears to have been fairly slow. There is also some reluctance among users of QFD to publish and share information - much more so than with other quality-related methodologies.

6.2 Fundamentals of QFD

According to Sivaloganathan (1997), the QFD technique is built around the following four principles:

1. It defines quality as meeting the requirements of the customer.
2. It uses the principle of Deployment.
3. It attaches numeric values to the otherwise qualitative customer requirement importance,
4. It uses matrices (quality charts).

QFD defines quality as meeting the requirements of the customers. Hence the development team start the product design by first establishing the customers' requirements. These requirements are then deployed throughout all functions and activities of the company. According to the principle of deployment, product quality can be assured through the quality of the subsystems, the quality of the subsystems can be assured through the quality of the parts and the quality of the parts can be assured through the quality of the process elements (Akao, 1990). Very notable in the QFD implementation is the generation of Quality Charts or Matrices. The matrices trace a continuous flow of information from customer requirements to plant operating instructions and thus provide a common purpose of priorities (Sullivan, 1986). In addition they serve to focus the decision-making interactions of the multifunctional team and also provide a visual display of the relevant information for ready reference (Clausing, 1994). The basic matrix of QFD is known as the House of Quality (HoQ).

The House of Quality (Hauser and Clausing, 1988) matrix is so named because of its shape, and is common to both approaches. It consists of seven "rooms" or blocks of information, with each representing a different facet of the development process. These are:

1. Customers' requirements or "whats
2. Importance rating of the Customers' requirements
3. Design elements or "hows"
4. Relationship matrix
5. Planning Matrix

6. Feature to Feature Correlation
7. Technical Matrix

Below is a description of the rooms.

1. ***Customers' requirements or "whats"***– this block contains the description of the product characteristics from the customers' perspective. This is known as the voice of the customer (VOC) and is the principal input of the design process. It is thus necessary to identify the groups of customers that are to be addressed, with the purpose of satisfying their needs (Franceschini et al, 1998). This is the phase where in-depth market research is called for and techniques like the use of questionnaires and interviews are employed. Through the use of the affinity and tree diagrams the customers' requirements are classified under a hierarchical structure which usually consists of three levels, namely, primary, secondary and tertiary.

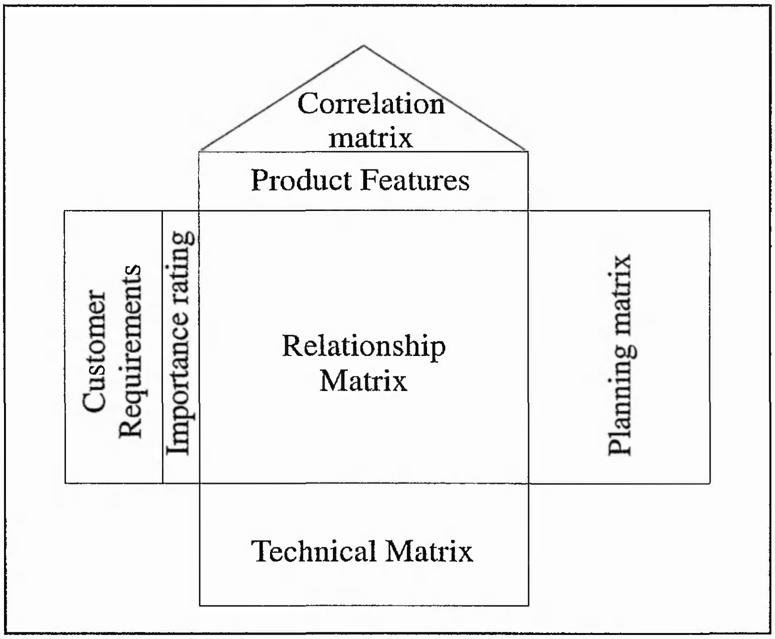

Figure 6.1 – The House Of Quality

The primary requirements are the needs which set the strategic direction of the product. They are of the highest level of abstraction and by nature are broad and lack precise information. The secondary needs are an elaboration of the primary needs, and specify the actions to be taken by the design team in order to accomplish the specific primary need. The tertiary elaborate on the secondary needs and also provide details for the development of engineering solutions for accomplishing the secondary needs. The primary needs are sometimes called “Strategic needs”, the secondary needs are called “Tactical needs” and the tertiary needs are called “Operational needs” (Hauser, 1993).

2. ***Importance rating of the Customers' requirements*** – the information contained in this block indicates the importance of each product features to the customer. It is usually one of three types of data and is obtained through a survey. These are:

    Absolute Importance: This is obtained by asking the respondents to rate the importance each need is to them based on a chosen scale.

    Relative Importance: This is measured by asking respondents to arrange needs in terms of importance. The respondents may be asked to assign values to the list to indicate the degree of importance. These values are usually placed on a percentage scale.

    Ordinal Importance: This like the Relative Importance is an indication of the order of importance. The difference is that it does not indicate the degree of importance.

3. ***Design elements or “hows”*** – this block is used to identify all the design features or elements that will satisfy each of the customer requirements. These like the customer requirements can be structured in a hierarchy as primary, secondary, and tertiary design elements or quality functions. These quality functions also known as the voice of the company (VoC) can be viewed as the measurable design elements which provide the demanded quality. The target values for these design requirements are established together

with their direction of improvement. They are then checked for conformity and trade-offs are proposed if necessary.

4. ***Relationship matrix*** – This matrix shows the impact of each product feature on each customer need. In filling this matrix the team evaluates the tendency of each product feature to satisfy each customer need if it is successfully achieved. Numeric values or symbols representing numeric values are used to indicate the strength of the correlation between them. A strong relationship is given a value of "9", a medium or moderate relationship is given a value of "3" or "5", and a weak relationship is given a value of "1". A value of "0" is given if there is no relationship. The usual symbols used are two concentric circles to indicate a strong relationship, a circle to indicate a medium relationship and a triangle indicating a weak relationship. A blank cell indicates that the product feature has no effect on the customer need.

5. ***Planning Matrix*** – This is used by the multifunctional product development team to prioritise customer needs by providing a systematic method for the development team to:
    1. Compare their product or services' performance in meeting customers needs to the competitions performance

    2. Develop a strategy for customer satisfaction that optimises the company or organisation's ability to both sell the product and keep the customer satisfied.

This matrix is made up of columns which contain the following:

The customer satisfaction performance:
This is the customers' perception of how well the current product of the company satisfies or meets customers' needs. This data is usually obtained through a survey. The level of satisfaction is based on a chosen scale and the customer is asked to grade his level of satisfaction according to how well the product has satisfied that need. Weighted averages are then computed using the relation:

$$\text{Weighted Average Perfomance} = \frac{\sum(\text{number of respondents for value } i) \bullet i}{\text{Total number of respondents}}$$

i = level of satisfaction

Competitive Satisfaction Performance:

This like the customer satisfaction performance indicates how well the competitions' product is meeting each customer need.

Goal:

In this column the team decides the level of customer performance they want to achieve in meeting the customers' needs. Generally it will be ideal to set high goals for each customer need but because of limited resources, it is necessary to know which aspect of product to place special emphasis on extra resource.

Improvement Ratio:

This is the ratio of Goal to the current Customer Satisfaction performance.

$$\text{Improvement Ratio} = \frac{\text{Goals}}{\text{Customer Satisfaction performance}}$$

This gives an idea of the effort required to change customers' current satisfaction performance to the set Goal.

Sales Point:

This column contains information about the ability to sell the product based on how well each customer need is met. Common values used are:

1. No Sales Point
1.2 Medium Sales Point
1.5 Strong Sales Point

Raw Weight:

This contains the overall importance of the customer needs and is expressed as

$$\text{Raw Weight} = (\text{Importance to customer}) \bullet (\text{Importance Ratio}) \bullet (\text{Sales Point})$$

Normalised Raw Weight:

This contains the raw weight expressed as a percentage or a fraction between 0 and 1. It is given by:

$$\text{Normalised Raw Weight} = \frac{\text{Raw Weight}_i}{\sum_{i=1}^{n} \text{Raw Weight}_i}$$

$i = 1,2 \ldots n$;

n = Number of engineering solutions.

6. ***Feature to Feature Correlation*** – This shows the impact of one product feature on another.

7. ***Technical Matrix*** – This section contains the Technical Response Priorities, Competitive Technical Benchmarks and Technical Targets.

Technical Response Priorities

This section shows the relative contributions of the product features to overall customer satisfaction. This is obtained by multiplying the value of the impact it has on customer need by the normalised raw weight to obtain what is called the Relationship. All the relationships of the product features are then added together to obtain its contribution to overall customer satisfaction.

Competitive Benchmarking

Here the team compares the performance of their product features to that of the competition.

Technical Targets

This contains the target measures of the product feature.

6.3 QFD Aproaches

There are two basic approaches to QFD (Figures 6.2 and 6.3), developed by Akao and Makabe. These are:

1. The Four-phased approach
2. The matrix of matrices approach

6.3.1. The Four-phased Approach

The four-phased approach, as the name implies, consists of four stages. This approach is based on Makabe's model. . The high level interrelationships between these phases are graphically illustrated in Figure 6.2, along with the major chart (or matrix) of each phase. The four phases are:

a) Product Planning Phase
b) Part Planning
c) Process Planning
d) Production Operations Planning

Below is a description of the phases:

a) Product Planning Phase

As Figure 6.2 illustrates, the Product planning phase drives the QFD technique. The matrix employed in this phase is used to analyse customer needs and critical product information. The stated customer needs, translated into design requirements, are documented in this chart in terms of their relationships, correlations, perceived measures of organisational difficulty, competitive engineering assessments, services repairs and costs, controls, and technical importance (see section 6.2). In addition, this matrix contains information regarding the company's relationship to consumers and its competitive position in the marketplace.

b) Parts Planning Phase

The outputs from the Product Planning Phase serve as inputs to the parts deployment matrix which facilitates the translation of product design characteristics into assemblies and parts, part characteristics, as well as objective target values for part design requirements. These are similarly supplemented with critical part characteristic values and perceived measures of importance. The information documented in this chart feeds into the process planning matrix.

c) Process Planning Phase

This phase details component and material flows, process elements, and critical process parameters. Also associated with this chart are assessments of process capability, the values of critical process parameters, and evaluations of their importance. The process-planning matrix is used to document and analyse the information generate in this phase.

d) Production Operations Planning Phase

The last stage is the Production Operations Planning phase. Finally, the production planning matrix provides a medium for the translation of material and component flows, as well as process elements, parameters and values into assessments of operational evaluation and planning requirements. Documented measures generally include those for operation difficulty and frequency, control chart usage, training and job instruction, preventative maintenance schedules and process cycle times, among others.

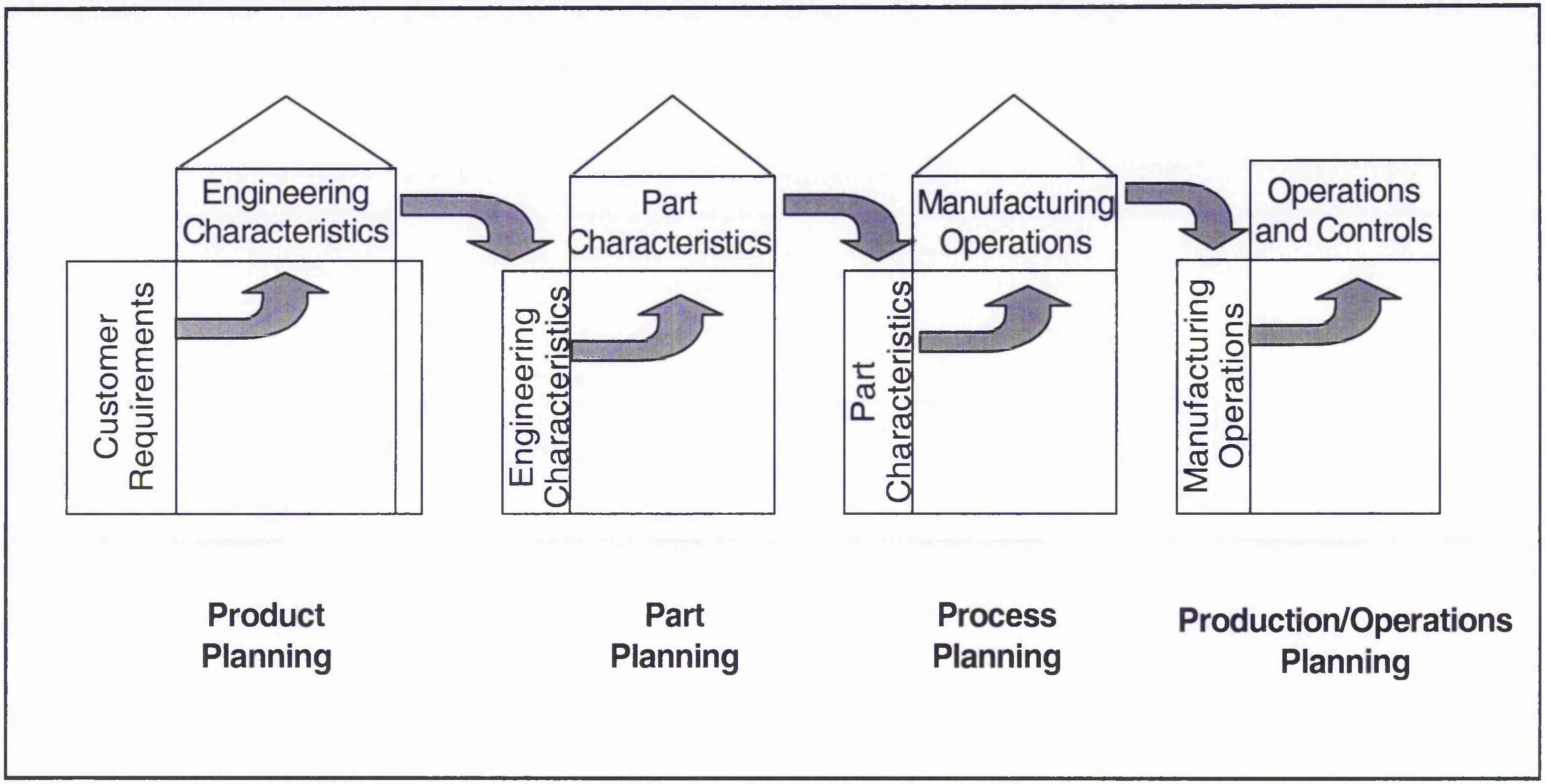

Figure 6.2 – The Four-Phase QFD process

6.3.2. The Matrix of Matrices Approach

The second approach, "Matrix of Matrices", presents itself as a set of tools which practitioners of QFD can use when they find themselves facing particular problems. It consists of about 30 - 36 matrices which describe everything from how to convert Customer Requirements into Product Characteristics to how to prioritise FMEA studies.

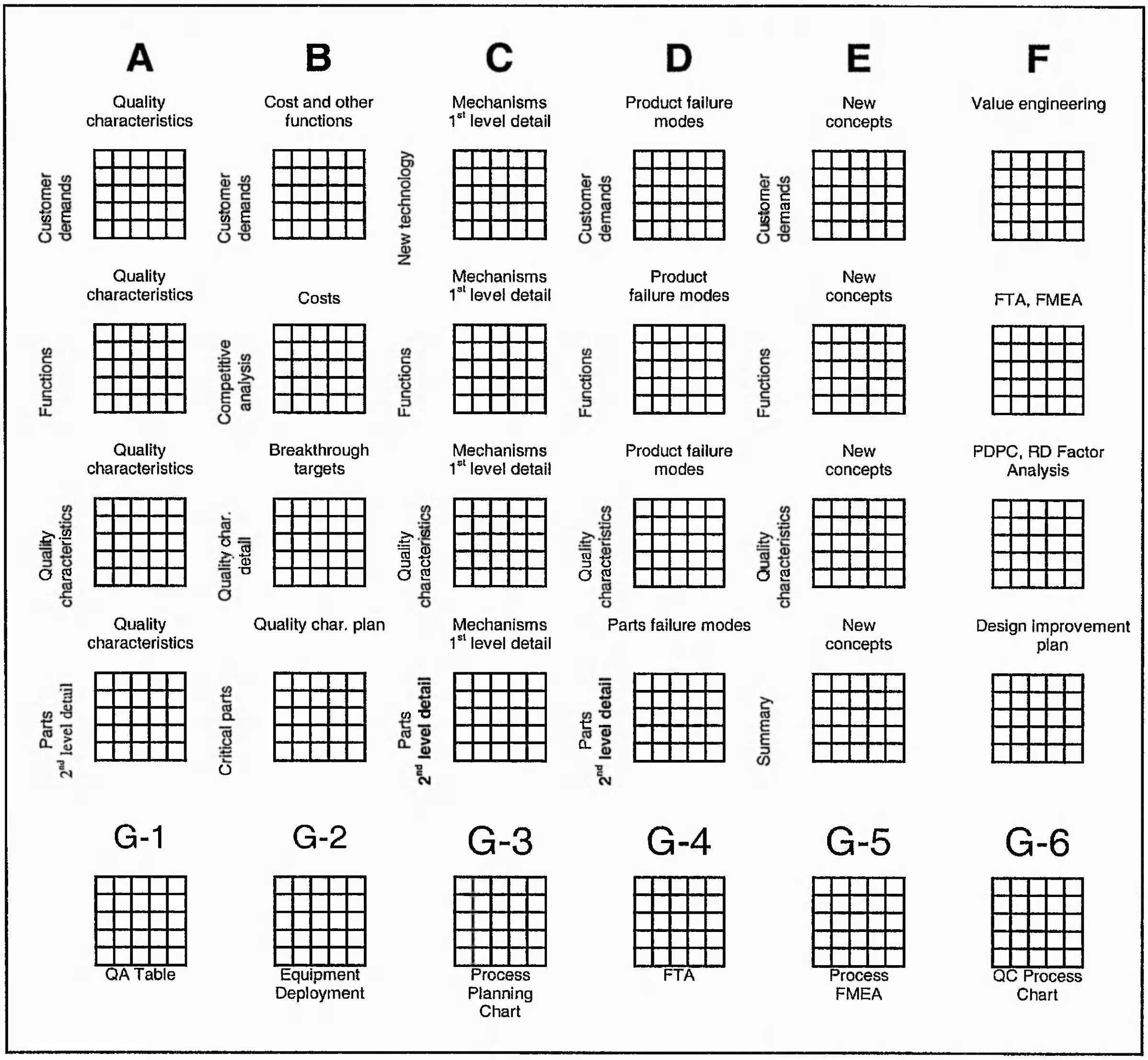

Figure 6.3 – The GOAL/QPC Matrix of Matrices

6.4 The State of The Art

The increased interest in QFD has facilitated research into its integration with other techniques to make it even more effective. Amongst these techniques are Fuzzy Logic, Multi-attribute design optimisation, axiomatic approach to design, and Taguchi Methods. Thurston and Locascio (1993) described the application of multi-attribute optimisation with QFD. The general method consists of determining the relationships between the "whats" and the "hows" and integrating all the important design criteria into a design objective function. This function represents the design attributes and the relationships between them as dictated by the end user. Once the model is created formal optimisation methods are used to get the best target values. Masud and Dean (1993) also reported on the use of Fuzzy Sets in QFD. The aim of the research was to investigate how the QFD analysis can be performed when the input variables into the charts are treated as linguistic variables, with their values expressed as fuzzy numbers. Generally, the use of QFD in Japan was for product improvement based on an existing model (Akao, 1997). Clausing and Pugh (1994) have shown that if the Stuart-Pugh Concept selection is coupled with QFD, it usage can be extended to new product introduction.

In addition to integrating QFD with other tools, other researchers made some structural changes to the QFD matrices. An example is Blitz QFD, which was developed by Zultner (ReVelle, 1998). This approach does not involve the use of matrices, and only the topmost important ranked customer requirements are deployed. This streamlined approach to QFD is particularly suitable for teams with severe constraints on people, time and money.

Although QFD is regarded as a powerful concurrent engineering tool, it is argued that it is a phased and sequential process and therefore does not allow for the parallel deployment of all artefact values such as manufacturability, cost, tools and technology (Prasad, 1998). In order to eliminate this phased nature, Prasad expanded the original definition of QFD to include parallel deployment and described it as Concurrent Function Deployment approach.

6.5 Discussion

The review has shown that QFD was originally used in the design of large product such as super tankers, but later applications were concentrated more on small and simple components. The reason behind this shift in application could be due to the size of the matrix as product complexity increases.

The analysis also revealed that, although the tool was of manufacturing origin, it has now gained wide applications in other fields such as the service and software industries. Available literature indicates that there are scattered cases of its implementation in the construction industry too.

Although the QFD technique is versatile, it is not without weaknesses. The technique is based on serial processing, therefore any error introduced at any stage will affect the outcome and lead to erroneous results, since it does not have any integrated error checking capabilities. It therefore depends on the expertise of the practitioners to ensure that the data entered into the matrices are free from error.

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CHAPTER SEVEN

THE QFD FRAMEWORK

7.1 Introduction

This chapter provides a description of the framework for the application of QFD in the construction industry and goes on to describe the architecture of the software component of the framework.

7.2 Components of the QFD framework

The framework (Figure 7.1) consists of two components - Clients Requirements Processing Diagram, and Roles and Responsibility Diagram. The client Requirements processing part of the framework includes a QFD program for the storage and retrieval of information and also tools for analysing and generating the QFD matrices. The combination of these components allows the client's requirements to be prioritised and transformed into specifications for the complete facility through a logical and structured pattern. The following sub-sections give a description of the components of the framework.

7.2.1. Client's Requirements Processing Diagram

This is used to determine and analyse the requirements of the client. The fundamental task at this stage is to determine what the client expects from the facility and how it is intended to be used. The stages of the client's Requirement processing Diagram is given below:

- *Appointment of Design Team* – To improve the effectiveness of the design and construction process and break down the traditional barriers that exist between designers and constructors, it is necessary to form an integrated design team once the feasibility of the project has been established and the decision to go ahead taken. This team will normally consist of the client/client's representative, an architect/engineer, and members of other professions such as quantity surveyor, structural engineer, landscape/interior designer, mechanical and electrical engineer and the contractor for the project. The involvement of the contractor could help in issues such as buildability.

  Whilst an integrated team of all the stakeholders concerned with the project could result in significant benefits with regards to buildability, some of the procurement systems such as the Traditional method do not easily lend themselves to such an approach. However, the client's direct contractual and functional relationship with the design team provides opportunities for the use of QFD.

- *Determination and Definition of Client's Requirements* – At this stage a more thorough study of the client's requirements and preferences are made, and alternative approaches to solutions considered. The requirements must be defined in terms of functions in order to give more room for the design team to manoeuvre. The client/client's representative must be able to make up his mind about the relative importance of his requirements and also state their priorities. The results obtained from this stage will determine which template to chose from the database.

- *Analysis and Translation of Client's Requirements* - Using the House of Quality matrix (obtained from the database) the client's requirements are adjusted to suit the current need. It is then analysed and deployed into engineering solutions. These solutions can be grouped under the building subsystems such as architectural, structural, landscape/interior design, electrical and mechanical. Interactions and possible conflicts between the engineering solutions are considered and tradeoffs are made at this stage. The engineering solutions are rated and the most critical and important chosen for the next stage.

- *Subsystem Deployment* – The parts deployment matrix is used at this stage to determine the components or parts of the building. Alternative components are considered in terms of cost, quality and ease of manufacture. The results from this stage are presented in the form of detailed drawings and specification.

- *Construction process Planning and control* – The main task at this stage is the transformation of the detailed design into a construction/fabrication plan and into day-to-day coordination and control of processes on site [Koskela, 1992].

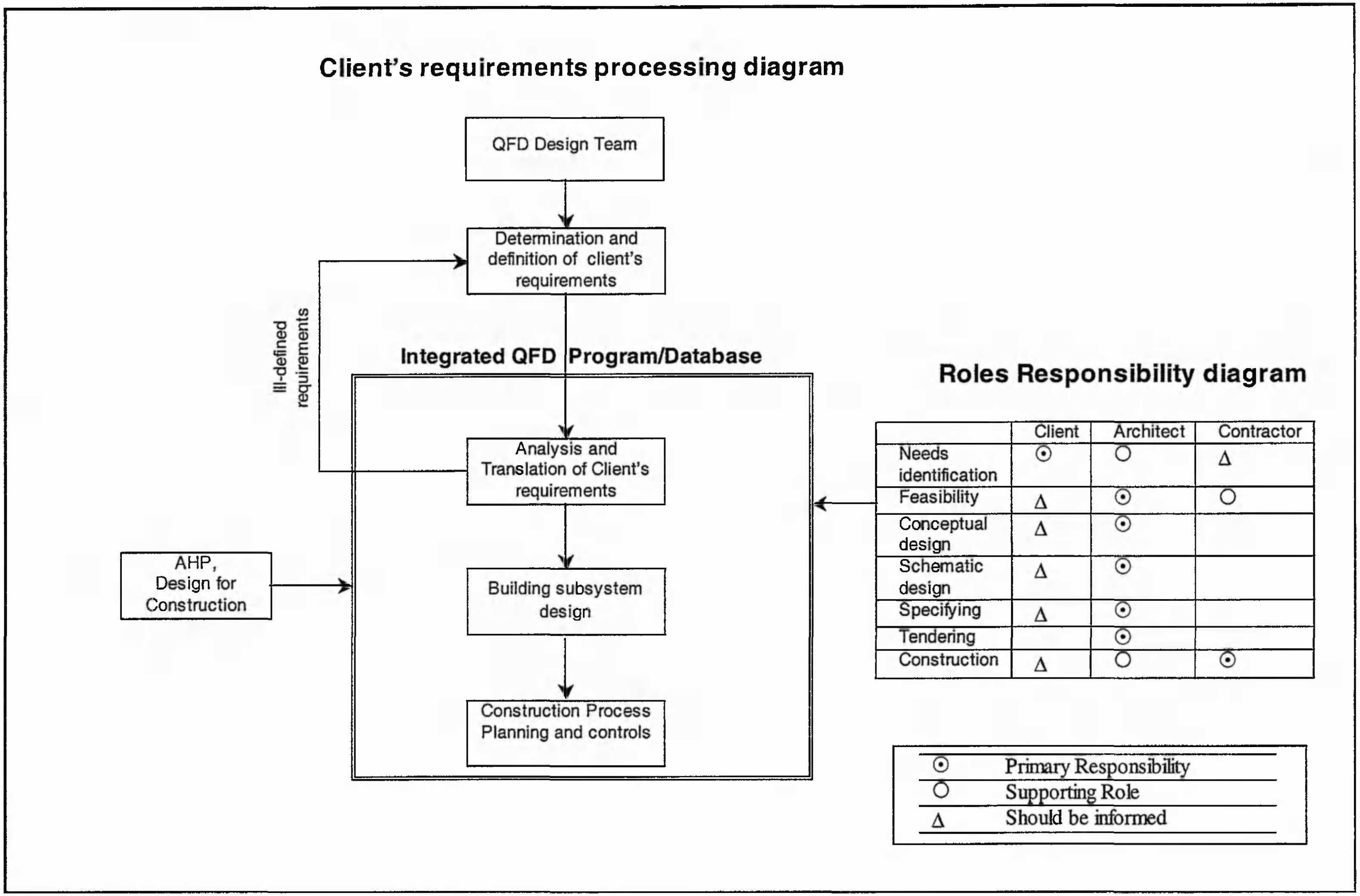

Figure 7.1 - Flow diagram of the QFD Framework

- *QFD database* – Because of the complex nature of construction products and the volume of information involved, a QFD program including a database is proposed to assist in the generation of the QFD matrices and also to store the information generated during the QFD process. Data already stored in the database will be used as a template for other similar QFD projects.

7.2.2. Responsibility Diagram

The second component of the framework is the Responsibility Diagram. This is used to determine the tasks and events necessary for the success of the construction project, and to identify the participants responsible for them.

7.3 Architecture of the House of Quality Software

The analysis of the available literature on QFD shows that one of the major difficulties encountered in QFD implementation is the volume of information generated. Even for a simple product, the size of the House of Quality (HoQ) can grow very quickly, thus making manual QFD inadequate. For a large and complex product, such as is found in the construction industry, a software-based House of Quality is an excellent choice for supporting the QFD methodology. This is to reduce the time and effort required to develop the HoQ. Taking this into consideration, the second phase of the research is to develop a software-based House of Quality suitable for use in the construction industry. Below is a description of the general architecture of the software.

7.3.1. The Components

The project investigated the Multiple Document Interface application architecture and examined how to enable users to work on different types of documents at the same time. The main type of document used was the flexible grid, which is supplied as an ActiveX Control by Microsoft Windows. The diagrammatic representation of the program architecture is shown in Figure 7.2.

The main components of the program are:

1. Main Menu
2. QFD Road map
3. House of Quality

Below is a description of the various components of the software.

1. **Main Menu** – This is made up of the system menu and the program specific menu commands

   a) The system menu

   This provides the default commands for storing and retrieving files, as well as enables the user to start a fresh project from scratch if no template exists for the specific project.

   b) The Program specific menu

   This menu provides the user with a road map of the House of Quality. The entries under this menu include commands for activating the various rooms of the house of quality matrix.

2. **QFD roadmap** – This consists of five different subcomponents, namely the Client Requirements Matrix, The Relationship Matrix, Correlation Matrix and the Benchmarking Matrix. Below is a description of the subcomponents.

   a) Client Requirements Matrix

   The Client Requirements Matrix allows the user to input new data or edit an existing data to suit a current project. This matrix is used to store the client's requirements (*Whats*) and importance ratings of the requirements.

   b) Construction Solutions Matrix

   The Construction Solutions Matrix is of a similar structure to the Client's Requirements Matrix. This matrix contains the design solutions or subsystems solutions (*Hows*) necessary to accomplish the client's requirements. This matrix can also be used to input new data or edit an existing data.

c) The Relationship Matrix

This is a graphical representation of the impact of the "*Whats*" on the "*Hows*". This matrix has the functionality of taking inputs from the other matrices and performing the computations involved in the QFD process.

d) Correlation Matrix

The Correlation Matrix is used to present the effect of one construction solution on another.

e) Benchmarking Matrix

The benchmarking matrix, which could be used for competitive benchmarking, is used to determine how well the firm is satisfying a client's particular requirement as compared to other construction companies providing similar services.

3. **The House of Quality** – This is generated from the inputs made by the user. A graphical representation of the House of Quality is automatically generated, ready for printing. This component cannot be edited directly. All forms of editing is done on either of the matrices described above. However the House of Quality component is able to update itself immediately the other matrices are edited.

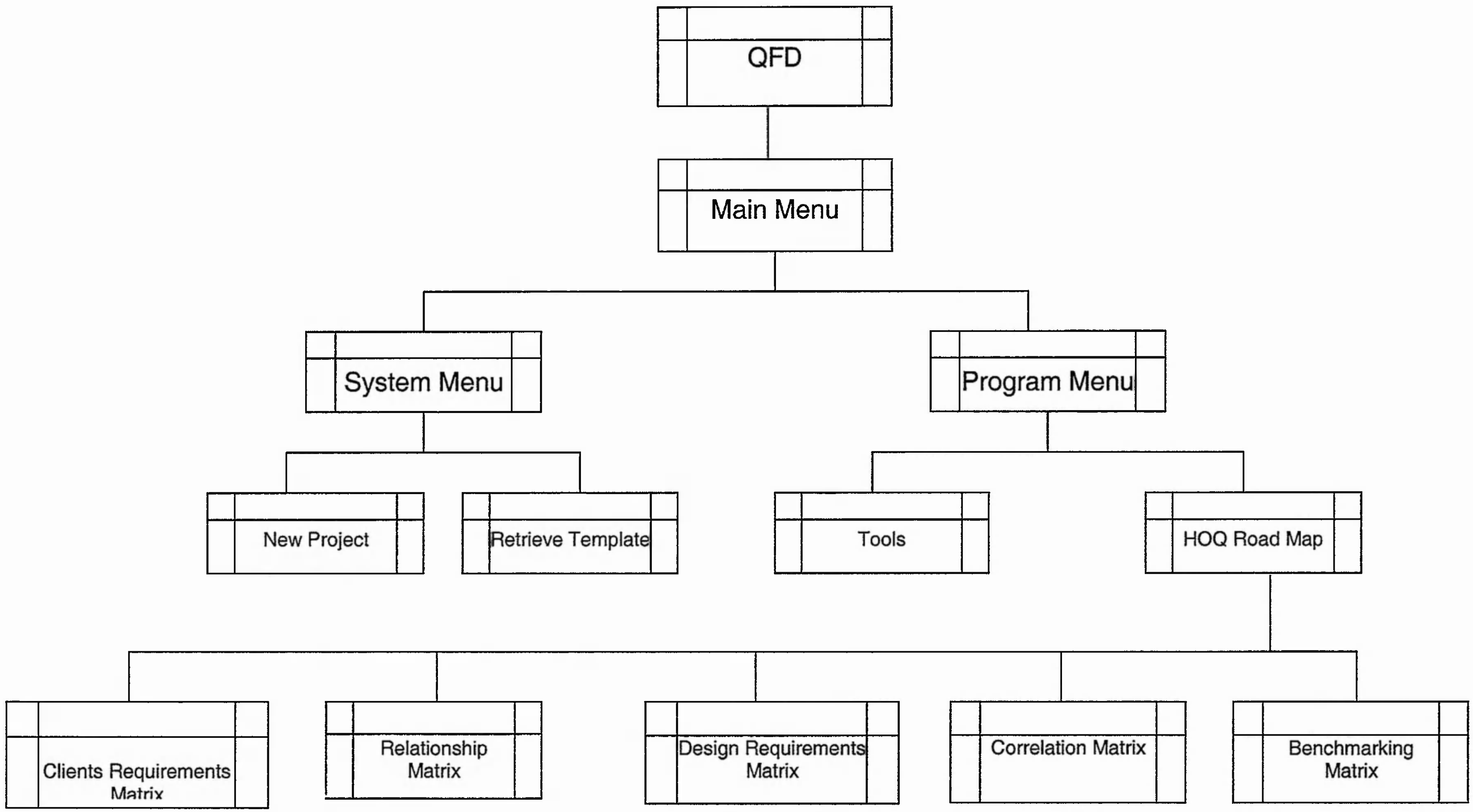

Figure 7.2 – QFD Program Architecture

7.4 Discussion

The fragmented nature of the construction industry has made it difficult for organisations to co-operate, integrate and communicate with each other effectively. In order to overcome this situation the construction industry needs to adopt a more integrated approach to construction through the use of multidisciplinary teams. The framework described above places much emphasis on using a multidisciplinary team during the design stage of the construction project. This is to reduce the possibility of having to redesign some or the entire product. Reduction in redesign leads to reduction of waste, product development time and cost. The use of the framework could assist the industry in such areas as shared responsibility, interpretation differences, reduction of design and construction time, and change orders. It provides a collective effort towards satisfying client needs in advance. Furthermore, the information captured within the database becomes freely available for repeated analysis and can easily be edited whenever updates are required.

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CHAPTER EIGHT

DEVELOPMENT AND EVALUATION OF THE QFD SOFTWARE

8.1 Introduction

The QFD process leads the participants through a detailed process, pictorially documenting their product development approach. This leads to the preservation of knowledge, thus minimising knowledge loss resulting from organisational moves or retirements. However, as shown in Chapter Five several problems can be encountered during its implementation. To a high degree, the QFD depends on serial processing, therefore errors introduced at one stage will propagate to successive stages [Brodie, 1994; Suttler, 1994]. Bias can easily be introduced at any stage resulting in an erroneous conclusion [Breyfogle, 1992; Griffin and Hauser, 1993]. In addition QFD is a complex and time-consuming process requiring a lot of detail [Brodie, 1994; Shen, 1994; Zairi and Youssef, 1995], especially as products become complex with a corresponding increase in the size of the QFD matrix. However, due to human shortfalls, performing QFD manually within a large matrix can be prone to errors [Chen et al, 2001].

The identified problems related to manually recording, analysing and updating QFD information could be addressed by storing the information in a computer. This chapter gives a description of the development and evaluation of the QFD software component of the framework.

8.2 Development of the Software

The software was developed using the Visual C++ Development Environment. Although other development environments such Visual Basic could also have been used, the choice was made based on the unique advantages of C++ over Visual Basic. Some of the advantages of Visual C++ over Visual Basic are:

- C++ can be compiled for non-Windows platforms.
- C++ allows more control of the code-generation process
- C++ can allocate memory without specifying what it is for
- C++ can be statically linked (no DLLs required)
- C++ can be easier to use to perform certain complex tasks

- C++ supports inheritance, automatically generates certain class member functions such as copy constructors, and allows parameters to be passed to constructors
- C++ allows overloading of functions and operators
- C++ doesn't restrict naming of functions as much as Visual Basic. For example, Visual Basic classes can't have a Print member function, since Print is a reserved word
- C++ can be used to manipulate memory and objects using pointers; this can be extremely useful
- C++ supports generic templates

The development of the software was based on the architecture discussed in chapter Seven. The following subsections describe the components of the software. Below (Figure 8.1) is a flow chart of the software.

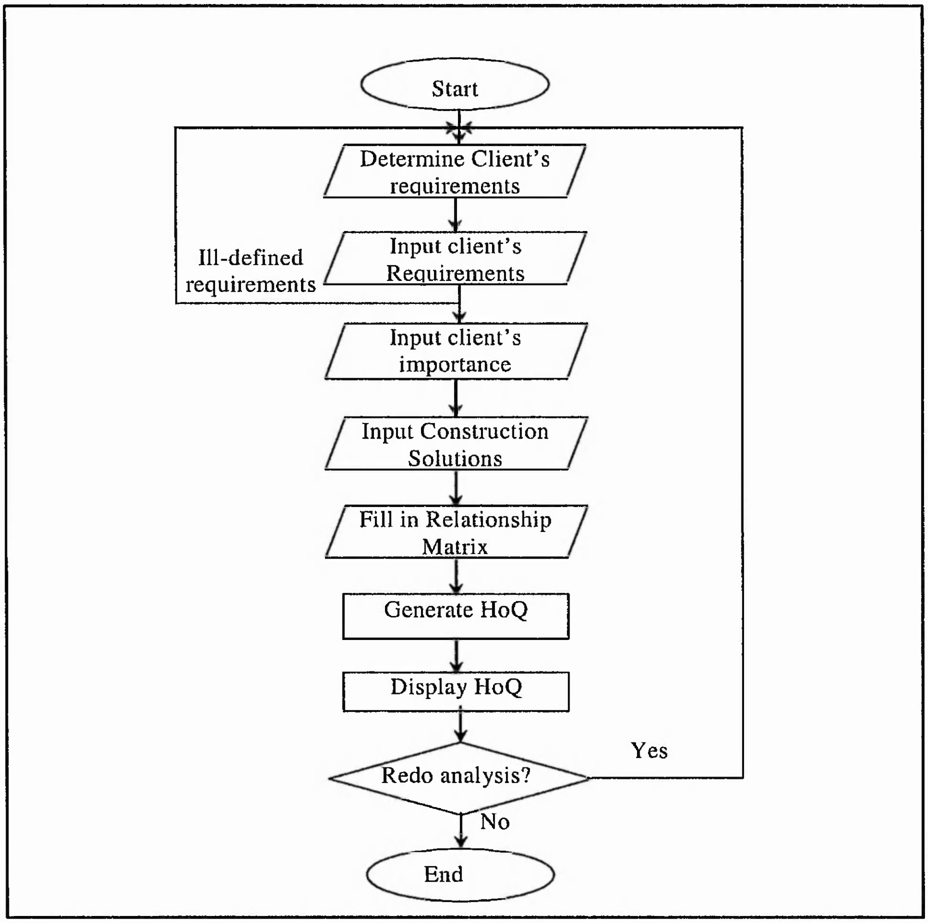

Figure 8.1– Flow chart of QFD Software

8.2.1. Main Window

The main window of the software is shown in Figure 8.2. The software utilises the basic windows interface in order to make the learning curve smoother. When the software is run, the user is presented with a schematic view (Map) of the house of quality. This view is contained in the "MAP" window, which consists of several rectangles and a triangle representing the various rooms of the House of Quality.

The rectangles are composed of sensitive bitmaps which when clicked on with the mouse, activates the corresponding matrix. Thus when the Client's Requirements bitmap is clicked on, it activates the Client's Requirements Table for editing. Likewise, clicking on the other bitmaps activates their respective forms. The same effect (i.e. activating the various forms) can also be produced by accessing the "Map" menu, which contains submenu entries for all the various views contained in the Software (Figure 8.3). In addition to providing a platform for launching the various views of the software, the main window also provides the functionality for storing the data collected.

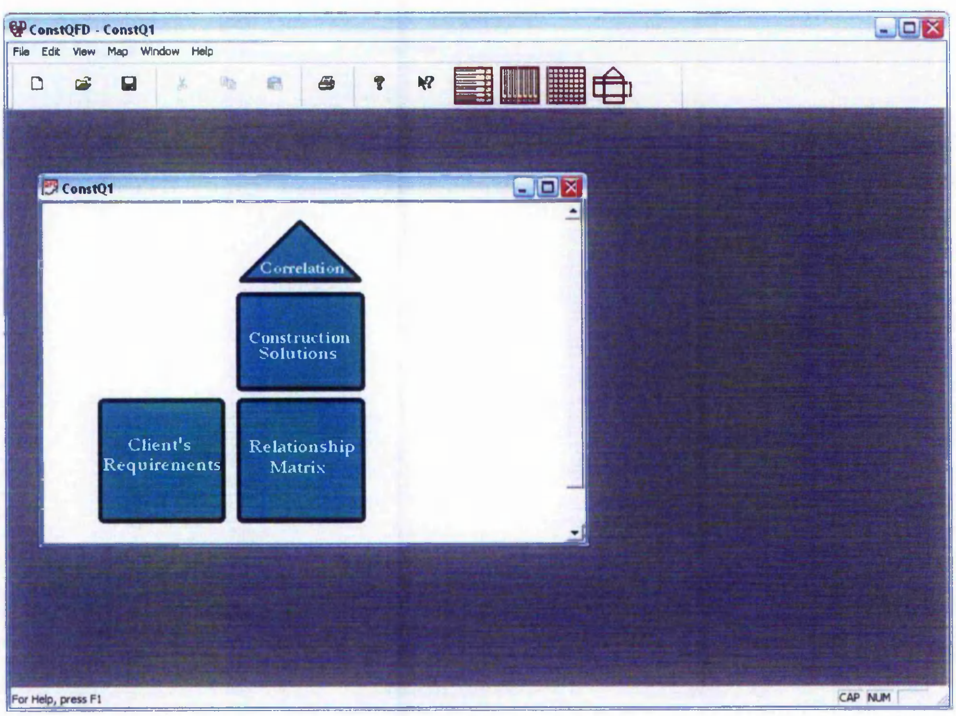

Figure 8.2 – Main window of the QFD Software

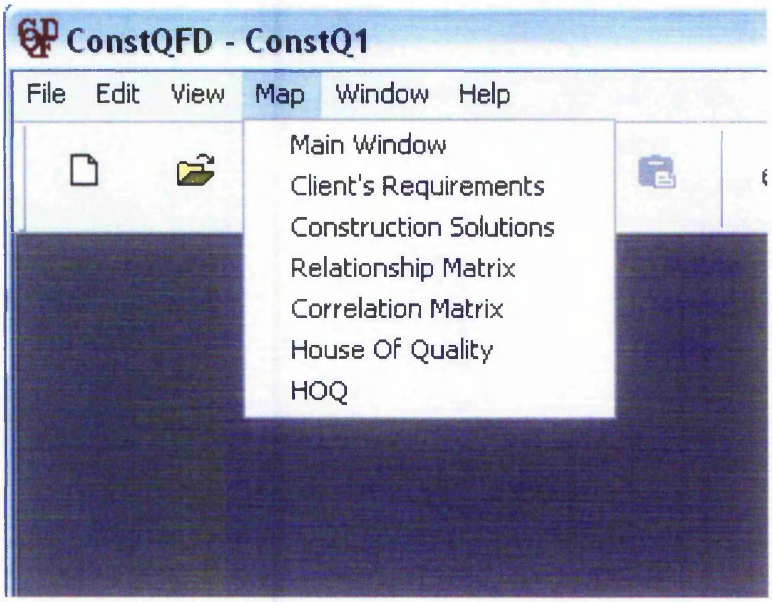

Figure 8.3 – The Map Menu of the QFD Software

8.2.2. Client's Requirements and Construction Solutions Components

The client's requirements component is used to gather and document the requirements of the client, whiles the Construction Solutions component is used to document the construction solutions generated (Figures 8.4 and 8.5). These components are built from a form with an integrated grid (specifically, the MSFlexgrid activeX). The integrated grid can be edited by double clicking the appropriate cell. Since the MSFlexgrid component can only be used to store textual information, the data gathered by the grid is stored in various vectors. This was done in order to separate textual data from numeric data. To store numeric data, the information from the grid is first converted to numeric values and then stored in a vector for future retrieval.

In order to populate the grid when an existing document is opened, the vector containing the relevant data is invoked. The data stored in the vector is then transformed into text before populating the grid with it.

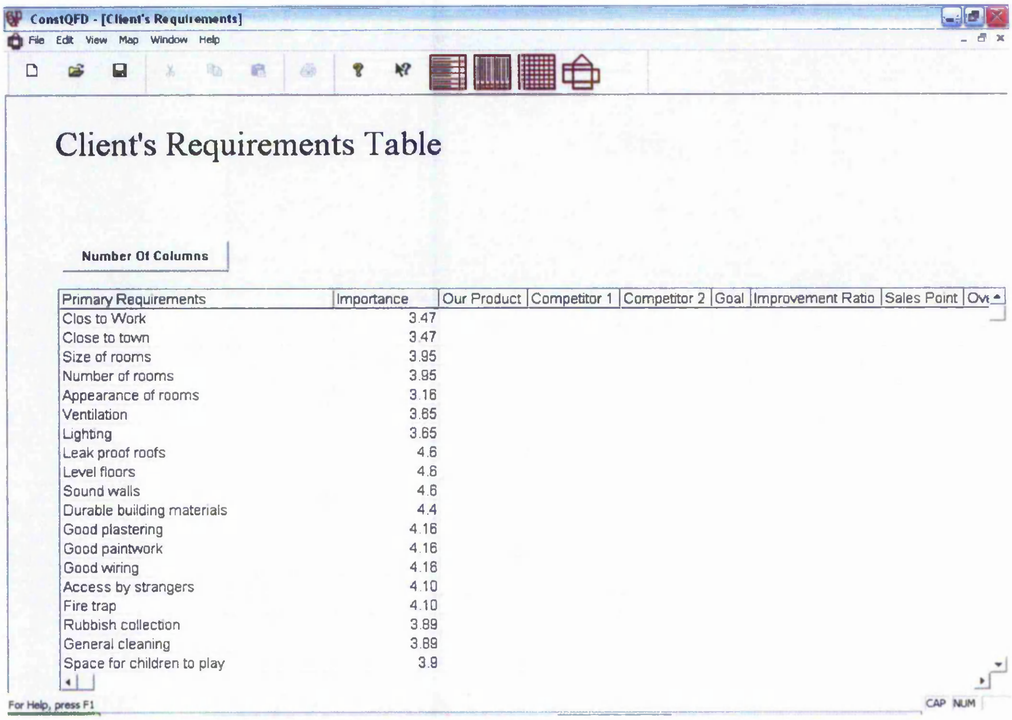

Figure 8.4 – The Client's Requirements Table

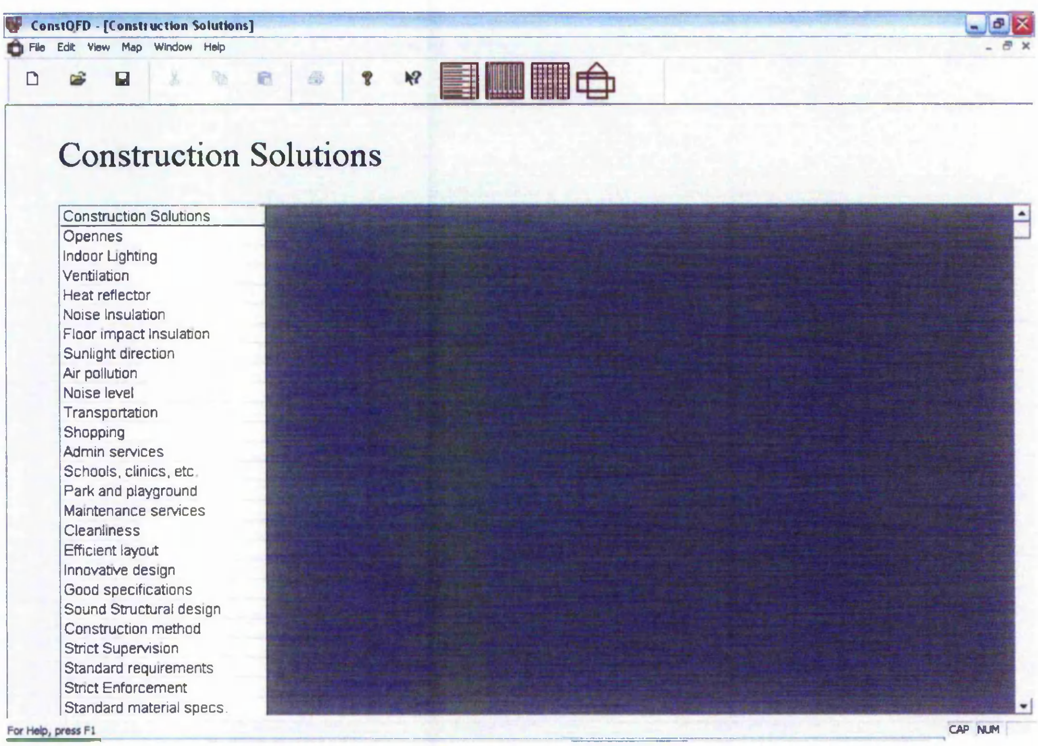

Figure 8.5 – The Construction Solutions Table

8.2.3. The Relationship Matrix

As describe in Chapter Five, the Relationship Matrix is used to map out the impact of the Construction Solutions on the Client's Requirements. This component of the software is a form with an integrated MSFlexgrid (Figure 8.6). Unlike the Client's Requirements and Construction Solution components, the flexible grid in the Relationship matrix does not allow free editing. Instead, a dialog box (Figure 8.6) with fixed values is provided. The cells in the Relationship matrix can only be populated by the values provide by the dialog box.

In order to map the relationship between a Construction Solution and a Client Requirement, the user needs to click on the intersecting cell. When the cell is clicked, the dialog box becomes activated. The user then can choose a value from the list provided. When the OK button is pressed, the value chosen is inserted into the cell. After all the necessary mappings have been done, the computations for the QFD process can then be made by clicking on the "Calculate Ratings" button.

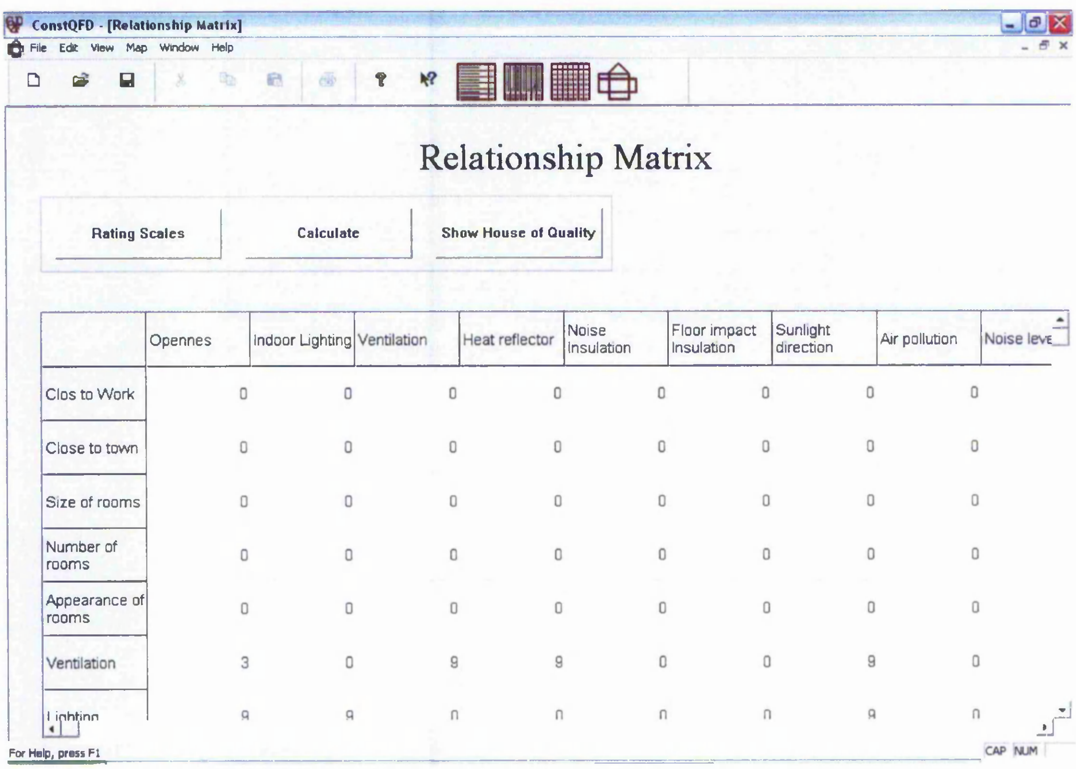

Figure 8.6 – Relationship Matrix

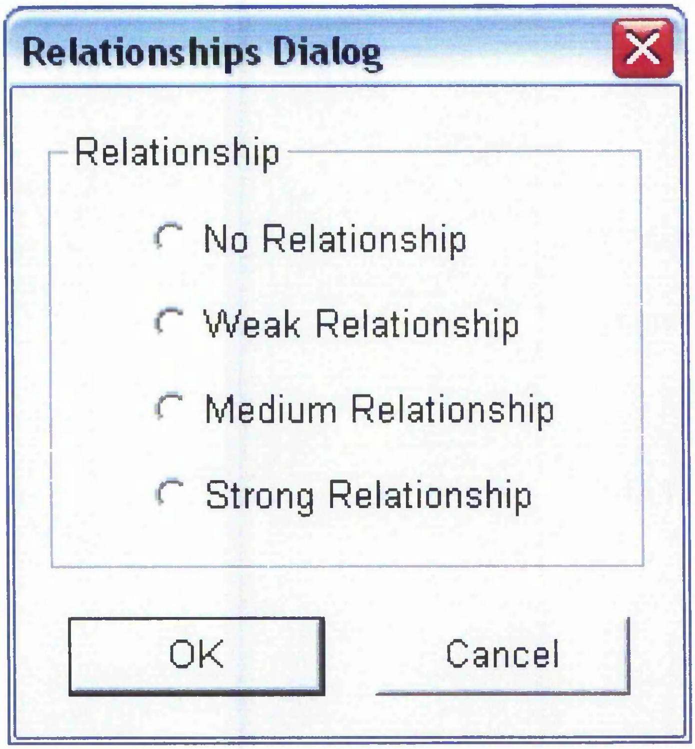

Figure 8.7 – Relationships Dialog Box

8.2.4. The House Of Quality (HoQ) Component

The House of Quality component (shown in Figure 8.8), as the name implies, is used to display the House of Quality. Unlike the other views of the software, which were built from a FormView this component is built from a ScrollView. This choice was based on the fact that the ScrollView provides a better drawing surface for the HoQ than a FormView. In addition, no specialised code needs to be written to provide scrolling capabilities.

The drawing of the HoQ was done through a series of lines, text and symbols. First the number of the Client's Requirement and the Engineering Solutions are determined. These values are used to determine the number of vertical and horizontal lines that need to be drawn. After the number of lines has been determined, their spatial positions are calculated and the framework of the HoQ is then drawn. The framework is then populated with the data from the Client's Requirements Form, Construction Solutions Form and the Relationship Matrix.

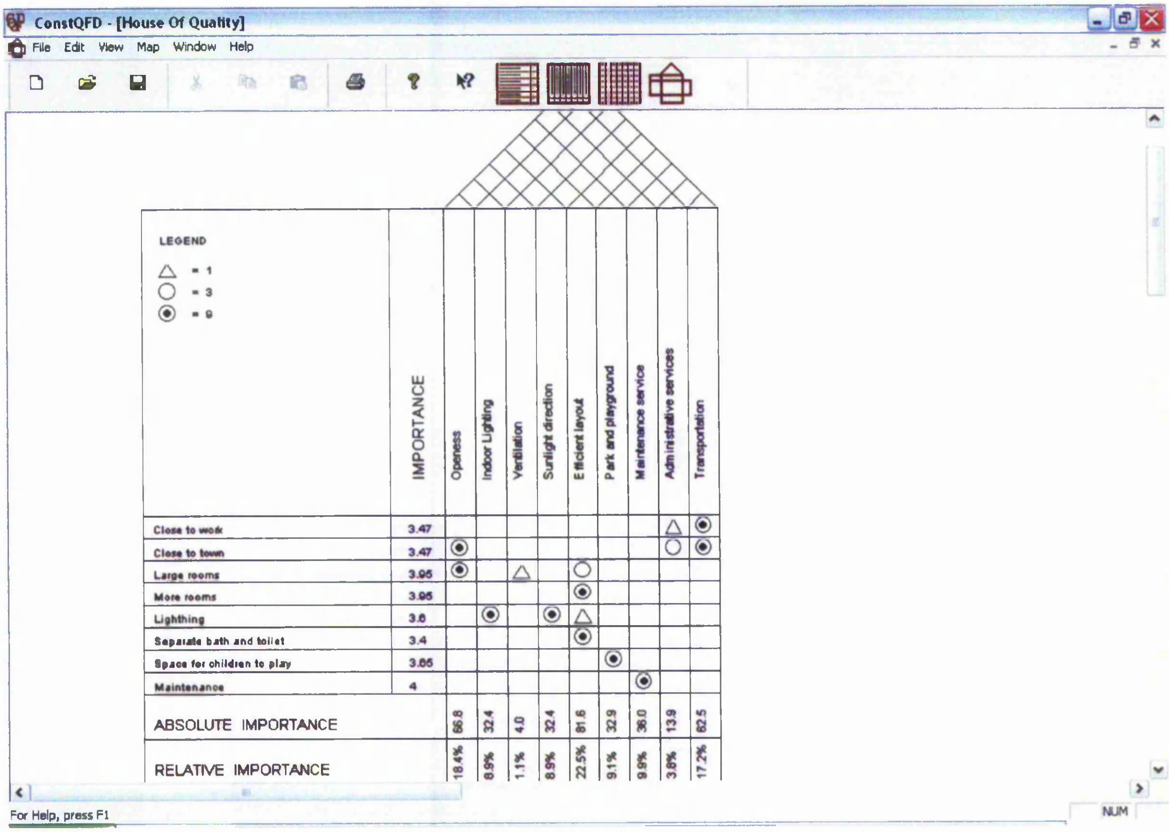

Figure 8.8 – The House of Quality Component

8.3 Software Validation and Evaluation

In order to develop an insight about the robustness and usefulness of the QFD software, testing was done to validate it. This was done so that defects can be found and eliminated before sending it out to companies for evaluation. The software was then sent out to various companies for evaluation. Below is a description and results from the validation and evaluation.

8.3.1. Software Validation

The validation was done by the author himself and other research students in the Faculty of Construction, Computing & Technology. The software was tested using data from available literature as inputs. The output generated by the software was then compared to the test data for consistency. Two examples of the validation exercise are presented in this thesis. The first was the analysis of a layout design for a restaurant. The table for the analysis is shown in Table 8.1. The results from the test values showed that the software is able to do all the computations with no errors. The House of Quality generated from the test values is shown in Figure 8.8.

Table 8.1 – Factors influencing the quality of a Restaurant

No.	Factors influencing the quality of a Restaurant	Level of satisfaction (Scale of 1 to 5)
1	Comfortable	4
2	Modifiable	5
3	Functional	4
4	Flexible	3
5	Attractive	4
6	Ample Capacity	5
7	Clean	4
8	Uncomplicated	5
9	Individualistic	2
10	Adaptable	3

LEGEND

△ = 1

○ = 3

◉ = 9

	IMPORTANCE	Modifiability of Lighting	Colours, textiles, plants	Acoustics	Different routes for personel	Dirt resistant joints of tiles	No fixed sections	Functioning collection of dishes	Tables around columns	Extra utility points
Comfortable	4	◉	◉	◉	△	△		○	○	
Modifiable	5	◉	○				◉			◉
Functional	4	△			◉		◉	◉	○	◉
Flexible	3				○		○	◉	△	◉
Attractive	4	○	○	○		△		○	△	
Ample capacity	5				△			◉	○	◉
Clean	4	○				◉		◉		
Uncomplicated	5		△					◉		
Individualistic	2	○	◉						○	
Adaptable	3	◉	○			◉			○	◉
ABSOLUTE IMPORTANCE		142.0	95.0	48.0	54.0	71.0	90.0	213.0	61.0	180.0
RELATIVE IMPORTANCE		14.9%	10.0%	5.0%	5.7%	7.4%	9.4%	22.3%	6.4%	18.9%

Figure 8.8 – House of Quality Matrix for a restaurant

The second test was done using the case of a client's requirements for the design of a flat. The results obtained from this test also showed no errors. The raw data for the test is shown in Table 8.2. The House of Quality generated for the second test is shown in figure 8.9.

Table 8.2 – Factors influencing the quality of a Flat (Source: Abdul-Raman, 1998)

No.	Factors influencing the quality of a low-cost flat	Level of satisfaction (Scale of 1 to 5)
1	Location of flat (urban, suburban, rural area)	2.89
2	Basic amenities e.g. water supply, electricity, shops, school, market, parking lots, playground/park etc.	2.85
3	Safety and stability of building from natural elements e.g. wind, rain, earthquake etc.	2.83
4	Building materials used for building, roof, floor, wall, door, windows, etc.	2.80
5	Layout of flat e.g. living area, kitchen, bathroom, bedrooms, balcony, etc.	2.75
6	Workmanship in installing ceiling, door, window, tiling, painting, plastering, plumbing work, electric wiring etc.	2.65
7	Internal condition – ventilation, temperature, lighting etc.	2.50
8	Appearance/outlook design of flat	2.47
9	Structural elements e.g. foundation, beam, column, roof, wall, flooring etc.	2.45
10	Home security and safety during emergency	2.30
11	Size of flat	2.25
12	Environmental conditions e.g. air quality, noise, traffic congestion	2.16
13	Maintenance work e.g. repair works, repainting building, garbage collection system, overall cleanliness and maintenance of building	2.05

LEGEND

△ = 1
○ = 3
◉ = 9

	IMPORTANCE	Opennes	Indoor Lighting	Ventilation	Heat reflector	Noise Insulation	Floor impact Insulation	Sunlight direction	Air pollution	Noise level	Transportation	Shopping	Admin services	Schools, clinics, etc.	Park and playground	Maintenance services	Cleanliness	Efficient layout	Innovative design	Good specifications	Sound Structural design	Construction method	Strict Supervision	Standard requirements	Strict Enforcement	Standard material specs.	Quality builders
Clos to Work	3 47										◉	○	○	○													
Close to town	3 47										◉	◉	◉	△													
Size of rooms	3.95																	◉	○					◉			
Number of rooms	3.95													○				◉	○					◉			
Appearance of rooms	3.16																	○	◉					△			
Ventilation	3.65	○		◉	◉			◉			◉	◉						○									
Lighting	3.65	◉	◉					◉										○	△					○			
Leak proof roofs	4.6																			◉	◉	◉	○	○	○	△	◉
Level floors	4.6																			○	○	◉	◉	○	○	△	◉
Sound walls	4 6																			◉	◉	◉	○	○	○	◉	◉
Durable building materials	4 4																			◉	◉	○	○	◉	○	◉	◉
Good plastering	4.16																					○	○	△	○	○	◉
Good paintwork	4.16																					△	○	△	○	○	◉
Good wiring	4.16																					△	○	△	○	○	◉
Access by strangers	4.10															△		○	○	○							
Fire trap	4.10	○																◉		○				◉		◉	
Rubbish collection	3.89															◉	◉							◉	○		
General cleaning	3.89															◉	◉							◉	○		
Space for children to play	3.9														◉			○	○					◉			
Space for relaxation	3 9														◉			○	○					◉			
Rowdy traffic	4 16					◉				◉										○				○	△	○	
Noisy	4 16					◉	◉			◉										○				○	△	○	
Dusty	4 16			○					◉											○				○	△	○	
Separate bath and toilet	3.85																	◉	△					◉			
Partition between kitchen and living room	3.85																	◉	△					◉			
Balcony	3.85																	◉	△					◉			
ABSOLUTE IMPORTANCE		56.1	32.9	45.3	32.9	74 9	37.4	65.7	37.4	74.9	95.3	74.5	41.6	25.7	70.2	74.1	70.0	279 0	103.0	198.2	136.2	158.2	119.6	497.2	127.9	202 0	276.1
RELATIVE IMPORTANCE		1.9%	1.1%	1 5%	1.1%	2.5%	1.2%	2.2%	1.2%	2.5%	3.2%	2.5%	1.4%	0.9%	2 3%	2.5%	2 3%	9.3%	3.4%	6.6%	4.5%	5 3%	4.0%	16 5%	4.3%	6.7%	9.2%

Figure 8.9 – House of Quality Matrix for a flat

8.3.2. Software Evaluation

In order to evaluate the capability of the software for clients' requirements processing, copies were sent to companies for evaluation. The copies of the software sent included example projects and instructions to guide the companies. Of the ten companies contacted only one was willing to undertake the exercise. The respondent company used the software to analyse an already completed project. Below is a description of the project and the results obtained from the evaluation of the software.

Background of Project

Increasing world competition in the health and beauty products, prompted Boots the Chemist (BTC), one of the largest pharmaceutical retailers in the country to introduce Health and Beauty centres (number of Beauty and Health treatment rooms) on their high street sales floors. The purpose is to provide health and beauty treatment to customers with products they buy from the store, without going somewhere.

The project involved the conversion of an existing building into the health and beauty centre. The existing scheme had basement, ground, first, second and third floors and roof level. The scope of works was internal, with the formation of the Health and Beauty experience (HBE) mainly on the first and second floors. Works to the third floor was refurbishment of staff accommodation and the extension of customer lift from the first floor to the second floor.

QFD Analysis of the Project

According to the respondent, one of the difficulties faced during the progress of the project was the inability to establish clear and concise communication routes between all parties to the project. Communication between client/ representative the architect (who was also the contract administrator), contractor's agent on site, contractor and sub-contractors, contractor's office based staff and site-based staff was not well established. No effective methodology or strategy was defined. Involvements of stakeholders were not defined from the beginning of the project development.

After explaining the nature of QFD and the framework developed to the respondent, a QFD matrix was constructed by modifying one of the samples sent with the software to suit the project. Table 8.3 shows the data used to construct the house of quality. The respondent admitted that although the QFD exercise was done using a pre-existing project it provides an effective methodology for communication between project participants. The House of Quality generated is shown in Figure 8.10.

Table 8.3 – Factors influencing the quality of the Health and Beauty Centre

No.	Requirements	Level of satisfaction (Scale of 1 to 5)
1	Space – adequate room sizes and corridor spaces to avoid congestion.	4
2	Aesthetics - E.g. Some of the walls were painted cool blue with flower graphic panels by them to give a nice relaxing atmosphere.	5
3	Ventilation – ability to maintain temperature and humidity (heat emitted by items for sale and people)	4
4	Lighting - Combinations of up-lighting and spotlighting were used to control the degree of luminosity within the spaces, mainly in the treatment rooms and in the corridors. Also, to enhance the pharmaceutical goods.	5
5	Layout Design – specialised rooms grouped together.	4
6	Building Materials – high impact glass, etc. to protect goods from vandalism	4
7	Workmanship	3
8	Security – security control points for restricted areas.	5
9	Space for Children to play	3
10	Surroundings	2
11	Structural Soundness	4.5

LEGEND

△ = 1
○ = 3
◉ = 9

	IMPORTANCE	Opennes	Indoor Lighting	Ventilation	Noise Insulation	Floor Impact Insulation	Playground/creche	Cleanliness	Efficient Layout	Innovative Design	Good Specifications	Sound Structural Design	Strict Supervision	Standard Specifications	Strict Enforcement	Standard Material Specifications
Space	4								◉	○				◉		
Aesthetics	5		◉													
Ventilation	4	◉		◉				○	○	△						
Lighting	5	◉	◉						○	△				○		
Layout Design	4		△						◉	◉				◉		
Building Materials	4		○		○			◉			◉	◉	○	◉	○	◉
Workmanship	3											△	◉		○	◉
Security	5	○	◉				○		○	○						
Space for children to play	3							△								
Surroundings	2				◉	◉		◉								
Structural Soundness	4.5										◉	◉	○	○	○	◉
ABSOLUTE IMPORTANCE		96.0	151.0	36.0	30.0	18.0	15.0	69.0	114.0	72.0	76.5	79.5	52.5	136.5	34.5	103.5
RELATIVE IMPORTANCE		8.9%	13.9%	3.3%	2.8%	1.7%	1.4%	6.4%	10.5%	6.6%	7.1%	7.3%	4.8%	12.6%	3.2%	9.5%

Figure 8.10 – House of Quality Matrix for Health and Beauty Centre

8.4 Discussion

The QFD Software supports the collection and analysis of QFD related information, and prioritises specifications for design effort, so that time and effort can be concentrated on improvements to construction design characteristics that add most value in terms of providing client satisfaction. The Software has concentrated on the first phase of the Four Phase QFD approach. The software has been designed in such a way that it can be used to start a new project or to edit an existing one to suit a current but similar project. Based on the requirements of the current project, the user can modify the charts with ease, thereby saving a considerable amount of time and effort.

The evaluation of the software also showed that it has potential benefits in improving communications between project participants. In addition, the use of the template for the evaluation exercise gives an indication of the usefulness of the software to enhance the QFD process. Hence, instead of starting from scratch, a template for a similar project can easily be modified to suit the current project thus reducing the time needed for the QFD process.

From the evaluation of the Software, it was also realised that the QFD process is greatly enhanced in terms of speed and accuracy. The software also allows values to be manipulated and the effects seen immediately. However, the software cannot be used as a substitute for expertise, but rather it helps the expert to distinguish the most critical client's requirements and discover the corresponding construction solutions.

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CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions and Recommendations

The issue of underachievement in the UK construction industry has, for many years, occupied a place in several governmental reports. Although various solutions have been proposed to improve on the performance of the industry, the level of improvement has still been elusive. Very notable amongst the proposed solutions was the concept of considering construction as a manufacturing process through the application of manufacturing techniques.

As a first step towards developing this concept, the structure and practices in the UK construction industry were reviewed under chapter two. This covered the nature of the construction industry and its importance to the economy, the diversity of its clients and products, and the various procurement methods employed. It was gathered from the review that because of the different types of clients and the wide range of building, there is not a single ideal solution suitable for all clients. Majority of building works and structures are individually designed and built to the unique requirements of the client. Probably the only exception is the speculative housing sector, but builders even rarely produce large numbers of identical buildings on the same site.

However, the majority of construction activities are the results of other activities which are common to both the construction and the manufacturing industries. These include the identification of the client's requirements, the formulation of the specifications for the design solutions, and the production information. Since these activities typically contribute about 10 – 30 per cent of the overall construction budget it is fair to say that between 70 – 90 per cent of a construction project's cost is determined during the initial period. Considering the front-end activities of both industries (requirements capture and design), there is nothing to suggest that well proven product planning and design techniques such as QFD might not be applicable to the construction industry.

Analysis of the UK construction Industry also revealed its importance to the economy and vice versa. The construction industry makes an important contribution to the UK economy by being a major employer and also a major contributor to UK Gross Domestic Product (GDP). Construction output is a response to the demand for new investment, for replacement or repair of existing buildings, and also for intermediate input into other industries. Thus variations in the economy could influence the demand for construction work and the associated employment.

The importance of the industry could also be seen in the effort to develop various procurement methods to improve its performance and give clients value for their investments. It is widely seen that the traditional procurement method separates the design function from construction and has encouraged adversarial relationships between construction project participants. Therefore the new procurements systems have focussed on integrating these two functions and to encourage a more collaborative atmosphere between project participants.

It has generally been agued that the new procurement routes lead to a more efficient construction process than the traditional procurement system. However, the comparisons are often made without reference to design quality. For example, the design and build procurement system encourages the integration of design and construction, and can deliver projects quicker. However, it is also known to produce less than optimum quality as compared to the traditional system.

Regardless of the form of procurement system, the quality of design greatly influences the quality of the construction project. Whereas some contractors could be blamed for producing poor quality work, majority of them are reputable firms that endeavour to carry out their obligations to a high standard. Contractors can only build in accordance with architects' design drawings using the materials specified, all of which to a varying degree are outside their control.

Since the quality of the output of any given process depends, to a large extent, on the inputs, it is of utmost importance that the inputs are as accurate as possible. For a construction project, the inputs are the client's requirements. If the client's requirements are not properly analysed and understood, the project team could apply the best of techniques, but the end result will be a product that does not conform to the actual specifications of the client. For any given procurement system, the briefing and design stages are very critical. Therefore the development of a tool capable of capturing and processing client's requirements during the initial development stages could undoubtedly contribute significantly towards quality of designs and performance of the industry.

Quality of designs and performance enhancement is also related to the extent to which the UK Construction industry is committed to Quality Management techniques. These techniques and their relevance to the construction industry were therefore reviewed in chapter three. It was identified that the issue of quality is not static, but keeps evolving. Quality Management should not also be restricted to only one department of an organisation but in all sections. Failure to meet the requirements of the customer or client in one part or area creates problems elsewhere, leading to more errors and yet more problems. When businesses were local and simple, craftsmen could manage more or less on their own. Business such as construction companies, are much more complex and employ so many different specialist skills. The industry needs to achieve significant improvements in terms of client satisfaction at each interface of the construction process. There is therefore the need for the industry to continuously improve upon its business processes in order to remain competitive. This is due to the fact that the reputation enjoyed by a company or firm is built upon quality, reliability, delivery and cost. This is the essence of Total Quality Management technique of which QFD is an instrumental part.

The various manufacturing techniques being implemented in the construction industry were examined in chapter four. The review showed that the strengths of these tools lie in the elimination of waste and improving productivity but lack an integrated mechanism for eliciting clients' requirements. However as discussed in chapters 2 and 3, the greatest savings could be made during the front-end activities such as client requirements processing. This indicates that, for these techniques to be more successful, they must be integrated with a tool which can provide a framework for the identification, structuring, analysis, and translation of clients' requirements into plans and specifications. Such a tool should be able to draw on all the conceivable sources likely to affect the final product, and be able to nurture a strong integrating mechanism and allegiance to the project objective. A methodology holistic enough is Quality Function Deployment.

In order to determine the extent of application and the impact of the manufacturing techniques a questionnaire survey was conducted in both manufacturing and construction industries as shown in chapter five. The survey was also used to gather primary data for a comparative analysis of both industries. The analysis showed that on a scale of 1 – 5, most of the mean values for the derived benefits were above 3.5. In addition the t-test conducted on the improvements derived did not show any significant differences thus indicating that the techniques brought some level of improvements in the performance of the companies. This analysis supports the notion of the relevance of manufacturing techniques in the construction industry.

The results also showed that the areas with the lowest mean values for benefits derived relate to communication and development time. These two areas contribute to most problems associated with product development and are the areas where QFD implementation could be beneficial to the companies.

In Chapter Six the inception, fundamentals and later developments of Quality Function Deployment technique was examined. It was found out that although the technique was developed for the design of supertankers (which are large and complex), later applications were concentrated on simpler products. The review also showed that out of the two QFD approaches, the four-phased approach is commonly used because of the smaller number of matrices involved. However, the size limits its application to only quality aspect of the product. The less popular approach (matrix of matrices), however includes other planning features such as cost analysis, Fault Mode and Effects Analysis, and Value Engineering. Even though QFD could be implemented as a standalone tool, maximum benefits could be obtained when it is combined with the TQM programme. The review also showed that QFD is being combined with other techniques such as fuzzy logic and artificial neural networks to make it even more versatile.

Chapter seven was devoted to the philosophy of the framework of QFD. The framework consists of two components - Clients Requirements Processing Diagram, and Roles and Responsibility Diagram. The roles and responsibility section was used to define the responsibilities of project participants. The framework places much emphasis on using a multidisciplinary team during the design stage of the construction project in order to reduce material waste, time and cost. The use of the framework could assist the industry in such areas as shared responsibility, interpretation differences, and reduction of design and construction period. It provides a collective effort towards satisfying client needs in advance. Furthermore, the information captured within the database becomes freely available for repeated analysis and can easily be edited whenever updates are required.

The development and evaluation of the QFD software, (ConstQFD) was covered in chapter eight. The software is the core part of the Client's Requirements Processing section of the framework and also used for the storage and retrieval of information. The Software was developed using the Visual C++ language. Three test cases were used to validate the robustness and reliability of the software and the areas tested included data input, data editing and computational capabilities. It was found out that the editable MSFlexgrid interface allowed changes to be made easily. The results obtained from the computations of the software were compared to standard results and was found out to be accurate.

The software was also sent to construction companies for evaluation. This was done in order to determine the applicability and potential benefits to construction companies. The results from the respondent company indicated that the use of the software could enhance the QFD and consequently enhance communications and co-ordination between project participants.

Due to the generic nature of the ConstQFD software the range of possible applications is large. For example, it could be used for material or component selection. The attributes required from the materials (such as cost and aesthetics) could be entered as inputs into the software. The available materials can then be entered in the Construction Solutions matrix. Based on the results from the software the project team can make informed decisions as to which material to select.

The UK construction industry has been continually criticised for its low productivity and poor quality since the early 1960s. Throughout this period, it has been widely recognised that building design has a significant impact on construction performance, and the separation of the design stage from the construction stage has contributed to the poor performance of the industry. Whilst it is tempting to conclude that overlapping the design and construction phases will solve the problems of the construction industry, evidence from design built projects show that this is not always the case. Rather significant improvements in performance could be achieved if the construction industry is to encourage closer integration and collaboration of all stakeholders at the design stage.

- The conclusions of the thesis indicate that manufacturing techniques are capable of being applied to the UK construction industry.

- This research has established that the construction industry could indeed improve on its performance by implementing manufacturing techniques such as TQM and Lean. It has also been established that these techniques are more effective when integrated with QFD as a client requirements processing tool.

- A novel computerised QFD tool "ConstQFD" has therefore been developed to overcome the complex nature of gathering and processing client's requirements in the construction industry.

The results of the ConstQFD evaluation indicate that there could be significant advantages when used as a decision support tool. The software would allow project team members to perform "what if" analysis by manipulating various variables such as clients' importance ratings and relationship values. In addition the software would relieve project participants from the laborious QFD computations so that their efforts could be spent on other design activities. Potential benefits of the software include:

- Enhanced identification and response to clients' requirements.
- More complete up-front planning.

- Reduced cycle time, through less redesign.
- Better cross-functional communication.

Even though the ConstQFD software has proved to be versatile in terms of computational speed, and allowed changes to be made quickly it could be improved by integrating techniques such as the Analytical Hierarchy Process (AHP) and Analytical Neural Networks (ANN). These techniques could make it more powerful in terms of information processing. Extensive field evaluation is however recommended to assess its commercial viability.

It is envisaged that the outcomes would enhance the performance of the construction industry and guide it towards strategic exploitation and delivery of quality. The results would hopefully serve as a proof-of-concept and as a case example of the potential benefit of QFD in the UK construction industry.

9.2 Suggestions For Future Research

As stated in Chapter Nine, although the ConstQFD software is very versatile, it is limited only to the product planning and design phase of the QFD technique. However, significant benefits could be obtained by extending it to cover the other phases of QFD. Although the ConstQFD software provides a means for data input, storage, manipulations and presentation, which are of practical importance, its functionality could be improved beyond computerising the manual work in QFD.

The object oriented nature of the ConstQFD software opens up possibilities for the integration of other tools such, Analytical Hierarchy Process (AHP) and Analytical Neural Networks (ANN). For example, the AHP process could be invoked to prioritise the client's requirements. Since this process is based on a pair wise comparison of items, the possibility of inconsistencies in the client's importance ratings will be reduced.

The ANN technique could be used to dramatically improve on the ConstQFD software. One area for which the construction industry will benefit is a software that is able to link design specifications to material selection and cost analysis. ANN could be used to achieve such functionality. The software database must first be populated with the required materials information and constantly be updated as new information becomes available. A well-trained ANN will bring significant improvements in the construction process.

APPENDIX 1

SAMPLE OF QUESTIONNAIRE

Innovative Management Techniques Review Questionnaire

Thank you for taking time to complete this questionnaire. Some of the questions are provided with multiple answers. Please circle the appropriate numbers.

Name of firm/company________________________________

Name of respondent (optional)________________________________

Position (title/status)________________________________

Tel., Fax, E-mail________________________________

1. Please tick the appropriate box to indicate the number of people presently employed in your organisation.

☐ Less than 50 ☐ 50 – 250 ☐ 251 – 500 ☐500 – 1000 ☐ 1001–2000 ☐ Over 2000

2. Please tick the appropriate box to indicate the approximate (present) annual turnover of this firm?

☐ Less than £5m ☐ £5m – £10m ☐ £11m – £20m ☐ £21m – £50m ☐ £51m–100m ☐ Over £50m

3. What industry sector do you belong to?________________________________

4. Main Product/Service________________________________

5. Is the firm/company ISO 9000/BS 5750 Certified? ☐Yes ☐No. If the answer is yes, please indicate the series (e.g. ISO 9002)____________________

6. What does quality mean to your organisation? ________________________________

____

____

Use of tools and techniques

7. Which of these product management techniques do you employ in your company? (Multiple answers apply).

a. Computer Integrated Manufacturing/Construction **(CIM/C)**

b. Quality Function Deployment **(QFD)**

c. Lean Manufacturing/Construction **(LM/C)**

d. Total Quality Management **(TQM)**

e. Agile Manufacturing/Construction **(AM/C)**

f. Just in time **(JIT)**

g. Others (please specify)________________________________

8. On a scale of 1–5 (1 = not important, 5 = very important), please rate the importance of the underlying reason for the implementation of the above technique(s) in your company?

	1	2	3	4	5
To be more customer focused	❑	❑	❑	❑	❑
Reduction in costs	❑	❑	❑	❑	❑
To gain competitive advantage	❑	❑	❑	❑	❑
To increase profitability	❑	❑	❑	❑	❑
Improved product specifications	❑	❑	❑	❑	❑
Better co-ordination of activities	❑	❑	❑	❑	❑
Improve performance	❑	❑	❑	❑	❑
Other (Please elaborate)______________________	❑	❑	❑	❑	❑

9. Using a scale of 1 – 5 (1 = No benefit, and 5 = high benefit), rate the level of benefits realised as a result of the implementation of the technique(s) chosen?

Benefits	**CIM/C**	**QFD**	**LM/C**	**TQM**	**AM/C**	**JIT**	**Other**
Product meets customer requirements							
Product right first time							
Customer focus							
Competitive advantage							
Reduction in mid-course changes							
Reduction in new product introduction lead time							
Reduction in New Product Development time							
Reduction in costs							
Reduction in waste and rework							
Product quality improvements							
Improved methods of working							
Improved profitability							
Better understanding of customer/client preferences							
Better communications between stakeholders							
Better understanding and tighter control over business processes							
Better co-ordination of activities							
Other ______________________							
Other ______________________							

10. How do you evaluate, in general, the implementation of the technique(s) in your company/firm?

____

____

____

11. On a scale of 1–5 (1 = low, 5= high), please indicate the degree to which the barriers (listed below) were encountered in the implementation of these technique(s) in your company.

	1	2	3	4	5
Conflicting interpretations by parties involved	❑	❑	❑	❑	❑
Insufficient time spent on training	❑	❑	❑	❑	❑
Lack of information	❑	❑	❑	❑	❑
Lack of management commitment	❑	❑	❑	❑	❑
Resource limitations	❑	❑	❑	❑	❑
Employee resistance	❑	❑	❑	❑	❑
Other (please specify)______________________________	❑	❑	❑	❑	❑

12. If QFD is one of the employed techniques (if not, go to Q13), which of these areas is it implemented?

❑Product development ❑Product improvement ❑Process development ❑Still Experimenting and learning how to use it

Other (please specify)____

13. From the list below, please indicate the those which best describe your firm/company if QFD is not one of the techniques employed

a. Never heard of it
b. Know of it but do not think it will be profitable
c. Too costly to implement
d. Firm does not have the resources to implement it
e. Other (please elaborate)____

____

14. Please indicate the departments/functional groups which were involved in the QFD process?

❑Management ❑Marketing ❑Design ❑Manufacturing ❑Suppliers ❑Customers/Clients

Other(Please specify)____

15. On a scale of 1-5 please indicate the degree to which these difficulties (if any) were encountered during the QFD implementation

	1	2	3	4	5
It is complex	❑	❑	❑	❑	❑
It is resisted by some employees	❑	❑	❑	❑	❑
It is not compatible with existing infrastructure	❑	❑	❑	❑	❑
It requires a change in culture	❑	❑	❑	❑	❑
Conflicting objectives among team members	❑	❑	❑	❑	❑
Do not lead to speedy results	❑	❑	❑	❑	❑
No other technique in place to support it	❑	❑	❑	❑	❑
Other (please elaborate):__________________________________	❑	❑	❑	❑	❑

Thank you for your kind co-operation. Please use the self-addressed envelope accompanying the questionnaire to return it.

APPENDIX 2

ConstQFD INSTALLATION MANUAL

ConstQFD Installation and Instructional Manual

Table of Content

Installation Procedure

1. Locate the setup.exe file on the root directory of the disk and double click on it. Alternatively, from the start menu, click on Run and type in the following: X:\Setup.exe. (X is the letter of the drive in which the disk is). Click on the "Next" button.

2. Accept the default settings by clicking the "Next" button for both the Destination Location and the Program Folder Dialog boxes.

3. Click on the Finish button to complete the installation.

Instruction Manual

This is a short instructional manual on how to start and use the ConstQFD software. The instruction covers a ConstQFD data entry through an example.

1. *Finding and running the program* – A link to the program in the form of an icon is placed on the desktop during installation. To run the program (Figure 1), double click the program icon on the desktop.

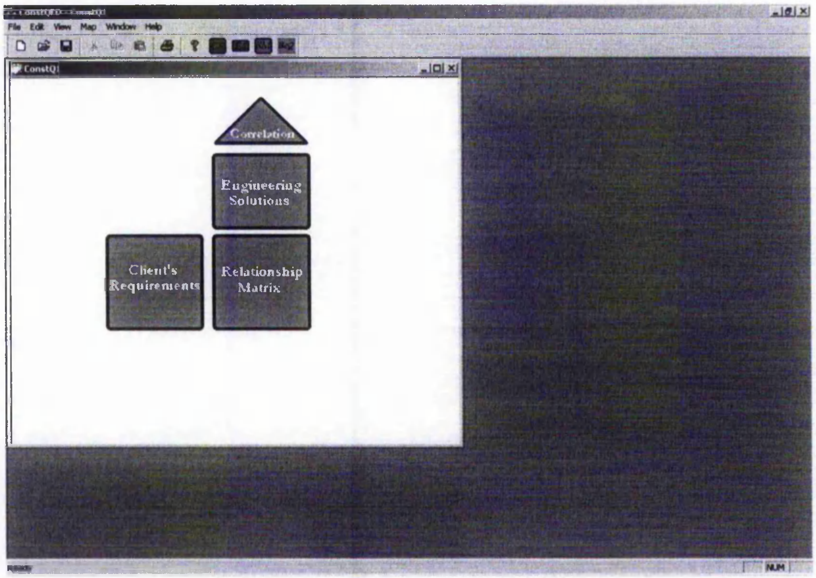


Figure 1 – Main window of the ConstQFD application

2. *Entering data in the Client's requirements matrix* – Click on the "Client's Requirements" box to open up a spreadsheet (Figure 2).

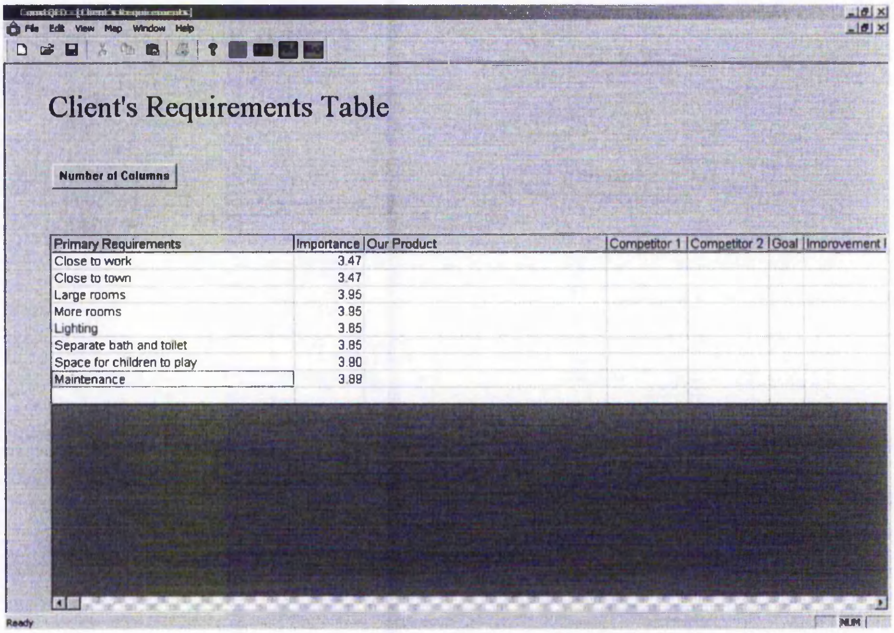
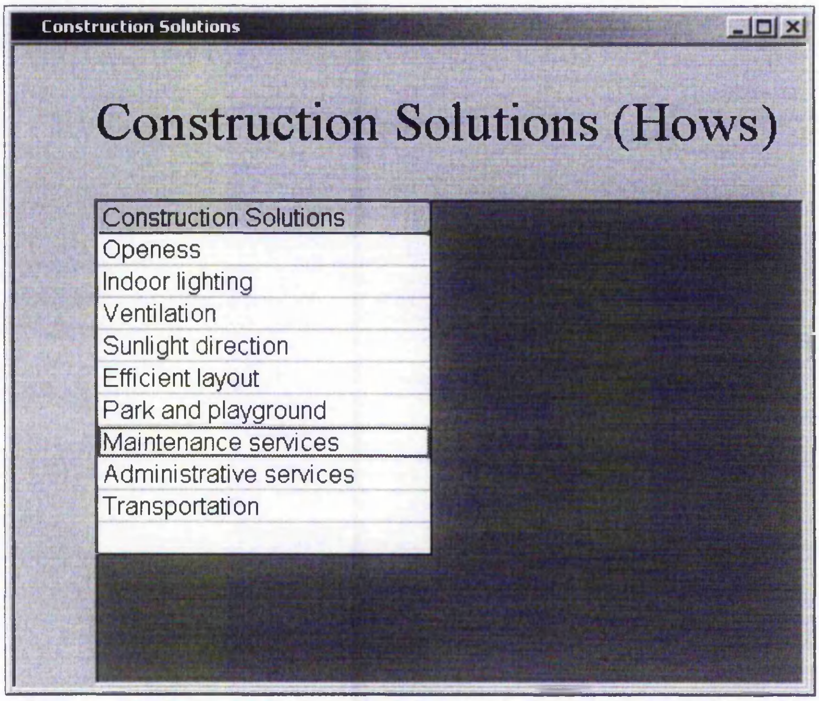


Figure 2 – Clients Requirements Table

3. *Filling the Construction Solutions Matrix* – Close the client requirements diagram after entering the necessary data and click on the Construction Solutions box to open another spreadsheet. Enter the Construction solutions and close the spreadsheet.



4. *Filling the Relationship Matrix* – Open the Relationship Matrix (Figure 3) by clicking on the "Relationship Matrix" box. Fill in the relationship matrix with the appropriate values.

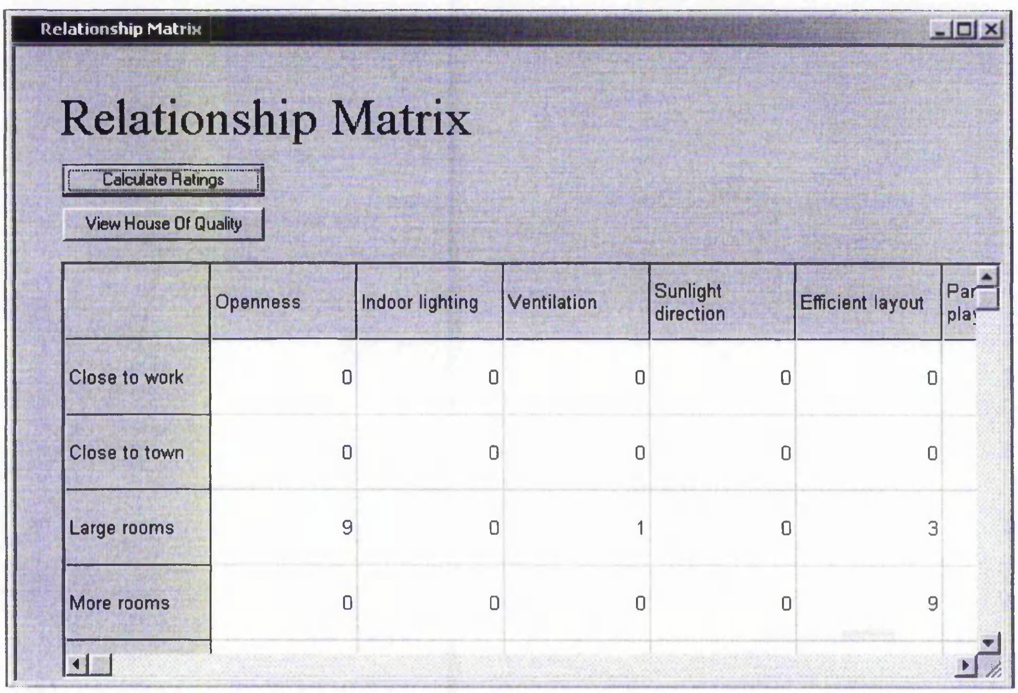


Figure 3 – Relationship Matrix

5. *Display the House of Quality Matrix* – To display the House of Quality Diagram (Figure 4) click on the "View House of Quality" button on the relationship Matrix dialog. To print, click on the printer icon on the toolbar.

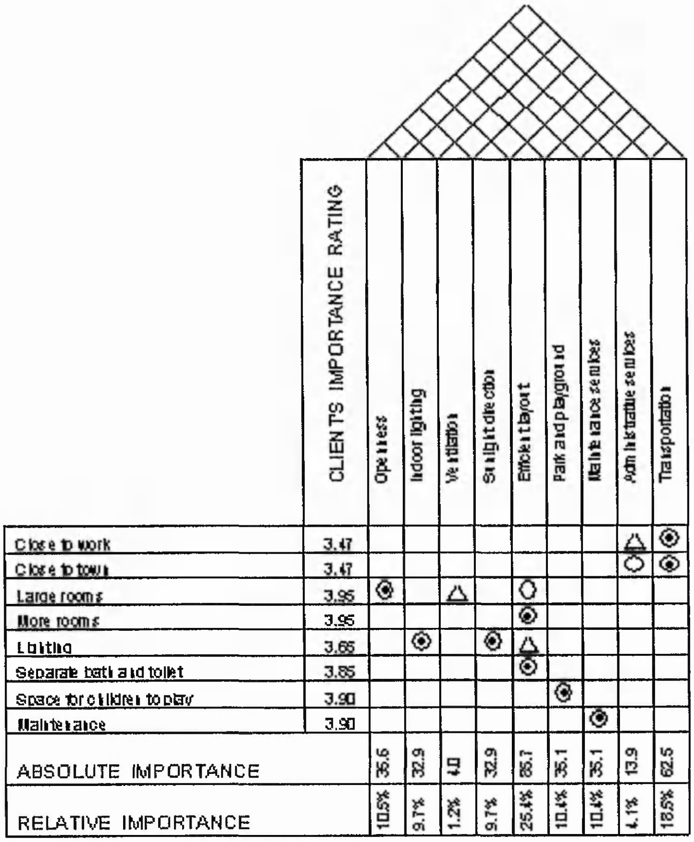


Figure 4 – The completed House of Quality Matrix

BRIEF DESCRIPTION OF QUALITY FUNCTION DEPLOYMENT

DEFINITION
Quality Function Deployment (QFD) is a method for translating clients' requirements (known as "Whats") into appropriate technical requirements (known as "Hows") at each phase of the building realisation cycle.

The features of QFD are as follows

- A structured process to help companies focus on satisfying the client
- An orderly process for determining and prioritising the technical requirements.

KEY ELEMENTS – CLIENT'S REQUIREMENTS ("WHATS") AND IMPORTANCE
The key factors determining the value of client importance are as follows:

- Ask the Client to state his requirements ("Whats") in his own words
- How important are the "Whats" to the client
- Client Ranking of their needs

KEY ELEMENTS - CONSTRUCTION SOLUTIONS ("HOW'S")
The key features to look for identifying "Hows" are

- How do you satisfy the client Requirement ("Whats")
- Client's Requirements
- Translation For Action

KEY ELEMENTS – RELATIONSHIP MATRIX
This matrix is used to determine the strength of the relationships between the "Whats" and the "Hows".

BENEFITS OF QFD IMPLEMENTATION IN CONSTRUCTION ARE:

- It encourages the establishment of multi-functional teams in the early stages of the construction process. This helps to foster a team environment and encourage appropriate and timely communication and decision-making.
- It enables the team to focus on 'front-end' activities, thus paying attention to the identification, definition and evaluation of the client's requirements.
- It reduces the uncertainty involved in building and process design.
- It enables better co-ordination of the participants and activities of the phases of construction projects and identifies the responsible parties.
- It increases client satisfaction
- Reduction in waste and rework, and hence reduced cost.
- Shorter building development time

APPENDIX 3

PUBLISHED PAPERS

Quality Function Deployment – Past, Present and Future directions

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Abstract
Increasing global competition, rapid technological advance, disappearance of niche markets, release of captive customers consequent upon collapse of national barriers, and proliferation of both guru and practitioner driven solutions are the realities of current turbulent business environment. The future of any business or firm as a player in the global market will depend on its ability to attract and retain satisfied customers. In order to meet the requirements of customers better, many companies are implementing new approaches and techniques which are built around the idea of more customer-focused, higher quality products, and the bringing together of multifunctional teams. One of such techniques is Quality Function Deployment (QFD).

QFD originated from Japan as a product development strategy for assuring that quality is built into products. The objective of Quality Function Deployment is to convert the customer's demands into substitute quality characteristics at the design stage and to deploy them into production activities, thereby establishing the necessary control and check points prior to production start-up. In addition it facilitates the process of concurrent product development and encourages multifunctional teams to work towards a common goal of ensuring customer satisfaction. QFD was introduced to the West in the mid 1980s and has met with varying degrees of success.

This paper reviews some historical developments of Quality Function Deployment (QFD) concept and also the state of the art. In addition it also analyses the published material on QFD and other related techniques. The potential future development of QFD is also discussed.

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INTRODUCTION

Quality Function Deployment (QFD) is a methodology for translating customer-required quality characteristics into appropriate product or service features (Ranky, 1994). The underlying philosophy of QFD is a focus on satisfying the customer [Akao, 1988; Ghobadian and Terry, 1995]. It is a method for systematically focusing all the departments in an organisation towards the features of their products/processes that are most important to their customers. Through the use of an integrated set of tools, QFD ensures that the customers' requirements translate into accurate technical requirements and actions throughout each stage of product development. In addition the QFD process facilitates multidisciplinary teamwork and ensures that priority is given to those aspects of the design with the most potential for improving customer satisfaction and competitive advantage.

There are several definitions for QFD [Cohen, 1995; Shillito, 1994]. Akao [1990], defined quality function deployment as "converting the customers demands (whats) into quality characteristics (hows) and developing a designing quality for the finished product by systematically deploying the relationships between the demands and the characteristic, starting with the quality of each functional component and extending the deployment to the quality of each part and process". There are two similar but different approaches to QFD (Figs 1 and 2), developed by Akao and Makabe. Akao's approach is the basis of the GOAL/QPC Matrix of Matrices developed by Bob King which includes about thirty matrices whilst the ASI Four-Phase approach is based on Makabe's model.

The QFD technique is built around the following four principles [Sivaloganathan et. al., 1997]:

1. Defines quality as meeting the requirements of the customer.
2. Uses the principle of Deployment.
3. Attaches numeric values to the otherwise qualitative customer requirement importance and,
4. Uses matrices (quality charts).

QFD defines quality as meeting the requirements of the customers. Hence the development team start the product design by first establishing the customers' requirements. These requirements are then deployed throughout all functions and activities of the company. According to the principle of deployment, product quality can be assured through the quality of the subsystems, the quality of the subsystems can be assured through the quality of the parts and the quality of the parts can be assured through the quality of the process elements [Akao, 1990]. Very notable in the QFD implementation is the generation of Quality Charts or Matrices. The matrices trace a continuous flow of information from customer requirements to plant operating instructions and thus provide a common purpose of priorities [Sullivan, 1986]. In addition they serve to focus the decision-making interactions of the multifunctional team and also provide a visual display of the relevant information for ready reference [Clausing, 1994].

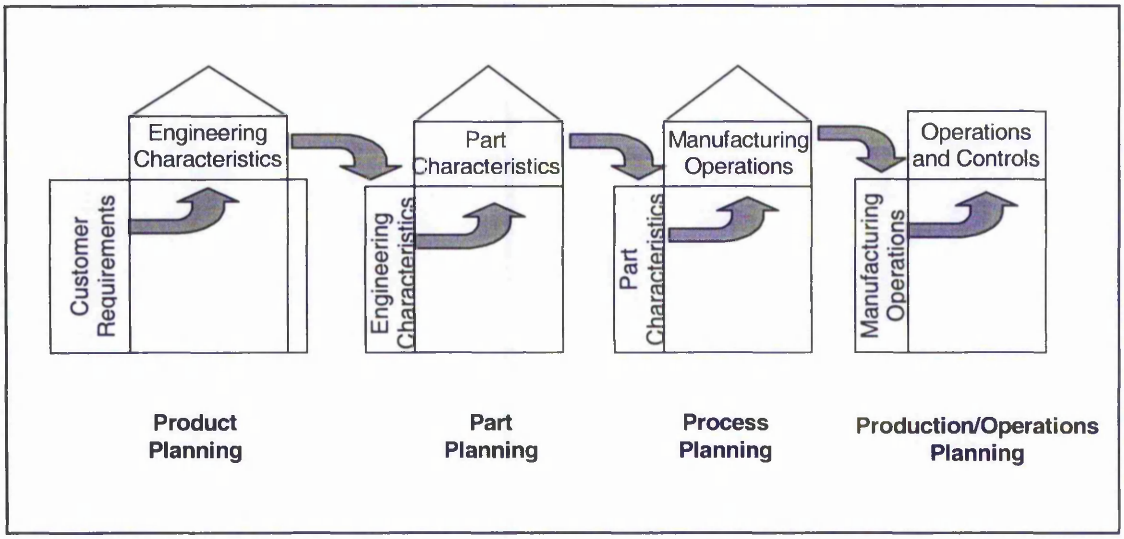

Fig. 1 –The Four-Phase QFD process

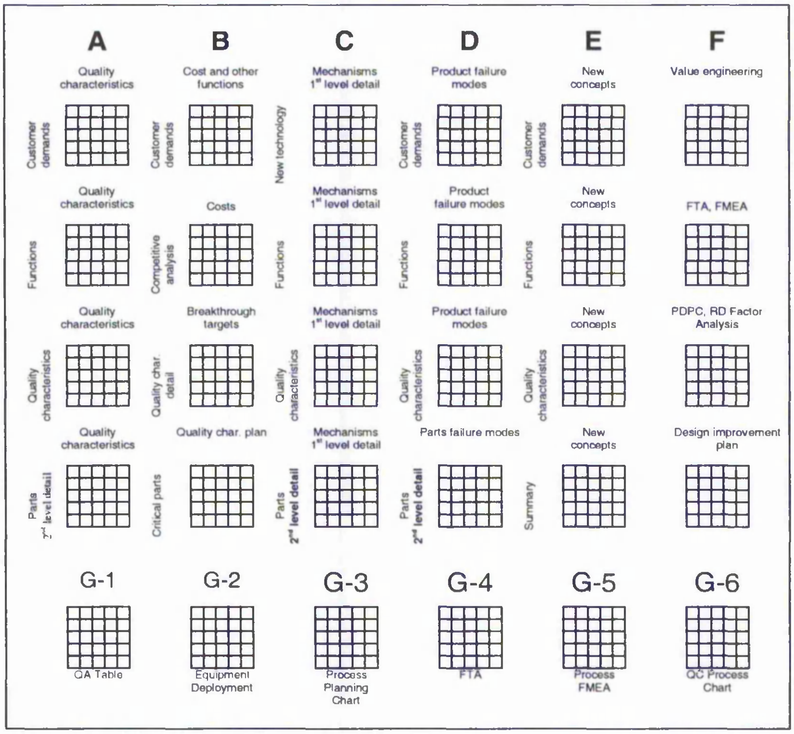

Fig 2 – The GOAL/QPC Matrix of Matrices

DEVELOPMENT OF QFD

Historical background

The concept of QFD was conceived by the Japanese in the late 1960s [Akao, 1990]. This was during an era when Japanese industries broke from their post-World War II mode of product development through imitation and copying and moved to product development based on originality. The purpose was to develop a quality assurance method that would design customer satisfaction into a product before it was manufactured. The first large scale application was presented by Kiyotaka Oshiumi of Bridgestone Tire, which used a fishbone diagram to identify each customer requirement (effect) and to identify the design substitute quality characteristics and process factors (causes) needed to control and measure it.

The technique generated very little interest until 1972 when the Kobe Shipyards, guided by both Dr. Shigeru Mizuno and Dr. Yasushi Furukawa [Akao, 1997], developed a table for the design of their super-tankers that "systematised" the true quality (customers' needs) in terms of functions, then showed the relationship between these functions and the quality characteristics. Akao called the new approach Quality Deployment (QD). At about the same time, Value Engineering principles were linked to what later became known as "narrowly defined QFD". Mizuno [1978] described narrowly defined QFD as " step-by-step deployment of a job function or operation that embodies quality, into their details through systematization of targets and means". The combination of QD and narrowly defined QFD gave rise to broadly defined QFD.

The introduction of QFD in the USA and Europe began with the publication of an article by Akao [1983]. Subsequent efforts by Larry Sullivan of the American Supplier Institute and Bob King of GOAL/QPC have led to the establishment of on-going QFD seminar programs throughout the United States ever since. The use of QFD in the US spans a broad range of industries, with particular extensive use in the automobile industry. In the USA the first serious exponents of QFD were the 'big three' automotive manufacturers in the 1980's, and a few leading companies in other sectors such as electronics. However, the uptake of QFD in the Western world appears to have been fairly slow. There is also some reluctance among users of QFD to publish and share information - much more so than with other quality-related methodologies.

The present State of the QFD Technique

Current Developments

The increased interest in QFD has facilitated research into its integration with other techniques to cater for it perceived weaknesses and to make it even more effective. Amongst these techniques are Fuzzy Logic, Multi-attribute design optimisation, axiomatic approach to design, and Taguchi Methods. Locascio [1993] described the application of multi-attribute optimisation with QFD. The general method consists of determining the relationships between the "whats" and the "hows" and integrating all the important design criteria into a design objective function. This function represents the design attributes and the relationships between them as dictated by the end user. Once the model is created formal optimisation methods are used to get the best target values. Masud and Dean [1993] have also reported on some preliminary work involving the use of Fuzzy Sets in QFD. The aim of the research is to investigate how the QFD analysis can be performed when the input variables into the charts are treated as linguistic variables, with their values expressed as fuzzy numbers.

Generally, the use of QFD in Japan was for product improvement based on an existing model. Clausing and Pugh have shown that if the Stuart-Pugh Concept selection is coupled with QFD, it usage can be extended to new product introduction. This may account for the reason why QFD implementation for the development of totally new products in the USA was higher than in Japan [Akao, 1997]. In addition to integrating other tools and techniques into the QFD methodology, other researchers made some structural changes to the QFD matrices [Mill, 1994]. Another approach, Blitz QFD, was developed by Zultner [ReVelle, 1998]. Blitz QFD does not use matrices, and only the topmost important ranked customer requirements are deployed. This streamlined approach to QFD is particularly suitable for teams with severe constraints on people, time and money. Although QFD is regarded as a powerful concurrent engineering tool, it is argued that it is a phased and sequential process and therefore does not allow for the parallel deployment of all artefact values such as X-ability, cost, tools and technology (Prasad, 1998). In order to eliminate this phased nature, Prasad expanded the original definition of QFD to include parallel deployment. He called this approach Concurrent Function Deployment.

QFD Implementation

QFD is used extensively by many companies in Japan, USA and by some companies in the UK. Companies which have successfully implemented QFD include Toyota, Ford Motor Company and GEC-Marconi [Hauser and Clausing, 1988, Johnston and Burrows, 1995]. Due to many reported benefits [Bossart, 1991; Hauser and Clausing, 1988; Lockamy and Khurana, 1995; Sullivan, 1988; Vonderebse and Ragunathan, 1997], more and more companies are now investigating the use of QFD [Kathawala and Motworani, 1994] for part or all of their product or service development and several case studies have emerged. For example, Tsuda [1997] compared two QFD models, a '2-storied quality chart' and a parallel flow quality chart with case studies on Japanese automobile company to prove the validity of the two models as good management tools. Delano et al [2000] described the application of QFD and Decision Analysis in an R&D case study in the selection of the design for a new cargo/passenger aircraft. Hochman and O'Connell [1993] used the case of a portable telephone to show how customer environmental concern can be integrated into QFD. Dean [1997] explained how to use the method for the successful design of large space systems.

Traditionally, the applications of QFD have tended to be focused on manufacturing. However it is now employed in wide ranging areas. Maddux et al [1991] reported the use of QFD as a strategic planning tool in the formulation of a strategy to successfully implement and manage a program called Production Engineering Tools. He contends that

QFD can be successfully applied as a strategic planning tool for the design of intangible products such as program or activity. In the same vein Crowe et al [1996] described how to use QFD in manufacturing strategic planning whilst Philips et al [1994] described the use of QFD in Policy Formulation [Sullivan, 1988] using a case study as an example. Ghobadian and Terry [1998] also examined how Alitalia, the airliner, successfully used QFD to design a new business class. QFD has also been applied successfully in the educational and health sectors [Einspruch et al, 1996, Pitman et al, 1996, Lim and Tang, 2000, Wiklund et al, 1999]. Various studies also describe its application in construction [Abdul-Rahman et al, 1999].

Although majority of the available literature give account of the successful implementation of QFD and it associated benefits, not every QFD project leads to the desired success. Essentially, the reason for this is a combination of several factors [Herzwurm et. al., 1998]. Most practitioners believed companies who are applying QFD for the first time to start with small projects, as these are more manageable and more likely to succeed. Also most of the literature agree on the fact that top management support is important for the success of the QFD implementation [Dickinson, 1995]. Although a matrix size of about twenty to thirty requirements [Laurikka et al, 1996] is considered reasonable by many authors, others [Griffin and Hauser, 1993] believe that it is important to get as many as possible.

The Future

Quality Function Deployment is accepted as a powerful methodology for incorporating customer requirements in the specifications of a product or process. The QFD methodology has established quality management in product development and has provided a communication tool for the designers. It can be deduced from the available literature that the future development of QFD will revolve mainly around two areas:

1. The incorporation of the necessary design methods [Sivaloganathan et al, 1997]
2. The development of software tools to support the QFD process

Incorporation of necessary tools

The versatility and flexibility of the QFD methodology allows it to be integrated easily with other development tools. Each combined implementation of QFD provides new opportunities and stronger contributions towards cost and productivity improvements. The incorporation of QFD with currently emerging tools like design for "X", CAD/CAM and computer aided process planning will aid product development teams to develop quality designs and to produce goods and services at acceptable costs.

Software support for QFD

In most QFD implementations the data generated are recorded manually. This can impose several general limitations on the ease of handling the tool, which includes issues such as size of matrix, editing, maintaining consistency and performing various computations [Reich, 1995]. For large and complex products, the number of items ("whats" and "hows") can run into hundreds or thousands [Clausing, 1993], thus making the matrix difficult to handle manually. One way of going about this problem is to streamline the number of requirements, but in doing so potentially useful information could be lost. A better solution is the use of software to assist the QFD process. Currently there are commercial software available for assisting the QFD process. Although these software have helped to alleviate some of the limitations, most of them are nothing more than editors for the QFD matrices. The incorporation of artificial intelligence techniques and other appropriate tools into these software to aid in detecting conflicts, checking inconsistencies, and in addition providing support for the decision-making aspect of QFD will go a long way in making the methodology much more powerful.

CONCLUSIONS

Quality Function Deployment is a well-established methodology in manufacturing systems. It is a powerful technique for designing products that meet the requirements of the customers. The popularity of QFD due to the benefits it gives, is evidenced by the number of publications on it. It can be inferred from the available published work that the majority of QFD implementations stop at the first stage matrix (House of Quality) and do not use the downstream matrices. Experiences from numerous QFD projects have shown that companies very often encounter some problems at the initiation stage. These problems are mainly due to the methodological and practical weaknesses in the published basic QFD approaches and the lack of comprehensive guidelines to generate information for the different quality tables [Pfeifer et. al., 1996]. With the advent of computers, it has become possible to handle, analyse and use very vast amount of information about design. Computerising the QFD process in addition to incorporating necessary design tools can enhance the capability and usefulness of QFD.

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A FRAMEWORK FOR THE APPLICATION OF QFD IN CONSTRUCTION

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Abstract
The ever-increasing competitive environment in which companies operate has resulted in an increasing demand for production quality and shorter lead-times. In addition the limited resource and increasing product complexity requires a more optimised product design in order to achieve a competitive advantage. Quality Function Deployment (QFD) is a systematic technique for translating customer's requirements into product specifications, and hence enhancing the quality of the product and increasing customer satisfaction. The QFD concept advocates the implementation of a multidisciplinary team approach to product development by encouraging collaborative decision making based upon team co-ordination and information sharing, and hence reducing waste and rework.

QFD is mainly applied in the manufacturing industry, but has also been applied in other industries like the service and software industries. The fragmented nature of the construction industry which results in poorly co-ordinated projects may be improved by the application of QFD during product development. Construction industries in Japan have followed their manufacturing counterparts in implementing QFD. However the practice of QFD in the UK construction industry is not widespread. Construction products are generally bespoke in nature and usually have the prototype is the product itself. This results in the need to get the product right for the first time. Although many of the construction firms in the UK are adopting the ISO 9000 Quality System, one area that the industry needs to improve upon is its ability to accurately determine client's requirements and successfully transform them into plans and specifications, which is a major feature of QFD.

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INTRODUCTION

Construction as a manufacturing process

With increasing international trade and global competition, rapid technological advance and the opening of global markets, companies are faced with increasing demand for production quality and shorter lead times. Coupled with the introduction of the Euro, and the likelihood of subscription by the UK, the British construction industry is at the threshold of a new competitive game plan. With the elimination of currency transaction difficulties as a result of a common currency across the EU, more construction firms may enter the UK construction market and thereby increase the competitive pressure. Whereas the manufacturing industry, stimulated by the advances in technology and changing customer needs, have adopted new working practices which have brought improvements in product quality and customer-focused operations, the construction industry has been slow to adopt new techniques (Roy and Chochrane, 1999). Traditionally, the construction industry has separated the design from the production of its buildings and structures and has encouraged the fragmentation of professional activities [Harvey and Ashworth, 1993].

Many construction clients have expressed dissatisfaction regarding the delivery of completed projects, the quality of service and the predictability of costs. As a result, several governmental and institutional reports (Phillips, 1950; Emmerson, 1952; Banwell, 1964; Gyles, 1992; Egan, 1998) criticised the performance of the construction industry. Most of these reports agree that the fragmented nature of the industry, lack of co-ordination and communication between parties, the informal and unstructured learning process, lack of investment into research and development, adversarial contractual relationships, and lack of customer focus is what inhibits the industry's performance. As a result of these reports attempts have been made to solve some of these problems through the implementation of new procurement routes and contract forms. However, the problems of construction are still apparent (Egan, 1998, Lee et al, 2000). The Latham (1994) report and more recently the Egan (1998) report shows that there is the need for improvement in the performance of the construction industry with regard to quality, responsiveness, and cost effectiveness. Although many construction firms in the UK have adopted the ISO 9000 quality system, they have been slow in adapting the techniques which have brought improvements in the manufacturing and other industries [Moatazed-keivani, et al, 1999].

The present day construction industry is characterized by the need to cope with change, and needs to address its problems in order to become an efficient and effective provider of quality construction products delivered on time and within budget [Smith and Love, 2001]. Recent publications suggest that the construction industry has much to learn from other industries, and the adoption of best practices from these industries, notably the manufacturing industry may improve the performance of the construction industry (Crowley, 1995; Powell, 1995; Gunasekaran and Love, 1998; Howell, 1999). Techniques like industrialisation (i.e. pre-fabrication and modularisation), computer integrated construction, process modelling, and robotics and automated construction (Koskela, 1992, Love and Gunasekaran, 1996) have been suggested to improve the industry. Crowley (1995), for example, argued that "construction can, and should be viewed as a manufacturing process", and in this context examined the concepts of computer integrated manufacturing (CIM) and lean production and their relevance to the construction industry.

Whilst it will be possible to identify useful ideas from manufacturing, it will require a change of attitude of mind towards system thinking based upon a better understanding of the integration of individuals wants and needs, resulting in an uncompromising focus on quality and production [Powell, 1995]. Fortunately some of these manufacturing techniques like Quality Function Deployment provide a framework for the integration of customer/client's wants and needs into product design and also facilitates the use of interdisciplinary teams.

This paper gives a brief description of the Quality Function Deployment methodology and goes on to propose a framework for its application in the construction industry.

QUALITY FUNCTION DEPLOYMENT

QFD is an interdisciplinary and systematic technique for designing products and services based on the customers' requirements [Akao, 1988; Ghobadian and Terry, 1995]. It has attracted a lot of attention since its inception in Japan at Mitsubishi's Kobe shipyard site in 1972, as evidenced in the volume of related articles in publication [Ghobadian and Terry, 1995; Kogure and Akao, 1983; Nicols and Flanagan, 1994; Prasad, 1998]. There are two similar but different approaches to QFD, developed by Akao and Makabe. Akao's approach is the basis of the GOAL/QPC Matrix of Matrices developed by Bob King, which includes about thirty matrices whilst the ASI Four-Phase approach is based on Makabe's model. The four-phased approach consists of four matrices (Product Planning Chart Part Planning Chart Process Planning Chart Production and Operation Planning Chart) which trace a continuous flow of information from customer requirements to plant operating instructions and thus providing a common purpose of priorities [Sullivan, 1986]. The GOAL/QPC Matrix of Matrices consists of about 30 matrices in a less structured format which describe everything from how to convert Customer Requirements into Product Characteristics to how to prioritise FMEA studies. The matrix of matrices approach provides more depth analysis than the four-phase approach. Although the success of QFD in manufacturing is well documented, QFD implementation in construction is not very well spread.

QFD is used extensively by many companies in Japan, USA and by some companies in the UK. Companies which have successfully implemented QFD include Toyota, Ford Motor Company and GEC-Marconi [Hauser and Clausing, 1988, Johnston and Burrows, 1995]. Due to many reported benefits [Bossart, 1991; Hauser and Clausing, 1988; Lockamy and Khurana, 1995; Sullivan, 1988; Vonderebse and Ragunathan, 1997], more and more companies are now investigating the use of QFD [Kathawala and Motworani, 1994] for part or all of their product or service development and several case studies have emerged [Tsuda 1997; Delano et al 2000; Hochman and O'Connell 1993; Dean 1993]. Traditionally, the applications of QFD have tended to focus on manufacturing firms. However it is now employed in wide ranging areas [Maddux et al, 1991; Crowe et al 1996; Philips et al 1994; Sullivan, 1988; Ghobadian and Terry 1998; Einspruch et al, 1996; Pitman et al, 1996; Lim and Tang, 2000; Wiklund et al, 1999].

QFD in construction

Although QFD has been extensively used in both the manufacturing and service industries, its application in the UK construction industry is not very widespread. However the available literature shows that there have been some applications and studies of QFD in construction elsewhere [Abdul-Rahman et al, 1999; Akao, 1988; Antti, 1995]. The low uptake of QFD, and in general manufacturing techniques, would seem to be due to the traditional conservatism of the construction industry and the concept of the "uniqueness" of construction. Although there exist some differences (See Table I) between the two industries that can affect the successful implementation of QFD in construction, if these differences are taken into consideration, the benefits of QFD can be realised in construction. Having said that, there are actually some characteristics of the construction industry which favours the implementation of QFD. For example, the active participation of the client in the construction process and the current move to more integrated forms of procurement like design and build provides a good groundwork for the success of QFD. Also the current move of some of the construction industry into entering strategic partnerships will encourage teamwork which is critical for a QFD project. The problem of the huge volumes of information required during the QFD implementation can be reduced by taking advantage of the power of IT [Stauffer et al, 1997; Pfeifer, 1997].

Table I. Differences between Manufacturing and Construction

Manufacturing	Construction
1. Products are usually production line type	Usually one-off
2. Product is usually simple in nature	Construction products are usually complex
3. Buyers of manufacturing are usually not deeply involved in the development process.	The owner (client) of a construction product is deeply involved in the construction process.
4. Product development involves the participation of permanent integrated departments in the same organisation	Temporary organisations formed on project to project basis
5. The product generally tends to depreciate over time	The product appreciates in value over time

THE QFD FRAMEWORK

The framework (fig. 1) consists of two components – Clients Requirements Processing and Roles and Responsibility Diagrams. The client Requirements processing part of the framework includes a QFD database program for the storage and retrieval of information and also tools for analysing and generating the QFD matrices. The aim of the framework is to know as much as possible the requirements of the client before a project is designed and constructed and also to encourage a multifunctional approach to the design of a construction project. The combination of these components allows the client's requirements to be prioritised and transformed into specifications for the complete facility through a logical and structured pattern. The following section gives a brief description of the components of the framework.

Client's Requirements Processing Diagram

This is used to determine and analyse the requirements of the client. The fundamental task at this stage is to determine what the client expects from the facility and how it is intended to be used. The stages of the client's Requirement processing Diagram is given below:

1. *Appointment of Design Team* – To improve the effectiveness of the design and construction process and break down the traditional barriers that exist between designers and constructors, it is necessary to form an integrated design team once the feasibility of the project has been established and the decision to go ahead taken. This team will normally consist of the client/client's representative, an architect/engineer, and members of other professions such as quantity surveyor, structural engineer, landscape/interior designer, mechanical and electrical engineer and if possible the contractor for the project. It is vital that all requirements and their acceptance criteria be rigorously determined and agreed between the client, the designer/architect, the manager and the contractor/specialist contractors. Also these contractors have the experience, knowledge and information about how down-stream issues can be affected by design decisions. Moreover, with the assistance of the client's and project advisor's involvement during design development, the project team can jointly develop the project's goals and objectives. This can be developed further through the initiation of partnering between contractor and design consultants [Love and Gunasekaran, 1997].

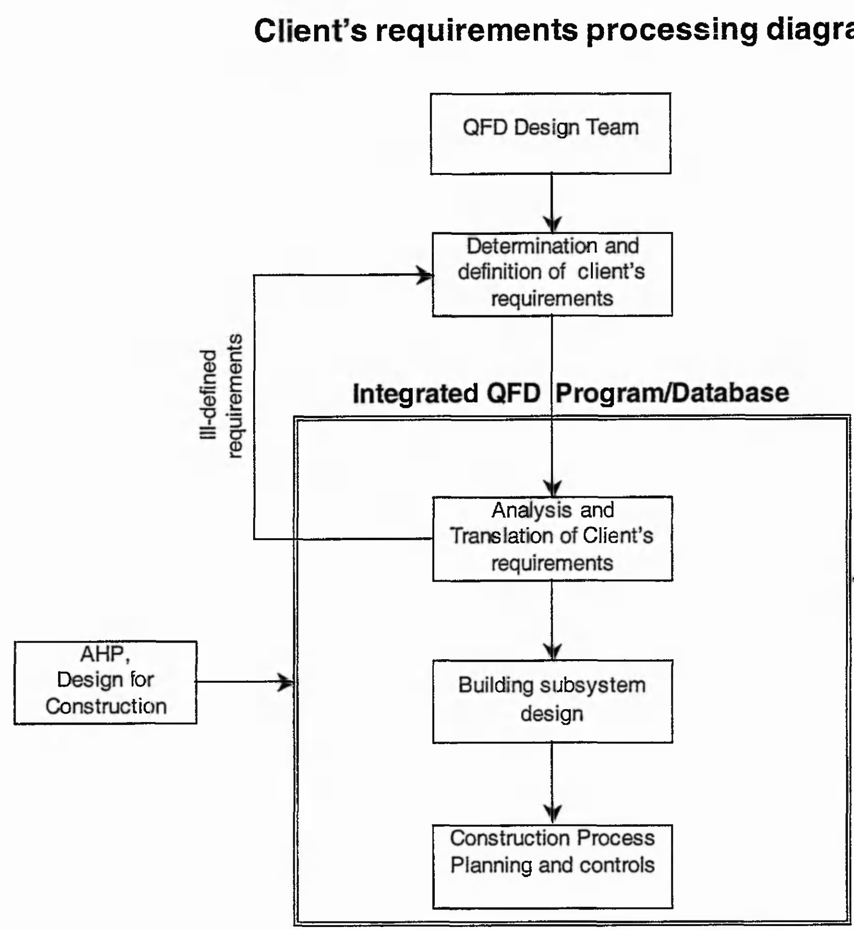
2. *Determination and Definition of Client's Requirements* – At this stage a more thorough study of the client's requirements and preferences are made, and alternative approaches to solutions considered. The requirements must be defined in terms of functions in order to give more room for the design team to manoeuvre. The client/client's representative must be able to make up his mind about the relative importance of his requirements and also state their priorities. The results obtained from this stage forms the input of the House of Quality.

3. *Analysis and Translation of Client's Requirements* – Using the House of Quality matrix the client's requirements are analysed and deployed into engineering solutions. These solutions can be grouped under the building subsystems such as architectural, structural, landscape/interior design, electrical and mechanical. Interactions and possible conflicts between the engineering solutions are considered and tradeoffs are made at this stage. The engineering solutions are rated and the most critical and important chosen for the next stage.

4. *Subsystem Deployment* – The parts deployment matrix is used at this stage to determine the components or parts of the building. The components can be generated from a bill of materials. Alternative components are considered in terms of cost, quality and ease of manufacture. The results from this stage are presented in the form of detailed drawings and specification.

5. *Construction process Planning and control* – The main task at this stage is the transformation of the detailed design into a construction/fabrication plan and into day-to-day coordination and control of processes on site [Koskela, 1992].

6. *QFD database* – Because of the complex nature of construction products and the volume of information involved, a QFD program including a database is proposed to assist in the generation of the QFD matrices and also to store the information generated during the QFD process.



Roles Responsibility diagram

	Client	Architect	Contractor
Needs identification	⊙	○	Δ
Feasibility	Δ	⊙	○
Conceptual design	Δ	⊙	
Schematic design	Δ	⊙	
Specifying	Δ	⊙	
Tendering		⊙	
Construction	Δ	○	⊙

⊙	Primary Responsibility
○	Supporting Role
Δ	Should be informed

Fig 1 – Flow diagram of the QFD Framework

Responsibility Diagram

The second component of the framework is the Responsibility Diagram [Ahmed, 1998]. This is used to determine the tasks and events necessary for the success of the construction project, and to identify the participants responsible for them. A comprehensive list of the construction project participants and their responsibilities can be found in Cornick (1991).

CONCLUSIONS

The fragmented nature of the construction industry has made it difficult for organisations to co-operate, integrate and communicate with each other effectively. In order to overcome this situation the construction industry needs to adopt a more integrated approach to construction through the use of multidisciplinary teams. Quality Function Deployment is a technique which offers a framework for a multidisciplinary approach to the design of products. The framework described above places much emphasis on using a multidisciplinary team during the design stage of the construction project. This is in order to reduce the possibility of having to redesign some or the entire product. Reduction in redesign leads to the reduction of waste, product development time and cost. The use of the framework could assist the industry in such areas as shared responsibility, interpretation differences, reduction of design construction time, and change orders reduction. It provides a collective effort towards satisfying client needs in advance. Further, the information captured within the database becomes freely available for repeated analysis and can easily be edited whenever updates are required.

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