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DETAILED DESIGN AND
CONSTRUCTABILITY

By
George Farage Jergeas

A doctoral thesis submitted in partial fulfillment of the requirements
for the award of Doctor of Philosophy of Loughborough University of
Technology.

May 1989

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DEDICATION

To my family Huda, Amar, and Dalal for their love and support.
DECLARATION

No portion of the research referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or other institution of learning.
ACKNOWLEDGEMENTS

This research has been completed within the subject area of construction Technology and Management in the Civil Engineering Department, at Loughborough University of Technology.

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ABSTRACT
The British Construction Industry has been criticised for many years. Comparisons have shown that construction in the United States, Canada, France, Germany and Australia is cheaper and quicker than present practice in the UK.

In the UK the traditional system of construction, separates the two main disciplines of design and construction. The design is carried out by a consultant and the construction is carried out by a contractor. As a result of this the construction industry is suffering from many problems such as design complexity, increasing costs and longer construction duration.

This thesis addresses the detail design stage of the design process. Detail design decisions have a significant impact on cost and time. The UK contractors have no important influence at the design stage, because designers do not take adequate and accurate account of construction methods, actual costs and the value of time. The traditional system prevents this involvement.

To overcome this problem, constructability was cited as being capable of improving project performance. There is, however no clear understanding of why or how to formally incorporate construction knowledge as part of the process of design. The designer could reduce problems for the contractor by being more aware of the construction process and the potential delays and inefficiencies which are often introduced during design. Similarly, the contractor could aid the design by contributing his knowledge of site practices to the designer and improving communications during the construction process.

The thesis focuses on integrating construction expertise with the design process at the detail design phase. It explores both the designer's and the constructor's view points, and presents a design process model.
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CHAPTER 1: INTRODUCTION TO THE STUDY

1.1 Introduction
1.2 Statement of the Problem
1.3 Main Objectives of the Research
1.4 Research Method
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INTRODUCTION TO THE STUDY

1.1 Introduction

Concern about the UK Construction Industry has resulted in many reviews of the industry and led to a series of reports which have identified areas for change [Nahapiet & Nahapiet, 1985]. Comparison studies have shown that construction in the United States, Canada, France, Germany and Australia is cheaper and far quicker than present practice here in the UK [NEDO, 1976], [Franks, 1977] & [Laing, 1979].

The traditional approach of construction separates the two main disciplines of design and construction. The design is carried out by a consultant and the construction is carried out by a contractor. The UK construction industry has no important influence at the design stage, because the traditional system prevents this, and also designers do not have adequate knowledge of construction experience [Gray, 1983]. Vanegas [Vanegas, 1987] indicated that current problems in the construction industry such as design complexity, increasing costs and tighter duration demands are forcing a re-evaluation of the traditional approach.

To overcome these problems, constructability was cited as being capable of improving project performance and a mechanism to overcome some of these problems [Vanegas, 1987], but there is no clear understanding of why or how to formally incorporate construction expertise as part of the process of design. The designer during the design stage could reduce problems for the contractor by being aware of the construction process and the site implications of his design decisions. Similarly, the contractor could aid the design by contributing his knowledge of site practices to the designer and improving communications during the construction process [Gray, 1983].
This study focuses on how the construction expertise could be provided to the design process at the detail design phase. It explores both the designer's and the constructor's viewpoints, identifies specific problem areas experienced during construction and lists some recommendations to avoid design detail problems broken down to drawings, foundations, structural frames, floors, reinforcement, formwork, material and pipelines. It examines the reasons behind design decisions which are taken without proper knowledge of their cost consequences or their impact on site operation, and presents a design process model for the traditional system of the UK construction industry. It identifies the weak points in the design process that produce poor constructability of designs. It determines who is responsible and who is paying for such problems, and by how much. It also assesses the degree of contractor's involvement on the design phase in normal contracts in order to find out whether or not there are more design difficulties in contracts where the detail design is completed before award of contract than in contracts where the construction process has been allowed to influence detail design. Finally it

presents research conclusions and recommended contractual arrangements all of which will bring designers and contractors together. It also recommends some further research work.

1.2 Statement of the Problem

From my personal site experience working for a civil engineering contractor, I encountered many problems which resulted from the separation of construction and design processes such as the design complexity and increasing costs.

However this needed stating in a scientific way and substantiating by factual evidence, therefore development of the statement of the problem was a very important stage of the research. This included
all the preliminary work required to prepare the aims and objectives of the study. The major activity of this stage was reviewing the available literature on the UK construction industry, in particular an historical background of the industry and reviewing previous works on constructability. This preliminary work had identified that some previous work at Loughborough University had been commenced [but never been taken very far or developed to any degree], but had started to identify the problem. A seminar had been held at Loughborough University of Technology to identify the areas for research and to gain prior knowledge of the problems facing the construction industry. This seminar was attended by seven personnel with a background in design, construction and research [See Chapter 3].

Using their work I was able to state that many problems still exist in the design of structures or elements of a structure. The major problem is that contractors are criticising the design detail work and they have no complaints about the concept of a design. They believe that different design detailing decisions lead to easier and cheaper construction and that design decisions are generally taken without proper knowledge of their impact on site operations and these are due to designers lack of construction knowledge. The evidence for this is the plethora of papers and recommendations intended to improve the constructability of designs.

The Literature survey revealed that the problems associated with design have been repeatedly published for so long with little emphasis on practical solutions [See Chapter 2].

The hypothesis of this research is that if we can produce recommendations on constructor's experience and knowledge, that if implemented into a new design work, would produce less design difficulties which should achieve easier, faster and cheaper construction. The consideration of constructability and the infusion of construction knowledge into the design activities will result in more efficient site operations, improved construction methods,
decreased construction difficulties, and greater recognition of local practices and limitations.

According to the practitioners [Contractors, designers and clients] surveyed in Chapters 3, 4, and 7 and also to Gray [Gray, 1983], contractors have practical skills which could benefit the client if only they could be incorporated in the design. The practical question is how to do it?

1.3 Main Objectives of the Research

The brief history of the UK construction industry [See Chapter 2], indicates the reasons why the industry has arrived in its present state of being less efficient than in many Western countries in terms of speed and cost of construction [Laing, 1979].

Against this background the obvious conclusion to the author is that some new approaches are required. Therefore the objective in formulating this work was to gain a better knowledge of the construction industry in general, and to understand if there was a problem of lack of construction knowledge during the design stage. If this was so, to promote awareness among designers of the costs and other implications, of their designs upon the construction process, and to highlight the significant aspects of design. All of this would help in bringing design and construction together and therefore enable contractors to provide the client with even better value for money.

The principal aim is to produce recommendations for junior designers, which if implemented would overcome design detailing problems and should achieve faster, easier and cheaper construction.
Specific objectives of this research were:-

1 To define and confirm that design detailing is the main problem [associated with design] regarding constructability in the UK construction industry.

2 To determine the scale and the extent of construction difficulties arising from design detailing decisions. This includes:

   2.1 To find data and evidence that design detail problems do exist, with a view to cataloging design details that, if varied, could have resulted in faster, easier and cheaper construction.

   2.2 To determine the cost, time and resource implications of design detail alternatives.

3 To determine the reasons for the details and the impediments to considering alternatives.

4 To establish, develop and validate a design process model of the UK traditional contracting system.

5 To identify the weak points in the design process where difficulties of poor constructability arise. This includes:

   5.1 To identify the points or the phases in the design process model where difficulties arise.

   5.2 To determine who is responsible.

   5.3 To determine who is ultimately paying for such problems.
To find out how design related problems could be prevented from happening. This covers the following two objectives:

6.1 To produce practical design principles and recommendations which if implemented should overcome the problems identified in items 1 and 2 within the existing traditional process.

6.2 To develop some new approaches [alternatives to the existing practices] which if implemented should solve design detailing problems and to find out how best to provide designers with the necessary construction expertise such as construction methods, cost analysis and constructability to assist their design.

1.4 Research Method

The stages of the research methodology followed were:-

1 Research plan

Developing the right research strategy in order to satisfy the hypothesis was one of the challenges faced by this research. This included all the preliminary work required to prepare the aims and objectives of the study. The major activity of this stage was reviewing the available literature on the UK construction industry, in particular a historical background of the industry. The second activity was a seminar, which was held at Loughborough University of Technology to identify the areas for research and to gain prior knowledge of the problems facing the construction industry.
2 Data collection and Surveys

Having established that a problem existed and produced the research objectives, the following actions were carried out to identify the problems:

1 A review of available publications was undertaken to assess previous work in this field.

2 Interviews were undertaken within 26 contracting organisations, to find evidence that design detail problems do exist and to collect contractor's views about design detailing.

3 Interviews and a postal survey were undertaken within 30 consulting engineer practices to discuss with designers the reasons for design detailing and the impediments to considering alternatives.

4 Interviews and a postal survey were undertaken within 30 consulting engineer practices to develop and validate the construction process model.

5 A postal survey was undertaken within 35 contractors, designers and clients representatives to investigate the degree of contractors involvement in the design process.

6 A survey of the American experience in the field of construction management. This has been achieved by:

- A review of publications in the field of constructability.

- Participation in the annual Project Management Institute (PMI) Conference held in San Francisco, in September 1988, to ascertain the state of the art in the field of Project Management in the USA.
- Visit to Stanford University in California USA, to talk to researchers and professors about their work in the field of design and construction integration.

3 Interpretation, analysis and results

The different surveys undertaken during the work were most productive, respondents were most co-operative and helpful in contributing their knowledge and experience. Comments and remarks obtained throughout all the different surveys of the research were transcribed in a summarised form. This was not easy, because of the unconstrained nature of the interviews in particular. The answer transcripts were then analysed, and all the responses to each question were brought together. The points of agreement were then apparent, as were the differences. The following interviews and surveys were undertaken:

1 Contractor Survey

In this survey views, data and evidence [drawings in particular] were collected from 26 contracting organisations identifying specific problem areas experienced by contractors broken down into drawings, foundations, structural frames, floors, reinforcement, formwork, material and pipelines. [For detail see Chapter 3 and Appendix1]

2 Designer Survey I

In this survey, 30 designers views discussing the reasons for design detailing and the impediments to considering alternatives were collected [See Chapter 4]. Personal interviews and a postal questionnaire were the main source of data. The questionnaire covered in detail the factors affecting the decision making during the design stage, in particular the factors which have a dominant influence on design decision
making which lead to the selection and specification of a particular material or a design detail. Designers were asked in depth about design thinking, what written information was used, experience and other influences and how they usually evaluate designs in cost terms.

3 **Designers Survey II**

In this survey, 20 designers views and comments were collected in order to develop and validate the design process model [See Chapter 6]. The data collected in this survey concerned influences, constraints, objectives and activities of the design process. The data was used to advance the model from its initial to final form.[See Chapter 6]

4 **Industry Survey**

In this survey, 35 designers, contractors, and clients representative views were collected to investigate the degree of contractors involvement in the design process. The answers were recorded in a numeric form. Information received was fed into the StatsWork computer package for statistical analysis. The data has been presented in graphical method, to show the decreasing or increasing level of influence [See chapter 7].

These surveys produced much useful information. It was obvious that respondents recognised the existence of design detailing problems and provided practical guidance on the way in which a different system may be used and the factors that must be considered in its design.
1.5 The Main Achievements

Overall the work proved that a problem of constructability still existed and that the separation of the design and construction processes perpetuated this situation.

This study provides new understanding of the design process of construction projects, by investigating the process from both designers and constructors points of view. It has established principles for increased understanding and future research requirements for constructability.

The main achievements of this work were:

1. A catalogue of 104 design details that, if varied, would have resulted in easier, faster and cheaper construction was produced after a detailed survey of 26 contractors. A total of 49 visits to contractors offices were made for the purpose of obtaining the data. Contractors personnel involved in these visits were Chief Engineers, Site agents, Formwork designers, Planners, estimators and civil engineering designers. Added to this an Iraqi state contracting company and a British formwork supplier helped in presenting examples from a water and sewage treatment projects in Iraq.

This catalogue proved that design difficulties are prevalent, and according to the contractors, present in every single contract. [See Chapter 3 & Appendix 1].

The main difficulties in the UK construction industry are over-complex shapes and designs, increasing costs and contractor's method of working not being taken into account at the design stage. The examples provided by contractors covered nearly all aspects of building and civil engineering. A total of 104 have been included in appendix 1 and have been grouped under the following categories.
A Drawings

Twenty examples of drawing difficulties encountered by contractors were cited during the survey. These difficulties comprised:

- Lack of co-ordination which produced conflicting information from different design sources such as Architects, Engineers, and Mechanical & Electrical consultants. Examples ranged from inserts in concrete pours being shown on the architects drawings but not on the engineer's drawings, to general confusion over the positioning of services.
- Unfinished details; the designers doing part of the design and leaving the contractor to finish it.
- Information not being sent to site but available at the design office.
- Dimensions scattered over several drawings. The Architects dimensions are frequently not tied in.
- No grid lines or datum levels, making setting out difficult.
- Minor details included with other unrelated details.
- Wrong bar bending schedule on the drawings.
- Poor information, often making it difficult to understand how the job should go together.

B Foundations

The complaints collected regarding foundation design were fewer than expected, but ten were cited.

Difficulties arose due to:

- Contractor's method of working not being taken into account at design stage, specifically on excavations such as stripping the site to a reduced level in one operation rather than individual areas excavated in isolation.
- The use of small quantities of materials at the expense of additional labour and plant time (also examined under the
materials section) such as small concrete details requiring extra formwork and labour for fixing, striking and placing concrete.

- Over-complex shapes.

C Structural Frames

Thirteen examples of difficulties with frame designs were cited. The main areas of difficulty were identified as:
- The mixing of trades within the structural elements.
- Little consideration given to speed of erection by the designers when detailing frame related structures, such as the use of insitu staircases and making openings through structural elements.
- Over-complex shapes.
- Poor sequence of operations.

D Floors

Five examples of design difficulties were cited with floors. These problems related to the use of flat soffits in formwork and the consideration given to services during the design of floor slabs.

Whenever possible flat soffits should be used in preference to beam and slab floors. The advantages are several:

- Simplicity of formwork. No changes in level to be accommodated producing savings in cost.
- Faster erection and turnaround of formwork.
- The design and installation of services is simplified, so fabrication costs are reduced.
E Reinforcement

Another problem area reported by contractors was reinforcement, with some fifteen examples cited during the survey. The difficulties with reinforcement commonly arising include:

- Over-complex shapes.
- Insufficient tolerances to allow for other trades and over congestion.
- Little consideration given to bending costs and cutting waste by designers.
- The sequence of concrete pours not taken into account during the design process.
- Insufficient use of prefabricated details.

F Formwork

Twenty eight examples of difficulties with formwork were collected during the survey. These difficulties included:

- Difficulties in the re-use and repetition of design.
- Not designing for the maximum use of mechanisation to reduce labour costs, for example table form and traveling wall forms.
- The grade of surface finish required on the concrete being difficult to achieve.
- Complex shapes, if the aesthetics of a design require a complex concrete shape then that must be accepted as a function of the design and so must be offset against the higher costs incurred. Frequently though, complex shapes seem to arise out of the belief that the minimum amount of material means the minimum cost. When dealing with concrete this is rarely the case.
- The type of surface finish called for. A high quality finish will call for an expensive plywood. Therefore in order to keep the unit cost down, it is essential that the maximum number of uses can be made with these materials.

Feature finishes, and type F3 (high quality finish which specifies no internal ties or embedded metal parts) finish are expensive to form.

- The extent of falsework support needed. Designers do not produce designs that exploit the full potential of proprietary support systems. A significant proportion of the cost of any cast in-situ concrete can lie in the falsework supporting the formwork. The larger the structure the more significance of falsework costs will be, especially in bridge works.

G Materials

Ten examples of difficulties arising from material were recorded. Designers were criticised by contractors in this area for the problems associated with the use of modern technology such as water-proofing/tanking treatments.

H Pipelines

Three examples from the author's experience in laying ductile Iron pipes in the city of Baghdad, Iraq. The difficulties with pipelines comprised:

- Pipeline conflicting with existing utilities (services such as gas lines, water lines, electricity and telephone cables).
- Not enough time and/or consideration seems to be given to site practicalities during design.
In order to have a sound and true costing, two case studies were prepared from the author's site experience. Two details for one structure were taken and just small changes in the dimensions of one of them made it more constructable than the other.

Costs of design detail differences, as well as their time and resource implications were evaluated. When the emphasis shifted to constructability, a reduction of 18% in cost was proved to be achievable on both case studies. While a reduction in construction time of 20% in case study 1 and 35% in case study 2 were proved to be achievable [See Chapter 5].

The reasons for these detail problems and the impediments to considering alternatives were established. The majority of designers surveyed agree that design detail problems do occur. The main impediment preventing designers from considering alternatives is designers are not in a position to take into account the special characteristics of the future contractors, mainly because of the competitive tendering method where contractors are unknown at the design stage and therefore no cooperation with contractors takes place. [See Chapter 4]

A design process model for the traditional system of the UK construction industry was established based on reviewing existing knowledge of the design process and extracting relevant data from literature. The design model then developed, by obtaining the industry comments through a survey among 17 designers. Finally the model was validated by subjecting it to the scrutiny of three consultants. The design process model comprises the following five main stages, briefing, designing, tendering, construction and commissioning. The design process model mainly covers the activities of project inception, project feasibility, outline proposals, scheme design,
design development and construction documents. [See Chapter 6].

5 The points in the design process where design difficulties arise were plotted on the design process model. Out of 104 problems, 77 were plotted to fall under the detail design phase, in which junior and senior designers are responsible. 9 designers out of 14 thought that clients bear the extra cost incurred, when constructability is not taken into consideration. The client also carries the burden if there is additional cost associated with the design details, while designers do not pay anything and contractors only lose some of their profits. [See Chapter 4, 5, & 6].

6 Practical design principles and recommendations from the contractor's point of view were produced, for the use of junior engineers. These recommendations cover pipe laying and concrete structural elements such as foundations, frames and floors. The reason behind choosing concrete structural elements and pipe laying is because they have most potential for improvement of construction-sensitive design. [See Chapter 3]. These principles and recommendations would help junior engineers working within the traditional system to overcome the problems identified by contractors such as overcomplexity, and not taking contractor's method of working into account at design stage.

7 Different contractual arrangements to overcome design related problems were recommended. The recommended systems attempt to bring designers and contractors together without introducing complete revolution in the existing practices and procedures. It puts the contractors very much in control of the working drawings and even the design content of the detailed construction.
Two systems were recommended. The first system introduces a new stage to the design process model called the **Redesign stage**, directly after the tendering stage. The new model will then consist of six main stages as shown in figure 8.1. In this system tenders are still based upon drawings and bills of quantities as is the case in current practice where the designer is expected to provide fairly detailed drawings. The detail design which shows how the design will be constructed could be arranged between the contractor and designer at this new stage [See Chapter 8].

In the second proposed system, the bidders submit two prices, one called **Conforming bid** and the second called the **Tag bid**. The first price conforms with all the drawings, and requirements of the engineers on which comparison could be carried out between contractors. While the tag bid option is a bid on which the contractor says how he can execute the same job using his own available resources, ideas and construction methods.

Again in this system tenders are based upon drawings and bills of quantities as is the case in the traditional UK system. But the most important thing is that the engineer would only look into the tag price if the conforming bid was the lowest.

In addition to satisfying the set of objectives, a scale of construction interferences in the design process that lead to better construction was established. This scale assesses the degree of contractor's involvement in the design phase in normal contracts.

Thirty five Engineers, Quantity surveyors, Builders and Architects working for Clients, Consultants and Contractors Organisations, were asked to consider what effect varying degrees of contractor involvement would have on selected problems from chapter 3. These problems were:
1 Poor quality of information provided for construction.
2 Inadequate consideration given to the practicality of detail.
3 Superficially economic design.
4 Poor sequencing of operations.
5 Longer construction duration.
6 Higher construction costs.
7 Inadequate construction quality.

Four distinct types of contract were suggested for consideration of their effect on the problems selected, each with varying amounts of contractor involvement in the design. These were:

A All designs complete before tender, with no contractor involvement in the design.
B Detailed design ongoing during the construction process, no direct dialogue exchanged between the designer and the contractor.
C Detailed design ongoing during construction and dialogue with the contractor.
D Contractor undertaking design detailing.

The results proved that we have less design difficulties in contracts where the construction process has been allowed to influence detail design, such as Type D or the American method where the contractor undertakes the detail design. [See Chapter 7].
1.6 Guide to Thesis

The thesis is divided into eight chapters covering the development of the research from the background investigations to the final conclusions. Figure 1.1 describes the research method followed step by step. The first section outlines a historical background of the UK construction industry. The literature survey of the UK construction performance and comparison with other countries follows; both were needed to increase the understanding of the current problems of divorcing design and construction.

To show and prove that there is a problem a survey among contractors was undertaken, which produced a catalogue of 104 examples, and some practical recommendations for better detailing. To find out more about designers experience, design process and impediments to involving contractor's experience in the design process, a designers survey was also executed.

The points in the design process where problems originated, and the cost and time implications of these problems needed to be identified to establish the scale of design detailing problems.

Finally in order to consider reasonable solutions for design detailing problems, a scale of the contractor involvement in the design process needed to be investigated.

The different parts of this thesis are as follows:

**Chapter two**, presents an historical view of the UK construction industry and a background of the subject of constructability and integrated design and construction. A detailed literature review in the UK and the USA of the concept and definitions of constructability is presented.

**Chapter three**, presents the contractors views about detail design problems and also presents a catalogue of design details that, if
altered, could have given rise to cheaper construction. This chapter presents the findings of the survey among contractors and their recommendations for making designs easier, faster and cheaper to construct.

Chapter four, shows how design staff work and organise themselves and presents designers reasons for their detailing and the impediments to considering alternatives. This chapter shows that the client in the main bears the extra cost incurred when constructability is not taken into consideration.

Chapter five, presents an evaluation of the cost, time and resource implications of the design detail differences. This chapter also presents the range of the extra cost and other implications incurred by clients when design takes place without construction in mind.

Chapter six, presents a design process model. It identifies the points in the model where difficulties arise and the personnel causing these problems.

Chapter seven, presents a scale of the degree of contractor involvement in the design process, where few sources in the literature directly address this issue from both designer and contractor viewpoints.

Chapter eight, concludes the findings of the research, by stating conclusions and recommendations that if implemented could overcome the problem of design detailing. It also recommends some further research work especially in the area of testing and implementing the research recommendation. Figure 1.1 Summarises the Research Scope.
Chapter 1 Introduction
The traditional approach, separates design and construction and therefore construction have no important influence at the design stage.
Constructability was cited as being capable of improving project performance, but it failed to infiltrate to the real design office practice.

Chapter 2 Literature Survey
Historical view to the UK Construction Industry.
Many studies of UK construction industry shows a disappointing performance of the industry when compared with that of many other countries. Each have stated, in their conclusions, that major change is required.

Chapter 4 Designers Survey
Interviews & postal survey to find out the current design practice & process. To discuss reasons for the design details and the impediments to considering alternatives.

Chapter 5 Contractor's Survey
Collect design detail problems prepared for concrete structural elements such as foundations, frames and floors. To know contractor views concerning making design easier, faster and cheaper.

Chapter 6 Design Process Model
- Establish a design process model
- Interview designer to comment on the model.
- Postal survey among designers to validate the model
- Identify the points in the model where difficulties arise
- Determine who is responsible
- Determine who is paying

Chapter 7 Contractor Involvement
- Scale of the degree of contractor involvement in the design process

Chapter 8 Conclusions & Recommendations for further research

Figure 1.1 Summarises The Research Scope
CHAPTER 2: LITERATURE REVIEW

2.1 Introduction
2.2 Historical View to the UK Construction Industry
2.3 The Structure of the UK Construction Industry
2.4 Constructability (Buildability)
2.5 Background Works
2.6 Construction Relative to Other UK Industrial Sectors
2.7 The American Practice V the UK Practice
2.8 Constructability and the Designer
2.9 Constructability and the Contractor
2.10 Constructability and Contractual Arrangements
2.11 The Summary
LITERATURE REVIEW

2.1 Introduction

There have been many studies of the British construction industry which suggest that the traditional separation of the design and construction processes is primarily responsible for the problems of current construction projects and for the less efficient performance of the industry when compared with that of many other countries. [Anglo-American Council on Productivity, 1950], [NEDO, 1976], [Laing, 1979], [Gray, 1983], [Nahapiet & Nahapiet, 1985]

This chapter will increase our understanding of the construction industry in general and its inherent problems in what is now referred to as the traditional form of contracting in the United Kingdom.

This chapter presents an historical background to the UK construction industry and presents briefly some of the previous reports and studies undertaken in the UK & USA on constructability and design influence on construction. It defines constructability and states the key types of benefits of integrating design and construction. Finally it presents previous comparison studies between the US and the UK construction Industry.

2.2 Historical View to the UK Construction Industry

Construction Industry techniques have evolved over the centuries relying mainly on labour intensive methods and low-technology materials and plant. In the past, design was strongly constrained by the type of materials and equipment, this means constructability was the primary concern of designers; evolution has reversed the considerations.
2.2.1 The guild system

Building in Britain started formally about the middle of the 13th century with the establishment of the craft guilds [Duncan, 1984]. These guilds created the foundations of the early British architecture and construction industry. They fell into two major groups, firstly masonry, and secondly carpentry.

The 13th century construction industry was highly labour intensive. The mastermason was the leader of the design and construction team. His task was to design the building, and organise and supervise the construction.

The next few centuries saw few changes to this method of working. One new craft bricklaying evolved to satisfy the 14th century passion for brick building [Dolan, 1979]. The great fire of London did establish brick laying as a separate craft. As a direct result of the fire an act was passed in 1667 making it compulsory for buildings to have walls of either brick or stone.

The enormous amount of rebuilding that was required, along with the need for rapidity, was too great a strain on the guild system. The challenge was met by the development of the building craftsman as entrepreneur [Roberts, 1987]. These new men were more concerned with getting the job done and realising on an investment than with the craftsmanship of the end product. This new approach had obvious advantages in the situation of crises which the rebuilding of London created. Thus, the new commercial building units tended to centre around an enterprising master craftsman from one of the guilds. Small enterprises undertaking bricklaying, carpentry, plumbing, etc., sprang up, each controlled by a man from the appropriate Guild background.

In order to coordinate these competing units, working at a higher rate than before, co-ordination was required. Under the Guild system with its slower tempo the design function was barely
separated from the construction function. This demand for co-ordination and design were the factors determining the rise of the role of the architect. It can be seen that the architect operated directly for the client and employed the various commercial trade units.

A difficulty which arose with the system was in agreeing a piece-rate. Because they felt they were at a disadvantage to the architect who had been privileged with a more formal education, the groups craftsmen would employ a man who was as skilled in calculating as the architect to measure their work and negotiate the rate. These men became known as measurers [present day quantity surveyor] and operated the system of 'measure and value'. As measurers became skilled at pressing the craftsmen's claims, the architect in defence would employ his own measurer to counter-claim. This situation gave rise to intense and bitter complaints and litigation at the expense of the public and to the detriment of the quality and efficiency of construction.

2.2.2 The Industrial revolution

With the beginnings of the Industrial revolution in the 18th century, the construction industry was to replace human and animal labour by machines driven by power from mineral sources. Industrialisation created sweeping changes across social life and the construction industry.

By 1870, in more and more manufacturing processes, the trend was towards the centralisation under one roof. This was attractive because of economies of transport, specialisation of function, the use of more powerful machinery and the imposition of effective work discipline.

The growth in the national economy was making an increasing demand on construction to provide for domestic and public as well as industrial buildings. Warehouses, mills, docks, factories, roads
and houses proliferated accordingly. The existing method of organising the building process was no longer adequate to the demands made upon it. Because it was cumbersome, uneconomic and inefficient, new thought in the fields of design, personnel and procedure had to be developed.

The greatest change in procedures brought about by the new order was in the development of the method of **Gross Tendering** during the period 1780-1820 [Dunican, 1984]. This was a system in which a general contractor would submit a comprehensive tender for an entire project. The tender would include the cost of all trades required. In addition, the general contractor would accept responsibility for the organisation, supervision, and discipline of the workforce.

During the Napoleonic war in 1805 **Gross Contracting** began to become standard procedure, and the industry began to re-form around it. The Government stepped in to encourage economy and speed in building. It passed a regulation that each job had to be under the control of one responsible contractor. In that period of time, the construction of large projects such as barracks and hospitals became national priority. New general contractors were encouraged by the Barrack Office, and soon began to achieve significant results, in the form of minimising delays, and raising the building standards as well as reduction in irregular employment.

All tenders were based on detailed drawings and specifications, and should provide for stage payments. Additional work should be valued on a fair assessment. This is the basis of much building work today.

The industry has not changed as much as it might have done except on one very important point. Unlike today's industry, the leader of the design and construction team in the early days was the **mastermason**, who was not only in charge of designing the building, but also of organising and supervising the construction; today's design and build contracts. Design, which is still the most
important single activity in the construction process, is now separated from the act of building under the traditional system.

2.2.3 Quantity surveying

The main contractor very quickly incorporated the other trades within his own organisation, although this process was not complete in all cases. There was still some contracting by separate trades, but it was now the main contractor rather than the architect who let what now become 'sub' contracts to other trades.

The measurer gave way to the quantity surveyor in the middle of the nineteenth century. The development of quantity surveying was as a response to the need to find a common basis for comparing the bids of main contractors for a job. Each would guess at the requirements of the drawings differently. To meet this need there were further developments, resulting in the introduction of the bill of quantities.

2.2.4 The consultant

The invention of Portland Cement in 1825 was the start of rapid development in building technology. It was some time before it became standard material and in its early days was handled by specialist sub-contractors. About the middle of the century, steel came into buildings. Later other new specialist materials became incorporated. The new materials and techniques arriving with electrical and mechanical engineering came into the industry through sub-contracting by specialists handling them. Their skills were also needed with aspects of the design. Thus they became involved with the architect or engineer in design. In due course specialist designing became separated from specialist sub-contracting in the role of consultant.

This is an important period in the study of constructability since it
represents the time where the separation of design from construction began. What began as a specialist function gradually spread throughout the construction industry with increasingly sophisticated techniques and designs.

2.2.5 Present day practice

With the increasing confusion of responsibilities and instability of pattern in the structure of the building team, clients became increasingly dissatisfied with the construction industry. It was felt that if the design and construction processes could be brought together under a single control which was directly responsible to themselves, a greater effectiveness might be achieved.

Also, contractors were dissatisfied with low profit margins. Like the clients, they wanted to establish single coordination. At the same time many clients who wished to see some overall control were not happy to achieve this by putting themselves entirely into the hands of the main contractor in his role as package dealer. From this situation there has emerged the role of management contractor.

In the UK, the traditional construction process separates design from construction through professionalisation demanded by contractual forms. It creates an environment in which parties must defend and uphold their rights, concentrating on apportioning the blame for deficiencies rather than encouraging team work.\cite{Gibbs, 1984}

Not only are new projects normally designed by separate organisations from that which will construct them, but since they must usually be priced before they are produced, there are great uncertainties for the contractor in that pricing process.

Over the last two decades or so, there has been a major development in the design and contract procedures used in UK, which seems to be significant to this research. It is the emergence of large
nontraditional arrangements which primarily seek to involve contractors in the design stage.

The emergence of an informed questioning of the traditional relationships between design and construction may be seen as systematic responses to weaknesses in traditional procedures, they provide important evidence of the direction in which improvements may be found. However some new methods of contracting procedures are developing which are overcoming this problem. We still lack sufficient facts about the industry to enable it to be planned more efficiently [Duncan, 1984].

Many problems exist in the design stage, among these are design decisions generally taken without proper knowledge of their cost consequences nor their impact on site operations.

Design organisations do not know:-

- what construction methods, plant and labour contractors would employ and each set of tenders will include a range of methods;
- the outputs or usage rates of labour and plant or the elapsed times for various operations;
- the breakdowns between direct costs and mark-ups.

2.3 The Structure of the UK Construction Industry

The construction industry is complex with its large range of contractors and professional firms, including main contractors and sub-contractors, small firms and international companies, low-tech firms and sophisticated specialists, builders and civil engineers and a whole range of professionals concerned with the industry. The products, especially buildings, include in their production a great variety of materials and components supplied by a number of
other industries. There is a great range of projects and works supplied by the industry including erecting, repairing, and demolishing buildings of all types, constructing and repairing roads and bridges, civil engineering work such as laying sewers, gas or water mains, and electricity cables, erecting overhead lines and line supports and aerial masts, extracting coal from open cast workings, multi-storey office blocks, houses and new factory complex [Hillebrandt, 1984].

2.4 Constructability (Buildability)

Constructability or buildability is a relatively new term attracting the attention of many industrial and academic organisations [Eldin, 1988]. Constructability was defined for the first time in the UK by the Construction Industry Research and Information Association (CIRIA) in 1979 [CIRIA, 1979] as:

"The extent to which the design of the building facilitates ease of construction, subject to the overall requirements for the completed building."

This definition is totally accepted and quoted in all works concerning constructability in the UK.

Also it was defined by Ove Arups the Consulting Engineers [Seminar on Buildability, 1986] as:

"The quality of design which enables the designer's intention to be achieved reliably and efficiently, in:- Form, Quality and Speed (Economy)."

Whilst CIRIA appreciates that ease of construction may be influenced by many organisational technical, managerial and environmental considerations, the major contribution was thought to lie in those factors which fall within the influence or control of the design team.

It is wrong to associate constructability purely with the aspect of
design, as there is increasing recognition for the contractors role and contribution of other parties in promoting ease of construction.

For the purpose of this thesis the following definition of constructability produced by the Constructability Task Force of the Construction Industry Institute based at the University of Texas is adopted [Constructability: A Primer, 1986]:

"Constructability is the optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall objective."

This definition is widely used in the USA in all work on constructability.

2.5 Background Works

Since the second world war there have been many studies of the British construction industry. Items 2.5.1 to 2.5.7 present briefly some of the important reports and studies:

2.5.1 Productivity Team Report [1950]

The Building Industry Productivity Team, which made a six week visit to the United States during the months of July and August 1949, highlighted the factors which make for high productivity in the US Building Industry as [Anglo-American Council on Productivity, 1950]:-

1. the complete pre-planning of the job by building owner, architect and contractor;
2. the proper co-ordination of sub contractor's work and the effective collaboration between them and the general contractor;
3  the adequacy of supplies of labour and materials and the absence of restricting controls.

The team also highlighted the following requirements:-
- the preparation of designs which have regard to ease of construction and saving of cost ...... and are based, as far as possible, on standard dimensions. Designs must take into account also the types of materials and equipment available;
- the completion, before the tender stage, of all essential working drawings, specification and schedules, and the issue to tenderers of such drawings and other details as are necessary to enable them to price the job quickly accurately.

2.5.2  The Emmerson Report [1962]

The Emmerson report [Emmerson, 1962] expressed the concern for the division between the construction and design processes. Emmerson identified the lack of communication and co-ordination between the design team and the construction team members. He attributed a number of problems as contributory factors to the inefficiency of the UK construction industry.

These included:
1  Inadequate preparation of design drawings and specifications before contracts are put to tender.
2  Pre-contract design procedures being inefficient due to their complexity.
3  Lack of communication between the client, the architect/engineer and the contractor and sub-contractors.
4  The need for competent management emphasising that modern methods of training must be developed to cover the complexities of modern building technology and human relations.
2.5.3 The Banwell Report [1964]

The Banwell Report [Banwell, 1964] called for greater attention to pre-contract planning and design formulation, particularly in defining the user's requirements. Professionalism was criticised for being too widely perpetuated giving rise to unnecessary and inefficient construction practices.

Banwell highlighted the following requirements:

1. The client must define his genuine requirements clearly at the start of the design formulation.
2. The complexities of modern construction design, requiring specialised construction techniques, demands that the design process and construction phase should not be regarded as separate fields of activity.
3. A review of traditional contractual practices to ascertain the roles of the professional parties and their codes of conduct to improve interdisciplinary relations.

Banwell commented that:

"design and construction must be considered together and that in the traditional contracting situation, the contractor is too removed from the design stage at which his specialist knowledge and techniques could be put to invaluable use".

2.5.4 The Tavistock Institute [1963]

Tavistock Institute of Human Relations undertook a preliminary study of the construction industry [Higgin & Jessop, 1963]. The attention of the research team was drawn to the statement in the Emmerson Report concerning the need for co-operation and cohesion in the building industry, and they were asked to bear in mind that better communications could be an important factor in
bringing about this general improvement.

The research team identified and presented numerous examples of misunderstandings because of poor communications. This was attributed mainly to the pattern of relationships and divisions of responsibility within the building teams.

Two propositions were stated for improving communications:

1. A coordinating function exercised over both design and construction functions by a single person or single group is better than one where functions have different coordinators.

2. If design and construction functions must have separate coordinators, then the best system of this kind is one where there is an early exchange of relevant information.

The first proposal bears an interesting resemblance to management contracting whereas the second may be achieved using a package deal, although it is more obtainable than the first in the traditional form of construction.

2.5.5 The Wood Report [1975]

The Wood report [Wood, 1975] recognised improvement in the design-construction relationship. It commented that:

"The traditional separation between design and construction was found to have diminished with consequent advantage all round ...... contractors have much to offer at the design stage, especially by way of advice on constructional implications of design solutions and decisions .... Yet, methods of procurement are still such that they are brought in too late for their advice and experience to be of practical use ..... the original problems still exist."
2.5.6 CIRIA Report

In 1979, The Construction Industry Research and Information Association (CIRIA) [CIRIA, 1979] embarked upon a research programme aimed at investigating the major problems of current UK construction practice. This renewed interest in the recurrent concern for the interrelationship between design and construction which had followed the Emmerson and Banwell Reports of the early 1960s.

CIRIA states that the problem of constructability exists; and puts it down to the comparative isolation of many designers from the practical construction process. The shortcomings as seen by the builders were not the personal shortcomings of particular people, but of the separation of design and construction functions which has characterised the UK building industry.

2.5.7 Griffith's Work [1984]

Griffith [Griffith, 1984 A], stated that constructability is presently within its evolutionary stages of development with both researchers and practitioners only beginning to recognise the benefits that may be derived and the true implications that are involved. The concern of past studies has been firmly focused upon design and the contribution that the architect can make towards the construction process. Presently, whilst design is considered paramount, the impact of management is also of great importance and it is striking the balance between design and management which is a key issue for future consideration. He therefore suggested that attention should be directed towards both building design and building management. [Griffith, 1984 A&B]

Griffith added, that most designs are buildable but some are clearly more buildable than others. A design that has taken due account of its implications upon construction, should be easier, quicker and
cheaper to construct. Used effectively buildability can lead to:

1. Simplified design leading to easier construction on site.
2. More accurate and effective communication of the design intentions.
3. More efficient and effective construction management on site.
4. Better use of design and construction resources.

2.5.8 The American Work

In 1978, [Barrie and Poulson, 1978] were concerned with the pattern of the inter-relationships between engineering design, construction and operating costs for a structure and the way in which the level of influence of the costs of a structure decrease as the project evolves.

A high proportion of the total project cost (70%) are determined at the completion of the early design phase. As the design is developed, decisions are made which lock the design into a certain set of relationships. These relationships became so complex that any subsequent change is virtually impossible or insignificant. Therefore, if there is any benefit to be derived from the construction planning contribution, that contribution must be made from day one of the design process. The nature and extent of the contribution, however, has not been tested to any significant degree in the UK because there is no method, within the traditional contract system, of the contractor interfacing so early in the design.

The Business Round Table study [B-1 1982], recognised the need for design and construction integration. The team reported [Tatum, 1987A] the following findings:

1. Effective integration requires that construction experts participate in conceptual development and planning for the project, in making decisions in design reviews, and in
scheduling and cost estimating.

2 There are barriers that prevent integration, such as resistance by owners because of perceived extra costs; traditional role of construction people which makes them unaccustomed to working in the office; reluctance of architects and engineers to accept input from construction personnel; lack of qualified personnel, training programmes, and incentives; and unawareness of potential benefits.

Five common elements of constructability which characterise many projects were investigated and developed [Tatum, 1987A]. These elements are:
- Commitment to increased cost effectiveness.
- Using constructability to meet project objectives.
- Early construction involvement.
- Pre-construction planning.
- Receptive designer.

Tatum suggests an overall project approach to improve constructability [Tatum, 1987B]. This approach provides a tool to analyse a project and identify opportunities and means for improving constructability. He first examines the significant differences in individual projects which create opportunities. Next they discuss means to improve constructability by four key actions: 1) setting the contractual approach; 2) building the project team; 3) making constructability a project concern; and 4) implementing constructability improvement. These actions by a project manager will provide a major start in realising the opportunity of improving performance by integrating design and construction.

Tatum also identified three key decisions which strongly influence constructability during conceptual planning [Tatum, 1987B]. These are: developing the overall project plan, site layout and preparation at the plot plan, and the selection of major construction methods of the project. He emphasised that early design decisions which preclude the use of desirable construction methods create major
constructability problems. Proper selection of the design approach and materials of construction brings about beneficial construction methods in many cases.

Tatum emphasised that it is very difficult to quantify savings from constructability improvement at an early project stage, because it involves calculating savings and requiring comparing estimates. This is suspect at best, and frequently unconvincing for management [Tatum, 1987B].

Vanegas in 1987, developed a model of existing influences and processes that operate during the initial design phases of building construction projects, identifying the main components of these processes and blending them into a single integrated process.

He provided a conceptual framework for design/construction integration. This framework and its implications highlight the greatest existing leverage points and the means for integration, identify what is required to implement design/construction integration during the initial phases of design, describe the integrated design process, and identify how the roles of owners, designers and constructors change under an integrated approach [Vanegas, 1987].

In constructability studies done at the University of Texas at Austin [O' Conner & Tucker 1986], concluded that:-

1 Constructability improvement in a project appears in the form of construction-sensitive designs, effective communication of engineering information, optimal constructor-originated techniques, effective construction management standards, vendor or sub-contractor service improvements, and construction input to design.
2 Some ideas on constructability improvement potential include:
- there is a need to improve construction-sensitivity of designs and the effectiveness with which they are communicated;
- the most potential for improvement comes from optimising construction techniques dictated by the engineer;
- engineering information availability is a more serious problem than understandability.
- construction technique improvements are largely activity sequencing improvements; and
- foundation, concrete and structure have most potential for improvement of construction-sensitive design;

3 Two-thirds of all engineering rework relate to constructability problems and some of the causes include incomplete or inadequate engineering information;

4 Constructability improvements generally include trade-offs between potential benefits resulting from better designs, use of equipment, and sequencing of operations, and the additional designs time expenses required to achieve this.

In a recent study [O'Connor & Davis, 1988] explored the ways in which construction knowledge and experience can enhance constructability during field operations. Their work was directed towards constructor organisations, and a single prime concept for field operations constructability was concluded: Constructability is enhanced when innovative construction methods are utilised. Innovative construction methods may involve innovations related to sequencing of field tasks, temporary construction material/ systems, hand tools, construction equipment, constructor- operational preassembly, temporary facilities directly supportive of field methods, or post-bid constructor preferences.
Finally Tatum states two key types of benefits of integrating design & construction [Tatum, 1988]:-

1 Direct Benefits

The following are directly support achieving project objectives:
- Lowering both design and construction cost as a result of increased focus on advantageous design alternatives and improved constructability.
- Decreasing the project schedule by better integrating the design and the construction schedules and shortening both.
- Improving quality by better defining requirements and planning the most efficient way to meet them.
- Improving external interfaces, such as with regulators, by making realistic commitments and incorporating them into the design and the construction plans.

2 Indirect benefits

The indirect benefits of design-construction integration are hard to quantify. But are perhaps more significant. These include:-

- building a team with a commitment to meet project objectives by mutually agreed-upon plans;
- increasing construction's understanding of design intent and design's understanding of construction's problems in building certain designs and training the representatives from each discipline to do their job better by considering the needs of others;
- increasing innovation in both design and construction;
- transferring construction experience from other projects;
- gaining competitive advantages for the firm.

To integrate design & construction Tatum suggests the following actions to be carried out by the project managers [Tatum 1988]:-
- bring construction aboard early;
- recruit team players in both design and construction;
- consider multiple alternatives;
- involve construction like a design discipline by assuring that they are available and creditable and that their prime function is input and not review;
- assure integration at key leverage points;
- use project objectives to resolve conflicts.

2.5.9 Summary

The quantity of publications indicates the concern shown by the industry as a whole for the problem of constructability. The main concerns were:

- The division between the construction and the design process. The contractor is too removed from the design stage at which his specialist knowledge could be put to invaluable use.
- The comparative isolation of many designers from the practical construction process.
- Lack of communication and co-ordination between design and construction team members.
- Inadequate preparation of design drawings and specifications before contracts are put to tender.
- The pre-contract design procedures being inefficient due to their complexity.
- The need for developing modern methods of training to cover the complexities of modern construction technology and human relation.

Everyone involved in the construction industry is in favour of contractor involvement in the design process. They agree it would create more efficiency and less problems during the construction phase. All reports recognised that contractors have much to offer at the design stage, especially by way of advice on constructional
implications of design solutions and decisions.

2.6 Construction Relative to Other UK Industrial Sectors

Briscoe [Briscoe, 1988] presented productivity levels in selected UK industries as can be seen in Table 2.1. This table presents the absolute level of output per person employed, in the context of construction, relative to other UK industrial sectors. This data for 1984 is based on a census of production information and it shows how construction is a comparatively low productivity sector. Certainly, when set against the manufacturing sector, construction is seen to achieve significantly lower output per head; construction productivity is only 72% of that for manufacturing. Historical data for earlier years confirms this finding and while the size of the differential varies to some small degree, construction is a consistently low productivity industry.

<table>
<thead>
<tr>
<th>Industry</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>10,171</td>
</tr>
<tr>
<td>All industry</td>
<td>13,545</td>
</tr>
<tr>
<td>All manufacturing</td>
<td>14,052</td>
</tr>
<tr>
<td>Chemicals</td>
<td>25,491</td>
</tr>
<tr>
<td>Metal manufacture</td>
<td>15,688</td>
</tr>
<tr>
<td>Car manufacture</td>
<td>13,218</td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td>13,642</td>
</tr>
<tr>
<td>Textiles</td>
<td>9,177</td>
</tr>
</tbody>
</table>

Table 2.1 Absolute Productivity Levels in selected UK industries in 1984.

The results of table 2.1 indicate how, compared to a capital intensive industry such as chemicals, construction achieves a very low level of absolute productivity. Some reasons for this low productivity given by Briscoe [Briscoe, 1988] are:

1 Low and discontinous demand.
2 Frequent changes in specification.
3 Inefficient methods of building.
4 Overmanning on site.
5 Poor management.

2.7 The American Practice V the UK Practice

Three main studies [Anglo-American Council on Productivity, 1950], [RICS, 1979], [Nahapiet & Nahapiet, 1985] have shown that the performance of US construction is better in terms of speed and cost of construction than that of the UK. There are many variables which might explain these differences; cultural factors, different industry structures and working practices. However, there is much to suggest that different types of contract used in the USA, along with the differences in organisation and planning and control procedures, may also explain variations in the efficiency and effectiveness of project delivery. In this part I would like to highlight these differences, specifically where an impact is made on constructability.

In the United States, the usual approach adopted is that of extensively pre-designed projects let out to competitive bid. Each contractor is responsible for ensuring that the execution and standards of the building comply with the intention of the design. It is often allowable for the contractor to modify the design to achieve simplicity. It is this point which is fundamentally different to the UK system.

The first major comparison between the US and the UK construction industries [Anglo-American Council on Productivity, 1950] highlighted the superior productivity performance in the USA; achieved through a contractual system which allowed the contractor to modify the design to achieve simplicity. This finding has been echoed consistently in nearly all the subsequent studies such as [Freeman 1980] which have examined the UK construction industry. All contain major sections exhorting the parties within the industry to work much closer
together and involve the contractor in design [NEDO, 1983].

In a recent survey [Nahapiet & Nahpiet, 1985], the current practice in the industry was examined in the United States and the United Kingdom, particular reference being made towards the managerial and organisational aspects. Their survey examined six major projects in the US and four in the UK. The US projects which range in value from £1.3 million to £19.4 million include three office blocks, two manufacturing facilities and one warehouse. The four UK projects are all office blocks and range in value from £2.5 million to £11 million. The survey gave the following points:

1. The majority of US buildings were constructed faster than those in the UK.

2. The factors identified as significant influences by those involved in the faster projects were:
   a. knowledge and experience of client;
   b. contractual arrangements;
   c. good working relationships between the main parties;
   d. simplification;
   e. standardisation of construction.

   Simplicity for example seemed to be an overriding rule in the form and detail of the structure, e.g. reinforced concrete frame design in the USA regularly allows 'Flying formwork', larger concrete pours, the elimination of kickers and short minimum striking times for falsework, the combination of which leads to ease of construction and much faster construction times.

3. The projects which were constructed quickly were all ones in which the client made a substantial investment in project management.

4. The difference between the performance of US and UK projects is not so marked on cost as it is on speed, although for the three most similar buildings, the costs of construction were
significantly less in the USA than in the UK as in Table 2.2

5 Two factors were identified by interviewees as contributing to good performance on low cost projects. These were contractual arrangements and the simplicity and standardisation of design.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Area (sq ft)</th>
<th>Construction time</th>
<th>Construction cost</th>
<th>Cost/sq ft</th>
<th>Area/week during construction (sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Industrial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing facility</td>
<td>53000</td>
<td>30</td>
<td>$2.3m</td>
<td>$43 (£24)</td>
<td>1766</td>
</tr>
<tr>
<td>Warehouse</td>
<td>360000</td>
<td>100</td>
<td>$34.8m</td>
<td>$97 (£54)</td>
<td>3600</td>
</tr>
<tr>
<td>US Commercial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corporate offices</td>
<td>440000</td>
<td>130</td>
<td>$42m</td>
<td>$95 (£53)</td>
<td>3385</td>
</tr>
<tr>
<td>Corporate offices</td>
<td>385000</td>
<td>143</td>
<td>$24m</td>
<td>$62 (£34)</td>
<td>2692</td>
</tr>
<tr>
<td>Speculative offices</td>
<td>230000</td>
<td>69</td>
<td>$14.4m</td>
<td>$56 (£31)</td>
<td>3333</td>
</tr>
<tr>
<td>UK Commercial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speculative shops &amp; offices</td>
<td>130000</td>
<td>134</td>
<td>$8.7m</td>
<td>£67</td>
<td>970</td>
</tr>
<tr>
<td>Speculative offices</td>
<td>72000</td>
<td>78</td>
<td>£2.9m</td>
<td>£40</td>
<td>923</td>
</tr>
<tr>
<td>Speculative offices</td>
<td>127000</td>
<td>78</td>
<td>£8.2</td>
<td>£64</td>
<td>1628</td>
</tr>
<tr>
<td>Corporate offices</td>
<td>220000</td>
<td>108</td>
<td>£10.9</td>
<td>£50</td>
<td>2037</td>
</tr>
</tbody>
</table>

Table 2.2 Project Performance Comparison Between the US and the UK Construction Industry.
The most noticeable feature of the American research reports has been the conclusion that their operatives are more productive than those in the UK. In a comparative study between America and the UK [RICS, 1979], it was observed that with a wage level four times higher in the USA and similar material costs, building costs were not significantly different. The conclusion was that the operatives were far more productive.

A study by Slough Estates Ltd in 1976 [Laing, 1979], compared the cost of providing buildings that were constructed for identical purposes for the same company in a variety of countries as shown in Table 2.3

<table>
<thead>
<tr>
<th>Countries</th>
<th>CC Index</th>
<th>Time (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>constr.</td>
</tr>
<tr>
<td>UK</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>Belgium</td>
<td>107</td>
<td>37</td>
</tr>
<tr>
<td>France</td>
<td>98</td>
<td>30</td>
</tr>
<tr>
<td>Germany</td>
<td>87</td>
<td>29</td>
</tr>
<tr>
<td>Australia</td>
<td>94</td>
<td>29</td>
</tr>
<tr>
<td>USA</td>
<td>74</td>
<td>23</td>
</tr>
<tr>
<td>Canada</td>
<td>59</td>
<td>21</td>
</tr>
</tbody>
</table>

**Table 2.3** Cost Comparison of Providing Buildings in Variety of Countries.

At that time they showed the construction cost index in Britain as 100, only Belgium was dearer, at an index of 107. France was 98, Australia 94, Germany 87, USA 74 and Canada 59.

Conclusions have been reached in numerous surveys, all pointing toward a more efficient construction industry in the United States. Generally the reasons given are:
1 Value Engineering
2 Apportionment of responsibility.
3 Contractual arrangements.
4 Constructability.

1 Value Engineering

It was pointed out that the ability of US developers to achieve cost reductions is due largely to the demand for value for money. It may be argued that this is no different from the UK but it is the constructor and his sub-contractors in the US who are encouraged to seek savings by improving methods when preparing the detailed design and shop (manufacturing) drawings. This is done with the aid of Value Engineering (VE) the provision of which is incorporated into normal forms of contract in the US [Barries, 1977].

Value engineering was developed after World War II primarily within the US defence departments. It was introduced into the construction industry from 1962 onwards, principally by Lawrence Miles who described it as; 'a disciplined action system attuned to one specific need; accomplishing the functions that the customer needs and wants' [Barries, 1977]. The basic function is to determine waste and wasted effort and to remove it. VE works by means of the contractor or designer reviewing the design, questioning every element in it to determine whether it is essential in meeting the client's brief. If it is not, or an alternative can be substituted which reduces costs, simplified construction or enhances the performance, then a VE approval is awarded and the amendments incorporated into design. It is normal, as an incentive, to share the benefits of the savings in cost between the employer and the contractor. VE proposals can affect many aspects of a project and the full ramifications of each change have to be presented. This calls for many skills to be input into the analysis. This is possible with the American contractual system because it places more
responsible and emphasis with the contractor and his sub-contractors. If the detailed and shop drawings are produced by the sub-contractor, practical solutions to design problems are achievable and there is a single point responsibility, the contractor, for producing the detailed design.

Barrie and Mulch [Barries, 1977] summarised the effectiveness of this technique in terms of the following potential savings:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On total budget</td>
<td>1-3%</td>
</tr>
<tr>
<td>On large facilities</td>
<td>5-10%</td>
</tr>
<tr>
<td>On incentive contracts</td>
<td>0.5-1%</td>
</tr>
</tbody>
</table>

Value engineering on US experience contributes a 0.5 to 10% reduction in the capital cost of the project, with between 3% and 4% as a realistic norm. It should also be recognised that the clients' request this contribution to be made via the existing contract system which is already highly competitive. However, it is a fact that over 70% of a project's costs are fixed very early in the design and value engineering could increase the return four fold, to say 14% [Barries, 1977].

2 Apportionment of responsibilities

Several observers have commented that the US client can normally exercise more control over time and cost on his/her project than is normal in the UK [Freeman, 1980]. This appears to be linked to, among other things, the division of responsibilities between the parties involved in the USA and the active discouragement of late variations in the designs.

Generally, the contractual responsibilities for design, cost control and construction appear to be simpler in the USA than they are here [Freeman, 1980] making for fewer co-ordination problems and clearer accountability.
In the USA the essential documentation issued for a construction project at tender stage seems to be simpler than is normal in current UK Practice [Freeman, 1980]. The reasons are basic to the contractual arrangements used and the practices of the US industry, in that bills of quantities are not normally used, and US contractors accept responsibility for much detailed design. There appears to be benefits to the client in terms of reduced professional fees (although these might be transferred to the tender sum) and in facilitating the contractor to gain involvement in developing the detailed design.

In the USA it is much more common to give the responsibility for producing the detailed design to the specialist sub-contractor who will actually carry out the installation. Such a sub-contractor is likely to seek better and faster ways of carrying out the task and so raise productivity [Briscoe, 1988]. In the UK, this responsibility remains predominantly with the architect and the design team. Frequently, communications difficulties arise between the designers, the contractors and the sub-contractors [Briscoe, 1988]. These difficulties often lead to delays in the production process and so productivity is reduced.

A study conducted in 1985 of US and UK practices [Nahapiet & Nahapiet, 1985] suggested that no one form of contract is universally most suited. The appropriate contractual arrangement was thought to vary according to the type of client, his time and cost requirements and the characteristics of his project. More specifically, it stated that:

- The lump sum and negotiated contracts were used only by primary constructors or experienced clients; inexperienced clients used management contracting.
Non-traditional contractual arrangements were used on all those projects where performance requirements were regarded as particularly demanding.

Where demanding project performance was associated with construction complexity, clients deliberately selected contractual arrangements which reduced the number of organisations involved and which simplified communication across key project interfaces.

4 Constructability

There is considerable evidence that, by comparison with the products of UK designers, design in the US takes greater account of availability of materials and components and of the operational sequences of the design for site processes, such as trade sequencing and mutual interferences, [Freeman, 1980]. Doubtless the US contractors' greater involvement in the detailed design has promoted such a development but whoever does the actual designing there are lessons of value to be derived for UK designers.

In a survey of UK and US projects [Nahapiet & Nahpriet, 1985] the following observations were noted:

1. The US urban sites were less congested than their counterparts in the UK allowing more freedom to construct.
2. In the US simplicity seemed to be the overriding rule in the form and detail of the structure, for example reinforced concrete frame design regularly allows flying formwork, larger pours, the elimination of kickers and short minimum striking times for falsework.
3. Planning restrictions and ground conditions in the UK limited the height of buildings more than in the USA, so that more economical and speedy structural frame construction was often excluded.
4. Design did not appear to be as clearly oriented towards construction methods in the UK. However, where construction
requirements had been taken into account, the case showed that ease of construction had resulted.

5 There was a comparative lack of external scaffolding on US site.

2.8 Constructability and the Designer

The general guidelines for good constructability as laid down by CIRIA [CIRIA, 1983] are as follows:

1. Carry out a thorough, complete and clearly presented site investigation and design before commencement of construction.

2. Plan for essential site production requirements. The layout of site and programming of phased completions should recognise the need for site access, materials handling and construction sequences.

3. The method of construction should encourage the most effective sequence of building operations and recognise the advantages of early enclosure of the building.

4. The construction (and fitting out of buildings) should encourage simplicity of assembly, recognise trade sequences and minimise return visits of individual trades.

5. Design of elements and details should encourage repetition and standardisation.

6. The design should recognise achievable and appropriate tolerances.

7. The specification of products and materials should allow for site conditions and should be suitably robust and protected.

The list is a good general guide to the kind of things an engineer should be noticing whilst on site or in an office.

CIRIA in an unpublished report presented design examples produced by designers of situations, in which they had considered constructability as an integral part of the design process, using the
following 16 general constructability principles:-

1. Investigating thoroughly.
2. Consider access at the design stage.
3. Consider storage at the design stage.
4. Design for minimum time before ground.
5. Design for early enclosure.
6. Use suitable materials.
7. Design for skills available.
8. Design for simple assembly.
9. Plan for maximum repetition/standardisation
10. Maximise use of plant.
11. Allow for sensible tolerances.
12. Allow for practical sequence of operations.
13. Avoid return visits by trades.
14. Plan to avoid damage to work by subsequent operations.
15. Design for safe construction.

2.9 Constructability and the Contractor

Further to the CIRIA requirements, a study in 1983 [NEDO,1983] cited the following requirements for improving production:

1. Fast building is possible without either penalty to cost or quality. Responsibilities within the team must be understood by all and the client must know who is the team leader.
2. Organisation of the contractor under traditional procurement procedures can create unnecessary complexity for the client.
3. Non-traditional techniques of design and tender lead to quicker projects, on average, than traditional methods. Tendering on bills of approximate quantities and choosing the contractor through negotiated tender, lead to faster progress.
4. Preparation of the design must aim at facilitating progress on site.
5 The design should take constructability into account by considering the procurement of materials and the organisation of different building operations.

6 Contributions from specialist consultants, the contractor, sub-contractors and suppliers must be obtained within sufficient time for effective co-ordination and input to the design function.

7 In the selection process, contractors' ability should be assessed as well as their respective bid. Early recruitment of contractor before the design is finalised may assist in programming, anticipation of site problems and producing more economic and buildable design.

8 Efficient site progress requires effective site management, clear communication between the client, architect/engineer and contractor and detailed feedback mechanisms to control progress.

9 The form of contract is not the determining factor to meeting requirements of construction process, it is the attitude of the parties. The Standard Form of Building Contract, invokes penalties for delays but no incentives for efficiencies. Industry must look for ways of sharing the benefits accrued from improved performance.

Thus, whilst the CIRIA guideline [CIRIA, 1983] highlights the importance played during the design phase in achieving good constructability, the NEDO report [NEDO, 1983] encompasses the equally important role of the contractor.

2.10 Constructability and Contractual Arrangements

In most forms of contract used for construction work [JCT Standard Form of Building Contract, ICE Conditions of Contracts and General Conditions of government Contract for Building and Civil Works] the contractor has no contact with the architect/engineer (A/E) until the documents are released for tender purposes. Any advice on cost
will already have been provided by the QS/Engineer on the basis of past experience. The contractor will be provided with a bill of quantities and usually an incomplete set of drawings. Any views that the contractor may have on simplifying the work will rarely be possible at this stage. Only when the contract is won and detailed drawings start to arrive will comments on constructability be possible.

This situation is variant to US practice for similar contract procedures. There the QS does not exist and the contractor will be asked by the Architect/Engineer to provide advice on cost and time, sometimes for fee. UK practice discourages contractor participation while in the USA it is actively encouraged. These different findings have been well described in "UK and US Construction Industries - A comparison of design and Construction Procedures" [RICS, 1979]. The report recommends that a detailed consideration is required of the current practice of divorcing the detailed design and construction phases of building projects.

Furthermore this study [RICS, 1979] concluded that:

1. Detail design decisions have a very high impact on costs and time. In the USA contractors have an important influence at the design stage because they have the knowledge of construction methods, actual costs and the value of time. The traditional UK system prevents this involvement.

2. Detail design cannot be divorced from construction without major cost and time penalties.

2.11 The Summary

To date the literature which has examined the divide between the design and construction processes, has concluded that a major change is required and calls for the early involvement of the contractor in the procurement process for more efficiency.
It has also been echoed that overlapping the design and construction function by adopting non-traditional approaches such as 'fast tracking' will bring about improvements and efficiency to the British construction industry. Many reports called for a detailed consideration of current practice of divorcing the detailed design and construction phase, and emphasising the fact that detail design cannot be divorced from construction without major cost and time penal ties.

All agree that the contractor has practical skills which could benefit the industry's clients if only they could be incorporated in the design. The practical problem was how to do it.

The industry cannot change overnight to an entirely new structure. Change has to be evolutionary rather than revolutionary, and must take into account the skills which exist within the industry.

This chapter has identified the major difficulties experienced during construction. The nature of these difficulties are:

- Design details seem to be drawn in isolation with little thought given to the incorporation of the detail into the construction process and not enough consideration is given to the practicality of a detail.
- Overcomplex designs which are often costly in construction time and disruption.
- Poor quality of information provided for construction due to lack of communication & coordination between design and construction team members.
- There is a significant divide between the design and construction functions.
- The pre-contract design procedures being inefficient due to their complexity.
- Construction in other developed countries is cheaper and quicker than present practice in UK.
- There is no contractor involvement in the design process despite the recognition that this involvement would create more efficiency and less problems during the construction phase.
- Reluctance of architects and engineers to accept input from construction personnel.
- Lack of qualified personnel, training programmes and incentives and unawareness of potential benefits.

A problem clearly exists.

The main lessons from this chapter were:

- Faster building is possible without either penalty to cost or quality.
- Non-traditional techniques of design and tender lead to quicker projects, on average, than traditional methods. A detailed consideration is required of the current practice of divorcing the detailed design and construction phases of a project.
- Contributions from specialist consultants, the contractor, sub-contractors and suppliers must be obtained within sufficient time for effective co-ordination and input to the design function.

To conclude, I found that the gap in the literature survey is:

- To date no major report studied the effect of design detailing on site operations.
- There is no clear understanding of why or how to incorporate construction knowledge as part of the process of design.

The thesis therefore will concentrate on the area ignored by other researchers, which is the problems of design details.
CHAPTER 3: CONTRACTOR'S SURVEY

3.1 Introduction
3.2 Methodology
3.3 Survey Findings
3.4 Recommendations
3.5 Conclusions
3.6 Concluding Remarks
CONTRACTOR'S SURVEY

3.1 Introduction

This chapter examines from the contractors point of view the subject of design details prepared for pipelaying and concrete structural elements such as foundations, frames and floors. The reason behind choosing concrete structural elements is because they have most potential for improvement of construction-sensitive design [O'Connor & Tucker, 1986].

This chapter surveys projects under the traditional system of construction with a view to cataloging design details, which if altered, could have resulted in easier, faster and cheaper construction. The reason being to find data and evidence that these problems do exist.

A catalogue of 104 design detail problems was produced after a detailed survey of 26 contracting organisations. This catalogue proved that design difficulties exist and according to the contractors, are present in every single contract.

This chapter also identifies specific problem areas experienced during construction and lists some recommendations from the contractor's point of view. These recommendations would help engineers working within the traditional system to overcome the problems identified by contractors such as over-complexity, and not taking the contractor's method of working into account at design stage.

3.2 Methodology

The work in this chapter including some previous work at Loughborough University, which had been commenced, but never been developed to any degree, followed the steps outlined below:-
A seminar was held at Loughborough University of Technology to identify the areas for research and to gain an insight into the problems facing the construction industry.

Interviews were undertaken within 26 contracting companies to collect examples of problems and to know contractor viewpoint on making design easier, faster and cheaper to construct.

3.2.1 Seminar

The seminar was attended by seven personnel with a background in design, two academics, one quantity surveyor, one director of public works, one SERC official, and six contractors. The seminar was opened with a general discussion followed by detailed discussion within five syndicate groups each tackling a different aspect of the problems identified during the general discussion. The main point that was made was that civil engineering contractors predominantly deploy an operational estimating method which comprises: the aggregation of bill items to form operations; the costing of the operations on a construction method which defines resources; and, a plan which defines elapsed times. The costs are then allocated to the bill items in a variety of ways. The relationship between the bill item quantity and rate does not, therefore, necessarily reflect costs. Since it was these bill item rates that became the source of designers' cost data there exists some doubt as to the worth of the data for estimating and cost comparisons.

The difficulties experienced by designers when taking into account construction method in designs and estimates were highlighted as:

- Not knowing contractors methods.
- A lack of information on comparative costs.

The contractors' representatives had no criticism of the conceptual aspects of design, but were critical of detailed work.
Design representatives said a lot of effort went into achieving constructability.
The purpose of the seminar was to answer the following questions:

1. What recurrent construction problems could designers reduce or avoid?
2. On what types of project or contract do these problems mostly occur?
3. What do these problems cost, as a percentage of project costs?
4. Are these problems due to different attitudes and divided interests? If so, how can they be remedied?
5. Are the problems due to designers lack of knowledge of construction methods and costs?

These questions were answered on the premise that the conceptual design was complete and assumed that the designer was trying to produce the cheapest solution for the client.

The answers were as follows:

1. Recurrent problems were generally a result of bad detailing. The following examples were given:-
   a. Bad detailing of weather proofing such as tanking and external weather protection.
   b. Lack of repetition of detailing i.e details not rationalised.
   c. Uncoordinated services design, resulting from a lack of co-ordination of services, structural and architectural design.
   d. Unnecessarily complicated details particularly for joints and expansion details.
   e. Details that do not take account of the cost savings that result from using plant instead of labour.
   f. Structural details which do not take into account the formwork design implications, particularly the number of times the formwork can be used such as a large number of different sizes of reinforced concrete columns and beams.
2 These problems generally occur most frequently on the following types of projects:

   a Underground basement and tanks.
   b Schemes with heavy foundations.
   c Contracts with many similar structures, for example, roads with bridges, sewage works and reinforced concrete frame buildings (columns and beams).

3 The percentage cost was not known, but on one contract known to one member of the group, rationalisation of the reinforced concrete column and beam sizes would have reduced a total formwork cost of £760000 by £130000.

4 Are problems due to different attitudes and divided interests and if so how can they be remedied?

The answer to the first part of this question was thought to be yes. The designer's prime objective was 'correct design' whereas that of the contractor was to make the highest profit- but only after he had achieved the 'cheapest tender'. Thus, at the time the contractor is able to suggest rationalisation he is not in a position to do so because his efforts are concentrated on obtaining the cheapest tender and at a later date when rationalisation might help maximise profit, there can be conflicts between 'correct design' and 'constructability'.

The basis on which designers fees are calculated was also thought to be a disincentive to reducing design costs because reduced construction costs lead to lower fees.

No remedies to the conflict of interest were suggested.

5 The answer to both parts of question 5 was yes. The design detail problems are due to designers lacking construction knowledge, this is why they thought that the proposed research would help.
A brief summary of the concluding discussion of this seminar is as follows:-

1. There was a belief that different design detailing decisions lead to easier and cheaper construction, but it was difficult to quantify the extent. An investigation should be undertaken to collect evidence and quantify the effects of different design detailing decisions on cost.

2. There were major differences between building and civil engineering and, therefore, the problems in these two sectors of the construction industry were different.

3. The accuracy of designers' estimates was important because they determined the appropriation of funds for the project.

4. The effect of design detailing on cost was not fully appreciated by designers.

5. In general, senior engineers were thought to have a good knowledge of methods and usually passed this knowledge on to their juniors. However, the group thought that training in construction methods was essential for all design staff.

6. Experience was thought to be the main source of construction knowledge. Education and training was another important source as was feedback, particularly cost feedback from previous contracts, and information published by professional bodies.

It was thought that the conventional methods of training design engineers prevented them from gaining knowledge of construction methods and it was, therefore, important that these methods be changed to ensure that design engineers spent a greater part of their training working for contractors.

7. It was thought that procedures which allowed the integration of design and construction did not produce better results.

8. There was a need to educate design engineers in the preparation of tenders. This would lead to an awareness that some of their details were expensive.

Whilst the seminar delegates recognised and had thought about the recurrent problems of construction it was agreed that the industry as a whole did not recognise the recurrent problem of design constructability and cost awareness.

### 3.2.2 Field Interviews With Contractors

Twenty six contractors were approached and asked to comment on the designs that they were required to construct. In the interviews with the contractors, specific aspects of designs were investigated, namely:

1. To what degree do designers display an appreciation of construction method, and the practical constraints involved.
2. If that appreciation was considered to be low, then to what extent do the designers fall short of simplicity and economy of construction.
3. The contractors suggestions for improvements of design detailing.

The survey of twenty six contractors was to determine the prevalence of difficulties arising from design details which, if altered would give rise to cheaper construction. The number of visits made to each contractor for the purposes of extracting information were as follows:

- Single visits: 14 companies
- Two visits: 8 companies
- Three visits: 2 companies
- Four visits: 1 company
- Seven visits: 1 company

A total of 49 visits to contractors offices were made for the purposes of obtaining the data. The distribution of these across the different personnel in contractors offices were as follows:-
<table>
<thead>
<tr>
<th>Role</th>
<th>Visits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimators</td>
<td>4</td>
</tr>
<tr>
<td>Planners</td>
<td>5</td>
</tr>
<tr>
<td>Chief Engineers</td>
<td>16</td>
</tr>
<tr>
<td>Civil engineering designers</td>
<td>2</td>
</tr>
<tr>
<td>Formwork designers</td>
<td>9</td>
</tr>
<tr>
<td>Site agents/Engineers and Contracts Managers</td>
<td>12</td>
</tr>
</tbody>
</table>

Added to that an Iraqi state contracting company helped to produce a catalogue of design difficulties from two water and sewage treatment projects under construction, which had been designed and supervised by two leading British Firms. In addition, a leading British formwork supplier provided a set of design difficulties encountered by them both in the U.K and Overseas.

Overall 104 design detail difficulties were recorded. Problems were categorised into the areas of drawings, foundations, structural frames, floors, formwork, reinforcement, and pipe lines [For details See Appendix 1].

Initially discussions took place with estimators on the assumption that they would appreciate construction costs. However the estimators considered that they were unable to provide significant cost data for design difficulties because they were not generally involved in or consulted about the constructability of the design during the construction period. Cost evaluation of difficulties arising from design details was more problematical because estimators prepare estimates from tender documents and in many cases these do not contain working drawings.

In addition, they saw their role in contracting as pricing tender documents in order to maintain a work load for the company and as such, they were not involved in the post tender problems with design detail difficulties. For the same reasons, they were not able to provide examples of such design detail difficulties as they did not keep records of these.
The estimators, although well informed about construction costs, could not provide the necessary information. It was thought that this information would be more forthcoming from the personnel involved with the practical difficulties encountered during the construction of a project.

Therefore all subsequent approaches were made to chief engineers, planners, temporary works designers and formwork designers. The response from these people was much more positive. These personnel were able to provide numerous and wide ranging examples where alternative design detail would have reduced costs and saved construction time. These personnel were responsible for constructing the contracts won by estimators, and they experienced many problems with the designs that they received.

They considered that they were not in a position to comment on the costs of alternative design details. The direct savings arising from altering details ranged widely and the true costs saved depended on the resourcing of the work as a whole and the method involved. The cost consequence of design details usually had considerable 'knock-on' effects, and were not always limited to savings (of labour, plant or materials) on the amended details.

In the first part of the research the true costs were not determined. The true costs were reflected in the total resources of each project and the 'knock-on' effects of difficulties were not evaluated.

3.3 Survey Findings

It was stated several times by some of the contractors interviewed, that generally they have no complaints about the concept of a design but rather the details that it incorporates. For a contractor tendering on a design and construct contract, the concept is crucial to his winning or losing the contract. It is possible that the reason for few complaints about the design concepts is that all contractors
know that they are tendering on an equal basis. However, at that stage, they usually do not have detail drawings, then having committed themselves to a price and a set of rates, they may receive the details only to find that the true costs of constructing those details are in excess of those rates on which they won the tender.

Design detail difficulties are prevalent and, according to the contractors interviewed, are present on every contract. The nature of the difficulties are as follows:

1. Design details seem to be drawn in isolation with little thought given to the incorporation of the details in the construction process.
2. Over complex designs which are often costly in construction time and cause disruption.
3. Poor quality information provided for construction, from site investigations to construction drawings.
4. Not enough consideration is given to the practicality of details, nor to the effect they may have on the construction as a whole.
5. Superficially economic designs are often more costly in construction time due to their complex shapes or processes of construction.
6. The contractors often choose to give away some material costs in order to save on plant and labour costs.
7. Poor sequencing of operations forced upon the contractor by the design.
8. The estimators are unable to provide the cost consequences of detailed design difficulties. They are not taken into account during the estimating process as feedback of site experience is insufficient in this area. They are able to cost major conceptual variations, but are not usually involved at a detail level.
9. There is still a significant divide between the design and construction function. This divide permeates the education and training of designers and constructors alike and to some
extent is maintained by various professional institutions.

10 The cost data base that designers use is largely bill rates for completed works from previous contracts. Little attempt is made to evaluate costs of designs which reflect construction method.

11 Generally a lack of space is allowed for services. Even when placed in ducts, insufficient space was allowed, congestion being so bad in some cases that the only way of placing the services was in a strict order.

Design detail difficulties have been grouped under the following categories [See also Appendix 1]:

1 Drawings
Twenty examples of difficulties encountered by contractors were cited during the survey.

Drawings were considered by some of those interviewed that they were not always suitable for site operatives to build to. Drawings were frequently criticised for poor quality which generally meant a lack of clarity and content.

Some of the examples given included the following:-
- Conflicting information and lack of co-ordination which produced conflicting information from different design sources such as Architects, Engineers, and Mechanical & Electrical consultants. Examples ranged from inserts in concrete pours being shown on the architects drawings but not on the engineer's drawings, to general confusion over the positioning of services.
- Unfinished details; the designers doing part of the design and leaving the contractor to finish it.
- Information not being sent to site but available at the design office.
- Dimensions scattered over several drawings. The Architects dimensions are frequently not tied in.
- No grid lines or datum levels making setting out difficult.
- Minor details included with other unrelated details.
- Wrong bar bending schedule on the drawings.
- Poor information, often making it difficult to understand how the job should go together.

2 Foundations

The complaints collected regarding foundation design were fewer than expected, but ten were cited.

Difficulties arose due to:
- Contractor's method of working not being taken into account at design stage, specifically on excavations such as stripping the site to a reduced level in one operation rather than individual areas excavated in isolation.

- The use of small quantities of materials at the expense of additional labour and plant time (also examined under the materials section) such as small concrete details requiring extra formwork and labour for fixing, striking and placing concrete.

An example of this are the individual pad foundations, especially if closely spaced and numerous as illustrated in Figure A1.1 not necessarily a cost saving, if individual areas excavated in isolation, rather than stripping the site to a reduced level in one operation.

A similar principle applies in constructing a service reservoir for instance where additional thickening of ground slab may be required at the column positions as illustrated in Figure 1.2

- Over-complex shapes, such as the detail shown in Figure A1.3 where foundation is designed as piles supporting very heavy ground beams between which spanned the ground slab.
3 Structural Frames

Thirteen examples of difficulties with frame designs were cited. The main areas of difficulty were identified as:

- The mixing of trades within the structural elements and poor sequence of operations. A ground slab detail as shown in Figure A1.6, is presented as an example of poor operational sequences. The block work was detailed as overhanging on the floor slabs. Therefore the floor slab had to be constructed before a start could be made on the inner block work.

Figures A1.7 and A1.8 present another example of poor operational sequences in a reinforced concrete semi-basement.

- Little consideration given to speed of erection by the designers when detailing frame related structures, such as the use of insitu staircases and making openings through structural elements. Wherever possible openings should be put through non-concrete (non-structural) walls which are constructed off the vertical critical path. There are several problems with openings in concrete walls:

a Reinforcement fixing is less straightforward;

b The fixing of the box-out sections to the formwork take extra time and cost more;

c Compaction of concrete under a square box-out is difficult to achieve and often leads to a poor finish requiring remedial work (Figure A1.5). If a hole is required, a circular one lends itself to a better finish.
Four Floors

Five examples of design difficulties were cited with floors. These problems related to the use of flat soffits in formwork and the consideration given to services during the design of floor slabs.

Whenever possible flat soffits should be used in preference to beam and slab floors. The advantages are several:

- Simplicity of formwork. No changes in level to be accommodated producing savings in cost;
- Faster erection and turnaround of formwork.
- The design and installation of services is simplified, so fabrication costs are reduced.

Figure A1.9 illustrates an example from the author's site experience of a roof slab in a pumping station in a sewage treatment plant. The slab was designed and constructed as a system of beams and slab, because it was thought to be economical in material terms compared to the flat soffit option.

Figure A1.11 illustrates and presents an example of a good coordination between the structural and the services engineer was cited in a Water Treatment Scheme, which produced a successful design of services for that project. All the electrical cables from the generating station to the pumphouse were fixed and passed through a cable tunnel connecting the two buildings at below ground level.

Five Reinforcement

Another problem area reported by contractors was reinforcement, with some fifteen examples cited during the survey.

The difficulties with reinforcement commonly arising include:
- Over-complex shapes.
The detailing of large in-situ culverts and pedestrian under passes or walkways were a subject of complaint by several contractors. The worst detail is that shown in Figure A1.41, using two 'U' bars.

The formwork has to be manhandled down the length of the culvert.
A slightly better detail is "L" bars with splice bars across the top see Figure A1.41

If the gap between the 'L' bars is not wide enough though, the forms are trapped again.

- Insufficient tolerances to allow for other trades and over congestion. Figure A1. 32 for example illustrates the problem of insufficient tolerances. The height of a concrete kicker was specified and 'U' bars were detailed to sit on top of it (Figure A1.32a). This was an economical easy to fix detail, providing the kicker was precisely located. Normally the steel fixer would set the two end 'U' bars to level, tie a supporting bar through them and then drop the remaining bars into place (Figure A1.32b). This worked when the kicker was low, if it was too high then the top of the precisely detailed 'U' bar was too high, and the cover was reduced. The fixer then had to crop the bottom of the 'U' bars so slowing the fixing operation.

To make the detail more flexible, the legs of the 'U' bars could be made shorter, and the bars from the base longer, to allow for minimum lap plus some extra to allow for adjustment, as in Figure A1.32(c).

The message from this example is that construction materials are not suited for factory like precision, because good details have to be
- Little consideration given to bending costs and cutting waste by designers. Figure A1.33 and A1.34 illustrate this problem. In figure A1.34 for example a multistorey frame and the column reinforcement was lapped so that it started 150 below the floor slab. This meant that the full-height column reinforcement was waving around during the construction of the floor slab.

- The sequence of concrete pours not taken into account during the design process. Figure A1.32 of a reservoir roof slab illustrates this problem. If the bay sizes that the specification allows are small and 12m bars specified, it means that the contractors would have to deck out a large area beyond the bay poured, in order to support the 12m long bars lapped into the bay.

- Insufficient use of prefabricated details.

   Reinforcement should be detailed in such a way as to allow prefabrication assuming that the contractor will have enough room on site for a prefabricating operation which is not always the case.

   Beam and slab floors lend themselves to prefabrication. The beam cages can be fabricated at ground level, then lifted and dropped into place, with continuity and splice bars placed insitu through the column and beam junctions as in Figure A1.35

There is one important aspect to prefabricating such reinforcement and that is to allow generous cover, particularly end covers.

It is no good prefabricating cages if when they are placed, there is insufficient cover, so that the cage has to be taken out and prefabricated it again. Tolerances must take account of the variations which might occur.
Twentyeight examples of difficulties with formwork were collected during the survey. These difficulties included:

- Difficulties in the re-use and repetition of design. Many consultants design the lift shafts of buildings as the bracing. However, as a temporary works designer will point out, that becomes the critical item on the construction of the floors. The four walls of the shaft form a nice box, but boxes are not easy to build. The construction is slower, access is difficult for men and materials, and the next floor cannot be started until the walls (lift shaft) are completed.

Considering the shutters themselves, the main difficulty is that the inner shutters all have to be cut to the correct lengths.

With a full box the problem of the detail shown in figure A1.12A occurs, with the shutters having very specific dimensions and hence restricted use elsewhere.

- Not designing for the maximum use of mechanisation to reduce labour costs, for example table form and traveling wall forms. Figure A1.29 illustrate an office building plan. The formwork designer could not recommend a Table form or Flying form because the columns on the outskirts of the building were larger than the inner columns.

- Complex shapes, if the aesthetics of a design require a complex concrete shape then that must be accepted as a function of the design and so must be offset against the higher costs incurred. Frequently though, complex shapes seem to arise out of the belief that the minimum amount of material means the minimum cost. When dealing with concrete this is rarely
the case. Examples A1.15, 16, 17, 18, 19, 20, 21, and 22, of Appendix 1, illustrate complex shaped designs.

- The type of surface finish called for. A high quality finish will call for an expensive plywood. Therefore in order to keep the unit cost down, it is essential that the maximum number of uses can be made with these materials.

Feature finishes, and type F3 (high quality finish which specifies no internal ties or embedded metal parts) finish are expensive to form.

One type of finish which is universally disliked by contractors is the 'F3' finish as specified in the Department of Transport's specification for road and bridge works[1]. It is generally felt that it is over used and often inappropriate.

The specification for the F3 finish specifies no internal ties or embedded metal parts. Without a through tie to resist the wet concrete pressures, the structural integrity of the shutter must be maintained by an external support system. This support must be substantial in order to keep the formwork rigidly in place, as illustrated in Figure A1.30.

- The extent of falsework support needed. Designers do not produce designs that exploit the full potential of proprietary support systems. A significant proportion of the cost of any cast in-situ concrete can lie in the falsework supporting the formwork. The larger the structure the more significant falsework costs will be, especially in bridge works. Figures A1.23, 24, 25, 26, 27, and 28, show typical examples of trough, waffle and ordinary slab arrangements examining the extent of falsework support needed.
7 Materials

Ten examples of difficulties arising from material were recorded. Designers were criticised by contractors in this area for the problems associated with the use of modern technology such as water-proofing/tanking treatments.

On the subject of water proofing, waterbars was singled out for criticism by a number of contractors. A centrally placed waterbar was considered to be probably the best way to make a watertight joint - if it is constructed properly. Unfortunately that is usually quite difficult under site conditions and if is not formed properly the result can be worse than no water bar at all. For instance there is a problem of getting concrete under or behind the waterbar and compacting it, largely due to air pockets which form under the bar.

8 Pipelines

Three examples from the author's experience in laying ductile Iron pipes in the city of Baghdad, Iraq. The difficulties with pipelines comprised:

- Pipeline conflicting with existing utilities (services such as gas lines, water lines, electricity and telephone cables). This causes many changes during pipelaying as illustrated in Table A1.2.

- Not enough time and/or consideration seems to be given to site practicalities during design. Figures A1.51, 52, and 53 illustrate the problem of laying pipes in a city where many services such as cables and sewers obstruct pipelaying.
3.4 Recommendations

To achieve better design detailing, and to avoid significant design modifications made on site, from the contractor viewpoint the following would be useful:

1 Drawings

- Should be fully dimensioned. If dimensions are spread over several drawings, then they should be referenced. Grid lines and datums should be used where applicable.
- The architectural, engineering and services designs and drawings should be checked and coordinated, to avoid conflict.

2 Structures

- Never mix trades or structural elements particularly at any one level.
- Vertical elements should consist of columns with a minimum of concrete wall consideration. See appendix 1 for more details.
- Eliminate beam formwork and changes in soffit levels wherever possible.
- Where beams are necessary, wide, shallow beam construction is preferable.
- Concrete slabs should be kept simple to allow for concrete placing. Maximum use should be made of straight reinforcement bars wherever possible.
- Where concrete elements are repeated, reinforcement should be detailed with prefabrication in mind, particularly in beam elements.
- Non-structural walls use brick or blockwork, not reinforced concrete. In this way non-structural elements are removed
from the critical path.
- Where concrete walls are necessary for stability, they should be designed without openings, and opening should be transferred to non-structural walls.
- Staircases (treads) should be pre-cast with in-situ landings (but watch their weight and possible craneage difficulties).
- Upstands should be non-structural, preferably in brickwork and off the critical path.
- Weights of precast units should be considered to allow for handling and craneage.
- When designing finishes the tolerances in BS 5606 [BS 5606, 1978] should be borne in mind. Avoid conflicting tolerances between different materials.
- Beware of mixing pre-cast and insitu concrete elements. The savings in pre-casting can easily be lost if they are tied in to insitu concrete construction.

3 Reinforcement

- Detail for flexibility to compensate for inaccuracies by other trades.
- Reinforcement for column/beam junctions, provide loose bar arrangements within the beam section of the cage (drop in the cages and fix the loose bars).
- Site space allowing detail for prefabrication wherever possible. This means standardisation and repetition.
- Wherever possible detail reinforcement in accordance with concrete pour heights, so that the shutters support, the reinforcement.
- Beware of locking in shutters, and avoid starter bars protruding from wall pours, unless they can be bent by hand.
- Beware of producing a 'steel curtain' in situation with heavy, congested reinforcement. These makes concrete pouring very difficult and quality invariably suffers.
- Allow access for compacting vibrators.
5 Formwork

- Wherever possible give a choice of full height or incremental pours for high structures.
- Avoid special concrete finishes where they are inappropriate. Reserve F3 finishes for limited small areas.
- Consider standardisation of concrete box-sections not just on one contract, but between contracts.
- Formwork striking times should be related to the individual member rather than a blanket specification, in order to increase formwork turn around time and usage.
- In slip formwork particularly, protruding starter bars should be avoided.

6 Materials

- Avoid using extravagant materials.
- Use locally available materials
- Care and thought should be given when a waterbar is specified, bearing in mind the fixing difficulties and the care required to ensure a good quality that will perform as required.

7 Pipe lines

It is important to remember the following when designing a pipe line in a city:

1 Obtain type, size and exact location of the services through as-built drawings and trail pits.

2 Obtain size, shape and locations of existing and proposed services structures, through as-built drawings and trail pits.

3 Think at the office about what to do with all existing services structures if they are in conflict rather than leaving it in the field.
4 If a proposed pipeline is to be placed parallel with and deeper than existing service, leave enough distance between them so undisturbed bank of earth remains.

5 If the existing service has to be supported, special construction practices must be followed, which always cost more than standard construction practices.

Recommendations on correctly locating services:

1 Form a special group for collecting information on services from local authorities and services departments. This could happen as follows:
   A Issue proposed route of pipes on a drawing and ask the relevant authorities to mark down their services on it.
   B Ask the relevant authorities to provide services drawings (for existing services and the future ones).
   C In case of there being no drawings available showing services, ask the authorities to appoint a representative to show the locations of their services on site.

2 All information gathered on a specific route should be submitted in one file to the design leader.

3 Provide a detailed sketch showing all the services locations, coordinates and depths, which should be sent to the trial pit gang. This gang is responsible for uncovering all services (using manual excavations) and measuring the actual levels, and coordinates of these services. The actual measurement should be sent back to the design leader.

4 The design team now can start detailing.

Designers taking these recommendations into account at the design stage would help in reducing contractors complaints about design details and reduce design modifications on site.
3.5 Conclusions

The design detail problems can be summarised as follows:

1 Design detail difficulties do exist and according to the contractors, are present on every contract. The nature of the difficulties encompass:

- The poor quality of information provided for construction, from site investigations to construction drawings.
- That not enough consideration is given to the practicality of a detail, nor to the effect it may have on the construction as a whole.
- That superficially economic designs are often more costly in construction time and disruption due to their complexity of shape or process of construction.
- Poor sequencing of operations forced upon the contractor by the design.
- Failure of the designs to allow contractors to use commonly available construction systems, or plant, to their best advantage.

2 The cost consequences of these design difficulties are not clear. They are not taken into account during the estimating process as feedback of site experience is insufficient to meet this. Chapter five will present an evaluation of the cost, time and resource implications of the design detail differences.

3 The estimators in general are unable to provide the cost consequences of detailed design difficulties. They are able to cost major conceptual variations, but do not usually involve themselves at a detail level.

4 The contractor often chooses to give away some material costs in order to save on plant and labour costs.
5 The planners, engineers, temporary works or formwork designers tended to solve the detailed difficulties without specific references to cost. Once the problem was resolved, it tended to be forgotten and was not documented, unless it became the subject of the claim, in which case the cost generally became the prerogative of the quantity surveyor.

6 The emphasis placed on unit rates and on elemental cost approach, by designers and contractors alike, largely because of the nature of the Bill of Quantities has two significant consequences:
- Such an approach obviates the fact that relatively small dissimilarities in details (to those on which the unit rates are based) can greatly affect the cost of construction, making it more expensive than the assumed rates.
- Even highly buildable designs are not apparent due to the nature of both the building and civil engineering standard methods of measurement, which are unable to reflect high or low buildability in a design.

7 The overriding conclusion is that there is still a significant divide between the design and construction function. This divide permeates the education and training of designers and constructors alike and to some extent is maintained by various professional institutions.

8 The nature of the design difficulties are:
- Design details seem to be drawn in isolation with little thought given to the incorporation of the detail into the construction process.
- Over-complex designs are often costly in construction time and cause disruption.
9 The cost data base designers use is largely bill rates for completed works from previous contracts. Little attempt is made in cost evaluations of designs which reflect construction method.

3.6 Concluding Remarks

The principles mentioned in the recommendations and conclusions above by no means expect the architect or structural engineer to make design the slave of constructability. But the practical awareness of these principles is the key to achieving better details.

It is therefore strongly recommended that constructability should be a design objective, which should be taken into consideration as an integral part of the design process.

The important message learnt from this chapter, which I wish to explore further with designers, is that not enough time and/or consideration is given to the practicalities during design. This often means that significant design modifications must be made in the field, in order for these items to be constructed.
CHAPTER 4: DESIGNERS VIEWS

4.1 Introduction
4.2 Literature Survey
4.3 The Designers Survey
4.4 Summary and Discussion
4.5 Conclusions
DESIGNERS VIEWS

4.1 Introduction

This chapter examines from the designers point of view the design detail problems raised by contractors, discussing the reasons for their detailing and impediments to considering alternatives. It will also examine the reasons behind design decisions which are taken without proper knowledge of their cost consequences and their impact on site operations.

A literature survey to increase our understanding on how the design team work, and what kind of experience and information input is used is presented. In this chapter, I wish to explore further with designers the problems identified by contractors such as the amount of consideration given to the design details which lead to various difficulties in the construction process, together with my desire to assert that data collected in chapter 3 and Appendix 1, is true and the contractor's evidence was real.

This chapter also presents 30 designers views [In two surveys personal interviews and postal questionnaire survey] and discusses the reasons for design detailing and the impediments to considering alternatives. The questionnaire covered in detail the factors affecting the decision making during the design stage, in particular the factors which have a dominant influence on design decision making which lead to the selection and specification of a particular material or a design detail. Designers were asked in depth about design thinking, what written information was used, experience and other influences and how they usually evaluate designs in cost terms.
4.2 Literature Survey

The aim of this section is to investigate how the design team work and what kind of experience and information input designers use.

4.2.1 Experience

Earlier studies [Mackinder and Marvin, 1982], found experience to be, by far, the greatest influence on design decision making. It became obvious from their case studies that experience accounts for the greatest information input into design decision making, largely because it enables the designer to save time. Experience carried in the head or obtained verbally from a client or colleague is more readily available and more acceptable than most forms of written information. Designers have three different types of experience:

- Experience of the decision making process;
- Experience of how a building is constructed;
- Experience of actual performance.

4.2.1.1 Experience of the decision making process

This is an important asset to the designer in that it enables him to organise himself to collect the necessary information and make decisions in an efficient sequence within a limited design time. The experienced designer[architect] seemed able to predict from the outset of a project, key problems which might arise [Mackinder and Marvin, 1982] and [Marvin, 1985]. While his consideration of these problems might not be obvious during the initial sketch phase of the project, the speed with which decisions were put on paper at a later stage in the project indicated that some sub-conscious acknowledgement of their existence had been made while the overall concept was being developed.
The less experienced designer had to rely more heavily on outside information and therefore tended to 'discover' problems as the design progressed.

The Standard Form of Building Contract and RIBA plan of work necessitates that all information should be present, correct and detailed. Use of experience therefore helps to speed up information retrieval and production. The experienced architect is able to go straight to the key issues and know which aspects of the design are likely to have an important bearing on the overall design.

Some work carried out in the late 1960's on the analysis of intuitive design processes [Mackinder and Marvin, 1982] revealed that designers who rely on direct retrieval from past experience or memory are rather better at predicting design problems and taking account of them when designing than those who rely on written information. Thus the experienced architect is likely to be able to organise himself more efficiently in order to spend more time progressing with the design.

Experience of the information sources available also appeared important. The younger designers not only used written references more frequently than their seniors, but also apparently had to consult a wider range of sources in order to obtain a satisfactory answer. When the designer has had previous experience of the information source himself he was able to obtain an answer more quickly by going straight to a reference which has previously provided data.

4.2.1.2 Experience of how a building is constructed

This enables the designer to make general assumptions about the form and construction of the building, without reference to a large number of outside or published references which would be immensely time-consuming and make every design project a large scale academic
exercise [Marvin, 1985].

Much of this type of information is 'learned' while the architect is still undergoing his college training. It involves the general principles of how buildings are put together, and what building forms and methods of construction are likely to be suitable for which uses. The younger designer will have only an academic view of these principles. The mature architect will have had opportunities to evaluate their use in live projects and thus build up practical experience.

As designers gain experience of how a building is put together, they use it extensively and identify it as an influence on decision making when discussing their work [Mackinder and Marvin, 1982].

4.2.1.3 Experience of performance

This is a more straightforward type of information which involves knowledge of how a building or an element of a building performs. This type of experience is very often used during the later detailed design stages to assist in the selection of a particular component.

Experience of this type very often tended to be negative; designer's attention being more likely to be captured by design faults and mistakes made previously than by success stories.

Previous research findings [Mackinder, 1980] suggest that this type of negative feedback is the most common, as failures are more likely to reach the architect's ears than successes, forcing him to look at the problem again. The architect rarely has the time to collect positive feedback, as this involves actually re-visiting a building and assessing its performance, and pressure of work rarely allows this. He therefore tends to rely on the idea that 'no news is good news' and more often than not repeats his design solution without checking that it has been successful.
4.2.2 Published Information

A study carried out by [Paterson and Farrant, 1984] investigated the sources of information used by people in the building industry, including architects, in making technical decisions. They found that on at least two-thirds of the occasions when architects consulted sources other than their own experience, the sources were people rather than written information.

A wealth of written design and product information is published or otherwise made available to designers. For example there are [Marvin, 1985] about 2400 British Standards and B.S Code of Practice concerned with building.

In the course of their research [Marvin, 1985] and [Goodey and Matthew, 1971] gave a list of organisations and the type of information they cover, as being an important source of technical information provided to designers.

- Manufacturer - product promotion, advice to encourage correct usage of products.
- Manufacture's Associations - promotion of product types, education.
- Book and Journal publishers - Commercial recognition and profitability.
- Professional Institutions - education and competence.
- Building Research Establishment - dissemination of research results and promotion of better building design.
- Central government - statutory responsibilities (building regulations), interests of avoiding poor design.
- Local government - maintenance of planning and building standards.
- British Standards institution - maintenance of minimum standard.
- Agreement Board - Performance standards.
- Practices Themselves - Avoidance of liability, interest of better design, saving design time.
4.2.3 How Designers Work

In the research by [Mackinder and Marvin, 1982] which concentrated on the early design stages, the pattern of information used in the design process was established.

The overall pattern of decision making emerging from their case studies was one in which;

- Designs were initially conceived in very general terms based on little information except where special feasibility research had to be carried out.
- The designs were sometimes modified as further information was revealed, or as the designer encountered difficulties not envisaged at the initial design stage.

In all the projects examined in the course of their research [Mackinder and Marvin, 1982], found designers concerned tended to develop a broad outline of the type of building they considered appropriate in response to their clients initial briefing, and their own reaction to the site conditions. This is broadly consistent with the recommendations for stage B and C of the RIBA plan of work [RIBA, 1973]. This part of the design is normally carried out very quickly, information input tends to consist mainly of client briefing, physical site constraints, requirements of planning authority and the architect's own experience and intuitive reaction to the site. The average designer uses very little written information, at least for domestic scale projects, or projects which have no characteristics unfamiliar to the designer.

At these early stages the designer generally feels competent to design using his experience of previous designs and of built examples; what he has learned during his training or what he has picked up from general reading. He rarely feels the need to search for documents specifically to help in developing the initial design concept. As designers developed and refined the initial concepts into detail
designs, more publications are consulted. Designers' early ideas normally formed the basis of the final design. They might be modified when the study of published information revealed further factors to be considered, or when unanticipated design problems were encountered [Marvin, 1985].

From the detail design phase onwards, the modifications made to ideas, the details drawn and the products chosen all have increasing likelihood of achieving reality. Therefore the designer can no longer rely on his memory quite so much but has to check more of his ideas, using published information, before committing them to paper.

As design progresses, the designer considers the appearance and function of every element in more and more detail, and begins to select specific materials, models and manufacturers. He begins to know the exact dimensions, behaviour, and fixing method of each item to determine whether it will fit into the whole scheme. The availability and supply of products, their maintenance and replaceability must all be considered.

Alternatives must often be chosen on the basis of cost. The designer may need to consider absolute and comparative costs of products, both initially and in use (in general terms) even though the details may be the quantity surveyor's function.

Some of the information needed at this stage is specialised and only relevant to a small proportion of projects. The designer may be unfamiliar with the documents providing this information, possibly using them for the first time. The information required is on the whole more detailed than before, and often changes in the course of time. It is therefore less likely to have been memorised by the designer. The use of publications particularly manufacturer's literature is more commonplace at this stage. The designer, because of this, usually has a better idea of what is available and where it can be found than is the case with types of information useful in the earlier stages.
Early research [Marvin, 1985] and [Mackinder and Marvin, 1980] observed that generally much more written information was used on stages E-F of the plan of work than on stages A-D. This indicates increasing use of published information towards the end of the design process.

The possible financial consequences [Marvin, 1985] of any design defects on large buildings probably prompted designers in certain cases to consult additional written information to check design parameters and design details. Large projects are more likely to be able to support the costs of project-related research, including the use of more written information and the development of experience. For large projects the time that can be spent designing an element is very often in proportion to its capital cost.

4.3 The Designers Survey

Designers views concerning design detail problems were surveyed. 30 offices were contacted via interviews, writing or telephone. Personal interviews and postal questionnaires were the main sources of data and consultants were asked to comment on the following remarks made by the contractors relating to design detail difficulties. According to the contractors in our earlier survey [See chapter 3], design detail difficulties exist and are present on every contract as follows, and these were presented to designers.

1 Design details seem to be drawn in isolation with little thought given to the incorporation of the detail into the construction process.
2 Over-complex designs are often costly in construction time and disruption.
3 Poor quality of information provided for construction, from site investigations to construction drawings.
4 Not enough consideration is given to the practicality of a detail, nor to the effect it may have on the construction as a whole.
5 Superficially economic designs are often more costly in construction time and disruption due to their complexity of shape or process of construction.
6 The contractors often choose to give away some material costs in order to save on plant and labour costs.
7 Poor sequencing of operations forced upon the contractor by the design.

4.3.1 Personal Interviews

Personal interviews with designers were an important source of data in this part of the study. A semi-structured interview technique was used for data gathering. The questions for the interviews were carefully planned and accurately worded [Leedy, 1974].

Fourteen consultants were interviewed for the purpose of extracting data to determine the reasons behind the design difficulties. The distribution of these across the different personnel in the designers offices were mostly project designers, structural designers, and research managers who had a significant amount of experience.

These interviews were conducted in the offices of these consultants. From the outset we set out to investigate specific aspects such as:-

1 Do construction difficulties, arising from design details, commonly occur?
2 To what degree do designers display an appreciation of constraints involved?
3 How do the designers organise themselves during the design process?
4 Who is bearing the cost of design detail problems?
5 What are the designers views and suggestions concerning better cooperation between themselves and contractors throughout the design and construction phases and how could designers take construction into account during design?
6 Factors affecting design constructability and designers cost awareness and how the designers cost experience could be enhanced?

4.3.2 Postal Survey

Over 60 questionnaire forms were sent to designers, 16 replies were received.

This part of the study covered in detail the factors affecting the decision making during the design stage, in particular the factors which have a dominant influence on design decision making which lead to the selection and specification of a particular material or a design detail. Designers were asked in detail about design thinking, what written information was used, experience and other influences and how designers consider the site requirements and how they usually evaluate designs in cost terms. Designers were also asked about cost data used and feedback information from previous projects.

I also set out to investigate specific aspects such as:

1. How the designers organise themselves during the design process?
2. Who is bearing the cost of design detail problems?
3. What the designers views and suggestions are concerning better cooperation between them and contractors through out the design and construction phases and how could designers take construction into account during design?
4. Factors affecting constructability and designers cost awareness and how the designers cost experience could be enhanced.

The questionnaire sent to designers were considered carefully by one specialist in questionnaire forms in the LUT Computer Centre and two other colleagues tested successive versions of the proposed questionnaires, to ensure that the research data provided by designers
was useful and compatible with my research requirements. Only when a fully piloted package of forms and instructions was available could the first 'real' designer start to receive a questionnaire. [See Appendix 2]

4.3.3 Designer's Views

Designers views discussed the nature and the sources of the difficulties and outlined specific aspects of the design constructability, construction economics, efficiency of the construction process, and designers experience.

Designers views of design detail problems could be summarised as follows:

1 All designers interviewed [forteen] agreed that design detail problems do occur. Designers agree that some design details are complex, especially when executed by young designers. Designers also agree with the contractor's main criticism that the main problems occur in detail design and that contractors do not have input in concept design.

But designers try to get some standard approach in structural design, and simplification and standardisation are taken very seriously in some practices, in order to achieve ease of construction, time saving and require less resources.

One consultant interviewed puts the blame on the contractors, because they keep asking for change in design details because [as they put it] the problem with the contractors, is they have their own shuttering systems and they want the design to suit it.

2 Nine designers out of twelve surveyed confirmed that designers are not in a position to take into account the special characteristics of the future contractors because:-
- Time constraints.
- Of diversified construction techniques.
- Competitive tendering method where contractors are unknown at the design stage and hence there no co-operation with contractors.

As a result of that, design solutions rarely happen to coincide with the special characteristics of the contractors and their realisation often requires extra production expenditure which could have been avoided if the design work had been carried out with the contractor's co-operation.

3 A consultant working for a large consulting engineers practice [Ove Arups] believed that the most suitable projects for applying Turnkey or Design and Build methods are industrial buildings, or those projects which the client is able to define precisely his requirements and performance standards in detail at the time of tender.

But another consultant interviewed believed that contractors in Turnkey and Design and Build projects try to change or specify some details or material which is of lower quality, and hence the client would get a high price for his project, while in a competitive situation the client will get the benefit. It is not necessarily the case that if you make the contractor responsible for all the detailed engineering and for co-operation between the involved parties, that a saving in cost might occur. Someone else is carrying the burden at the end of the day and he must be paying.

4 Junior engineers are involved in the detailed design, senior engineers are less involved. All designers surveyed said that senior designers are in charge of the Outline design and Scheme design, while 7 designers out of 10 said that junior engineers are in charge of the design detail. But designers organise themselves in a team. The senior engineer (team leader) sees all the drawings. But he does not check everything mathematically. This team is only
engaged in one design at a time. There is therefore a question mark over the supervision of junior engineers who undertake detailing work.

5 Ten designers out of 16 said they consult contractors during the design phase, this only happens:

- when necessary for specialist circumstances and for specialist information;
- if needed, and this depends mostly on the designer's own site experience;
- in Turn-Key type contracts.

It was found that designers on big projects usually consult a site expert or contractor during the design phase, in addition to their experience and discussion with the team. The designers for their part either discuss their design proposals with a potential contractor with no obligations, or employ a construction adviser to provide sound advice on how the building is put together, construction method and technologies. It was suggested that Management Contracting might be beneficial in this field of combining design and construction.

A designer emphasised that they have a system of review, where, in the design stage they talk and discuss all the details and the key activities with potential contractors, suppliers and users, without any commitment what so ever. This is why they, as he puts it, "achieved whatever is built is cost effective".

A large consulting engineers practice (Ove Arups) have their specialist construction consultancy (which is a sister company within the group), for construction advice. In this way they have brought designers and contractors together. This specialist consultancy contains some retired personnel from major contracting companies, who spent all their life in construction. They know exactly what the problems are and the
consequences of design decisions in cost and time terms.

It must be said though that a designer in a small design firm has not got the opportunity of having a subsidiary construction company to assist him realising the right solutions. He has to consult a contractor or appoint him earlier.

6 11 designers out of 16 evaluate their design in cost terms using historical data from previous contracts. They do not have a cost data base for evaluating designs which reflect construction methods because of:
- traditional contracting procedures;
- difficulty in obtaining the site feedback.

Costing alternative designs by designers was found to be difficult. The cost data available to designers is the historical data of completed jobs, and is not broken down, and the designers are therefore not in a position to evaluate designs which reflect construction methods.

Time constraints can have effects on design. Time was found to be the main limiting factor on the number of design alternatives investigated by designers.

Some designers who said that they do not know the true cost of constructing their own designs, thought contractors themselves did not know the true cost of construction.

7 Discussion with consultants confirms that there is no real site feedback system at the disposal of designers for use in future projects, especially when it relates to costs. Designers do not actively seek feedback information on completed projects for the following reasons indicated by designers them selves:-

- shortage of time;
- no interest;
- practicalities of gaining access to the building once the contract is finished;
- the cost of such scheme - who would fund it?

8 As found in an earlier study [Mackinder and Marvin, 1982] experience has the greatest influence on design decision making, and as a source of design information. Ten designers surveyed out of 16 quoted experience to have the dominant influence on design decision making.

Designers consider the construction requirement by consulting:
- their own experience from previous work [chosen by all 16 designers surveyed];
- colleague's experience [chosen by 13 designers];
- contractor's experience [chosen by 6 designers];
- manufacturer [chosen by 10 designers];
- specialist construction consultancy or site experts [chosen by 6 designers].

My survey also confirms what the earlier study [Marvin, 1985] found concerning what published information is being used by designers, as a source of useful information in the design decision making process. The most important material being used by designers is:

- books and journals [chosen by 12 designers];
- British Standards [chosen by 12 designers];
- Professional Institutions Publications [chosen by 10 designers];
- manufacturers literature [chosen by 9 designers];
- in-house guidance and manuals produced by the practices themselves [chosen by 7 designers].

It was felt by 11 designers out of 13 that they prefer tried solutions for the following reasons:

- keeping an economic time schedule for the design;
- the industry wants that. Designers do feel that the policy of their practice is to use tried and tested solutions wherever possible;
- unless they think of something better.

9 All thirty designers surveyed in both postal and personal interviews think that the enhancement of the cost experience of designers has beneficial effects because as one designer put it "effective budgeting is essential for survival". To achieve that designers suggest:

- site experience to see first hand the problems that design detailing can lead to, and the general methods of construction adopted by constructors;
- exposure to the full range of the building route to completion and preferably to its use;
- design and build package contracts;
- meeting a contractor to discuss a project before the tender documents are issued. However it is not likely that the time and money would be available to do this;
- secondment to a contractor's estimating department, to study relative merits of rate buildup and costing total resource mobilisation;
- experience and information dissemination.

10 All thirty designers surveyed in both postal and personal interviews agree that close co-operation between designers and contractors has beneficial effects on the cost of constructing the building. Designers must be careful to distinguish the roles, and responsibilities must be clear.

For better co-operation between designers and contractors throughout the various phases of the design and construction work, the following suggestions were derived from the designer's survey.
- Remove barriers set up by contractual systems. They also believe that there is a conflict of interest between the designer and the contractor. The contractor has emphasis on getting money more than the designer, while designers are professional bodies, they provide their services in a way to protect the client as well as getting their fees. The solution must be by removing some of the barriers in the contracting system.

- Experience of how a contractor will build the designed work.

- Involvement of contractors in the design stage is very difficult as contractors often have varying preferences for methods of construction and therefore cooperation with one contractor may not help due to a competitive tendering situation. This is only possible for negotiated type contracts.

- Involvement of contractors in design phase for specialist projects. Proper communication between designer/contractor during construction phase.

- Co-operation between designers and contractors can only be achieved by awarding a contract before detailed design is carried out.

- Initial meetings between designer/contractor at the conceptual stage.

- Improved communication - not necessarily Turnkey contracts. Communication can be improved only through a change in attitude. Many design engineers look down on counterparts in construction, and a similar attitude exists in reverse. This attitude must be changed to improve communication.

- Negotiated contracts.

11 All thirty designers surveyed in both postal and personal interviews agreed that the more experienced the designers, the greater the constructability.

12 Fourteen designers out of sixteen surveyed think that clients pay for the design problems. Designers admit that clients pay and carry
the burden if there is additional cost associated with the design details. Designers do not pay while the contractors lose some of their profits.

One consultant commented that in Turn-Key jobs, the client thinks that he puts the risk on the contractors, but what would happen later is one of the following:

- either the contractors have not put all their requirements in the tender resulting in the contractor start moaning or perform in less satisfactory manners;
- or put in the cost of all the possibilities in the price and client would get a high price for his project.

13 One designer commented on the idea of getting the contractor to do the detail design. This is difficult in his view because it will take the client a longer time and cost more to analyse contractor's offerings.

14 Twelve designers surveyed out of sixteen said that they attempt to avoid possible problems on site or with budgeting by:

- simply using their experience gained from designing previous projects or their previous work for a contractor;
- knowledge of availability of supplies and reliability of suppliers and of buildability;
- knowledge of standard of site supervision.

Again experience was stated to be a dominant factor in studying the viability and cost comparison of the design proposals.

15 10 designers out of 16 confirmed that they do not keep a written record of all design decisions, but only the important decisions so that it can be used later in another project.
4.4 Summary and Discussion

In the traditional contracting system the contractor is selected after the completion of the design work, and as confirmed in section 4.3.3 item 2, the designer is not in a position to take into account the special characteristics [such as the production facilities, construction techniques, skills available etc] of the future contractor. In the absence of the necessary information, the designer cannot make reliable assessments on the cost consequences of design decisions, despite his attempt to consult other people's experience, including contractors, experts and specialists as indicated in section 4.3.3, item 3 and 8. Therefore design decisions are generally taken without proper knowledge of their cost consequences.

Design solutions rarely happen to coincide with the special characteristics of the contractors. This can be traced back to the lack of co-operation with contractors, the diversity in construction techniques used by local contractors, and because contractors are unknown at the design stage in the competitive tendering method. The realisation of these facts often requires extra cost which could have been avoided if the design work had been carried out with a contractor's co-operation as confirmed in section 4.3.3, item 2.

Consultants agree that the use of the Package Deal, Turnkey or Design and Build systems of contracting are particularly suitable for industrialised type projects. Because these types of project execution systems require a higher degree of harmonisation as regards the parameters of the design and those of construction methods that can be achieved only through continuous co-operation between designers and contractors. [See section 4.3.3, item 5]

All designers who participated in our survey mentioned efforts aimed at ensuring the possibility of closer contact between the design team and the contractor and their continuous co-operation throughout the various phases of designing and construction work. Although designers believe that closer co-operation between designers and
contractors has beneficial effects on the cost of construction and on constructability, they believe that the client would get less durable structures. The effects of the design prepared under the Turnkey or Design and Build systems on the cost of the buildings may be less beneficial because contractors would try to change or specify some details or material which is less good in quality and hence the client would pay high price for his project in Turnkey contracts. [See section 4.3.3, item 10 and 12]

It is not necessarily the case that if you make the contractor responsible for all the detailed engineering and for co-operation between the involved parties, that a saving in cost might occur. The survey shows that designers would like it to be borne in mind that while lower construction costs do not necessarily bring about lower construction prices, they may bring about inferior buildings.

According to the traditional method of contracting, the contractor has to guarantee the correct realisation of the given project within the terms of the contract as regards the price, completion date etc, but he is not responsible for the functional performance, and the cost and aesthetics of the project which are outside his responsibility. The designer, commissioned directly by the client, functions as the client's agent and does his best to promote the clients interests and should take responsibility for the efficiency of the building design, even if he is not financially liable for the economics of the project. In Turnkey contracts, however, the designer's position is changed: in this case he is working for the contractor. Accordingly he has to take the contractor's interests first of all, which quite often may be inconsistent with the client's interests. The main danger involved in design work carried out through co-operation between designers and contractors or by contractors themselves lies in the contractor's aims to minimise construction costs. Though from the contractor's point of view these aims are fully justified, the reduction in cost may lead to a reduction of the quality of the project.
4.5 Conclusions

In general it was substantially established from the consultants' replies that there are problems arising from designers not taking account of construction methods or designing with construction in mind.

Designers claimed contractors ask for design changes merely to suit their own production facilities such as shuttering systems. Designers argue rightfully that this cannot happen in a competitive bidding situation.

A change in thinking, by considering the design process and the construction process both as the responsibility of the designer and the contractor on equal bases, and improved communication, through a change in attitude and removal of barriers set up by contractual systems, would have a great impact on constructability. One consultant claimed that many design engineers look down on their counterparts in construction, and a similar attitude exists in reverse.

Experience, which is highly respected and valued by consultants, has the greatest influence on design decision making, but needs to be improved and made more reliable. Enhancing designers' experience of how a contractor will build the work as designed would be very useful. Training engineers, especially junior ones should be taken very seriously.

The overriding conclusion is that there is still a significant divide between the design and construction function. This divide permeates the education and training of designers and constructors alike. In particular there is a question mark over supervising and training junior engineers who undertake detailing work.

Constructability principles could be applied at every point of the design process. It should be applied at every level and by all the people who make decision.
There is now a clear picture of the problem of constructability as seen from the consultants point of view.
CHAPTER 5: COST AND OTHER IMPLICATIONS

5.1 Introduction
5.2 Constructability and Cost of Formwork
5.3 Cost Evaluations of Details
5.4 Conclusion
COST AND OTHER IMPLICATIONS

5.1 Introduction

Previous chapters outlined the evidence of detail design problems and showed that not enough consideration is given to design details. As they were not properly considered, construction and peripheral cost become higher than anticipated, construction time increases, and field changes are made to the design details.

This chapter evaluates the design detail alternatives to determine the cost, time and other implications. This would provide an indication of the extra cost incurred by the client, when constructability is not taken into consideration.

Tatum [Tatum, 1987B] found it very difficult to quantify savings from constructability improvement, because it involves calculating savings and requiring comparing estimates. This is suspect at best, and frequently unconvincing for management.

Gray [Gray, 1983] recognised that the actual benefits are extremely difficult to measure, but he thinks it is possible to extrapolate a potential cost benefit to the UK industry's Clients, as a whole, of between a 1% and 14% reduction in capital cost if advice upon the practical aspects of constructing a building are incorporated into the design thinking.

In order to have a sound and true costing, two real life case studies were chosen from my site experience, where two details for one structure were taken and with just small changes in the dimensions of one of them made it highly more constructable than the other. The two different details, were evaluated to determine the cost, time and other implications using the Wessex Building Price book.
5.2 Constructability and Cost of Formwork

Formwork is a very significant cost item, and contractors give serious thought to minimising the formwork requirements. An indication of the costs of producing reinforced concrete is shown in Table A1.1.

Bennett [Bennett, 1988] found that people in the US build quickly because it is cheaper, and to do that they need to know about "Constructability" and have a basic sense of formwork logic. He also found that the sole concentration on saving on permanent material leads to neglecting the most important influence on the frame cost-Formwork. In the US, formwork can account for up to 50% of the frame cost.

Bennett [Bennett, 1988] recommends that constructability, or making a structural frame faster, simpler and less costly, should be a design objective, starting design with constructability is more productive and cost effective than modifying a design later to reduce costs. To engineer constructability into a project he suggests the following basic rules on formwork logic:

- Design for repetition of bay layout and floor grid to encourage greater re-use of forms, optimise on labour productivity and effect a production-line work cycle.

- Standardise member sizes: base designs on readily available standard form sizes. The cost of non-standard forms is usually charged to the project and consequently more expensive.

- Keep it simple: simplify by maintaining constant storey-height, uniform floor depth and equal column and beam spacing.
Illingworth [Illingworth, 1982] details several factors in the cost of formwork.

- Amount of repetition possible.
- Complexity in shape.
- Extent of falsework support needed.
- Degree of mechanisation possible to avoid high labour content.
- Surface finish called for.

All of these are directly influenced by the design, not just in building work but in all concrete structures.

To illustrate the influence of formwork on cost and time of a structure, two real life examples of a wall details are presented below. The examples show that when the emphasis was shifted to constructability, the detail was made simpler, a reduction in cost and time was achieved.

5.3 Cost Evaluations of Details

5.3.1 Case study 1

A retaining wall section is shown in Figure 5.1. Presumably this detail was designed in this way to take advantage of the reducing earth pressures higher up the wall. It was detailed to be cast in five separate pours.
The stepped section was not detailed to carry brick wall cladding as is sometimes the case but merely to act as a retaining wall.

The contractor elected to change the shape of this wall and cast it in three pours as can be seen in Figure 5.2, making use of available forms (The maximum height which can be poured using the strip and re-erect method is 4.10m).
The saving in concrete, over a wall section was calculated to be 7.35 m$^3$. However, the wider section in detail B would have allowed the contractor to erect his formwork as two straight shutters, a quick and easy process.[For cost calculations see Appendix 3]

The contractors option was to cast the wall in three pours, a continuous section, thus giving away 7.35 m$^3$ of concrete. It is an indication of the cost of formwork that contractors will consider doing this in some circumstances.

Detail B simplified the steel, got rid of the kickers, less water stop bars and less concrete area scabbled, as well as simplified formwork.

Most contractors in this situation would give away concrete. A straight wall would make for a much simpler sequence hence
providing a time as well as material saving. Table 5.1 shows a cost comparison between the two details.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DETAIL A</th>
<th>DETAIL B</th>
<th>% DIFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORMWORK</td>
<td>£ 6071.940</td>
<td>£ 3799.488</td>
<td>37.4%</td>
</tr>
<tr>
<td>CONCRETE</td>
<td>£ 5477.680</td>
<td>£ 5755.187</td>
<td>-4.82%</td>
</tr>
<tr>
<td>STOP BAR</td>
<td>£ 1225.355</td>
<td>£ 835.161</td>
<td>31%</td>
</tr>
<tr>
<td>KICKER</td>
<td>£ 1117.460</td>
<td>£ 0.000</td>
<td>4.6%</td>
</tr>
<tr>
<td>REINFORCEMENT</td>
<td>£11889.100</td>
<td>£11338.036</td>
<td>33.6%</td>
</tr>
<tr>
<td>SCABLING</td>
<td>£ 701.400</td>
<td>£ 465.166</td>
<td></td>
</tr>
<tr>
<td>EXTRA TANKING</td>
<td>£ 403.200</td>
<td>£ 0.000</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>£26887.142</td>
<td>£22193.038</td>
<td>17.445%</td>
</tr>
</tbody>
</table>

**Table 5.1** Cost Comparison Between Detail A & B of Case Study 1

In design A the period required for completion of this project was 85 days. The total cost was £26887.142. In design B, the same detail was redesigned to accelerate the entire construction process. The emphasis shifted to constructability in formwork. The duration was reduced to 68 days, this means 20% reduction in overall duration and the total cost was £22193.038 with 17.445% reduction in overall cost.

The Figures in Table 5.1 do not include costs incurred from insurance, site administration and interest.
5.3.1.1 Other implications

1 Detail (A) had five major lifts and this would have the following consequences:

- The job would be attended by every gang five different times. Delay might be experienced due to the gangs other workload.

- It is very unusual for a gang to start immediately after the other gang has left. Site experience shows mobilisation takes a considerable amount of time (not included in the construction programme).

- The job would be visited, checked and approved by the Resident Engineer and his staff five times. Experience shows that this is a time consuming activity and in some cases very costly, especially when the detail is complex. It is usual for the RE to demand improvements, additions or changes, to obtain full satisfaction.

2 Resources in case 1 would be locked-up on site for an additional period of 16.68 days say 17 days.

Resources available

Formwork gang

- Scaffolders = 10 men at a rate of £3.37/hr
- Carpenters = 2 men at a rate of £3.37/hr

Steelfixing gang

- Steelfixers = 10 men at a rate of £3.37/hr
- Foreman = 1 man at a rate of £4.50/hr
Scabbling

Worker = 2 at a rate of £3.37/hr

General

Engineer = 1 at a rate of £4.5
Surveyor = 1 at a rate of £4.5
Foreman = 1 at a rate of £4.5

Plant

Mobile crane, rubber tyred, lorry mounted, telescopic 18 tonnes = 1 at a rate of £7.46/hr

Dumper 4 wheel drive-hydraulic tip = 1 at a rate of £3.20 /hr

Tractor = 1 at a rate of £2.68/hr

Air compressor = 1 at a rate of £6.65 /hr

Scabbler = 1 at a rate of £1.50 /hr

5.3.1.2 Who bears the extra cost

In this particular example the saving in cost went to the contractor, who suggested the detail B (as additional profit).

The designers survey explained in chapter 4 shows that the client in the main, bears the extra cost incurred, when constructability is not taken into consideration. The client also carries the burden if there is additional cost associated with the design details, while designers do not pay and contractors lose some of their profits.
The only benefit the client obtained was the cost of 7.35 m\(^3\) concrete, which represents the difference in concrete quantities between the two details as shown in Figure 5.1 & 5.2 (A & B). [For cost calculations see Appendix 3]

5.3.2 Case study 2

Two reinforced concrete retaining walls of a Low Lift Pumping Station in a Sewage treatment Plant were detailed and executed as shown in Figure 5.3 detail A.

![Section A-A](image)

Figure 5.3 Retaining Wall section, Detail A of Case Study 2
A better detail for the contractor would have been the stepped wall, as can be seen in Figure 5.4 detail B

![Diagram](image)

**Figure 5.4** Retaining Wall section, Detail B of Case Study 2

The saving in concrete, over a two wall section, was calculated to be 12.25 m$^3$. However, the straight section in detail B would have allowed the contractor to erect his formwork very quickly and with ease.

Detail B would have simplified the steel, reduced congestion, and simplified formwork and reduced the duration. Most contractors in this situation would give away concrete as shown in Chapter 3. Table 5.2 shows a cost comparison between the two details.
**Table 5.2** Cost Comparison Between Detail A & B of Case Study 2

In design A the period required for completion of this project was 90 days. The total cost was £23892.524 in design B, the same detail was redesigned to accelerate the entire construction process. The emphasis shifted to constructability in formwork. The duration was reduced to 58 days, this means 35.5% reduction in overall duration and the total cost was £19604.975, an 18% reduction in overall cost. The Figures in Table 5.2 do not include costs incurred from insurance, site administration and interests. [For cost calculations see Appendix 3]

### 5.3.2.1 Other implications

Resources (Labour and Plant) in detail A would be locked-up on site for additional period of 33 days, more than they should be.
## Resources available

<table>
<thead>
<tr>
<th>Resources available</th>
<th>Rate £/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formwork gang</td>
<td></td>
</tr>
<tr>
<td>Scaffolders = 10</td>
<td>£3.37</td>
</tr>
<tr>
<td>Carpenters = 2</td>
<td>£3.37</td>
</tr>
<tr>
<td>Steelfixing group</td>
<td></td>
</tr>
<tr>
<td>Steelfixers = 10</td>
<td>£3.37</td>
</tr>
<tr>
<td>Foreman = 1</td>
<td>£4.50</td>
</tr>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Engineer = 1</td>
<td>£4.5</td>
</tr>
<tr>
<td>Surveyor = 1</td>
<td>£4.5</td>
</tr>
<tr>
<td>Foreman = 1</td>
<td>£4.5</td>
</tr>
</tbody>
</table>

### 5.4 Conclusion

Designers seemed not to work to minimise formwork costs, and the problem of over complexity in shape was quoted many times in our survey [See Chapter 3 and Appendix 1] as the most important difficulty in formwork.

If the aesthetics of a design require a complex concrete shape then that must be accepted as a function of the design and so offset against the higher costs incurred. Frequently though, complex shapes seem to arise out of the belief that the minimum amount of material means the minimum cost, when dealing with concrete this is hardly ever so.

Constructability in formwork can be introduced into a design detail by following the basic rules on formwork outlined in Appendix 1.
The approach to constructability, by no means asks the architect or structural engineer to make design the slave of formwork systems. Practical awareness of formwork costs and formwork technology is the key to easy, simple and less expensive structural solutions in concrete.

In the two real life examples, about 18% of overall cost, and 20% and 35% of construction time were reduced. Therefore I do believe, it is worthwhile designers and detailers considering constructability and formwork logic, particularly when we know that the main beneficiary from this exercise would be the client and the contractor as well as the consultant reputation.
CHAPTER 6: DEVELOPMENT OF A DESIGN PROCESS MODEL

6.1 Introduction
6.2 Models
6.3 Analysis of the Results
6.4 Design Process Model
6.5 Problem Locations
6.6 Literature Survey
6.7 Conclusions
DEVELOPMENT OF A DESIGN PROCESS MODEL

6.1 Introduction

Previous chapters focused on the constructability problems in the detail design phase and explored both the designer's and the contractor's viewpoints. The impact of these problems on cost and time was identified.

I set out in this chapter to produce a design process model for the traditional system of the UK construction industry, showing in detail the activities and information flow at each stage. The benefits from building such a model were firstly to help in understanding how designers work and secondly in identifying the points in the design process where these difficulties arise.

This chapter includes a literature review presenting design process models and design activities. It also presents a survey among 20 designers, outlining their views and comments to develop and validate the design process model. The data collected in this survey concerned influences, constraints, objectives and activities of the design process. The data was used to advance the model from its initial to final form.

6.2 Models

Models have become widely accepted as a means for studying complex phenomena. A model is a substitute for some real equipment or system. The value of a model arises from its improving our understanding of obscure behaviour characteristics more effectively than could be done by observing the real system. A model, compared to the real system it represents can yield information at lower cost. Knowledge can be obtained more quickly and for conditions not observable in real life [Forrester, 1969].
There are four necessary skills for developing models [Lave, 1975] and [Vanegas, 1987]:

1. An ability to abstract from reality to a model. It is necessary to form abstract representations of complex and intrinsic realities.

2. A facility at derivation within an abstract model. The value of a model lies in its meaningful implications.

3. A competence at evaluating a model. Not all models are good and some may lead to inaccurate or wrong derivations.

4. A familiarity with some common models. There is a large number of models in science. It is necessary to have a base of standard models and work from there.

[Lave, 1975] and [Vanegas, 1987] propose three 'rules of thumb' for model building:

1. Think 'process'. A good model is a statement about a process; bad ones fail because they lack a sense of process.

2. Develop Interesting Implications. Whether something is interesting or not involves a judgment call. Models should allow the researcher to find interesting implications or predictions.

3. Look for Generality. The more situations a model can represent, the better. Generality leads to a greater variety of implications.

The investigation involved in developing a design process model consisted of three main phases:
Phase 1 Preliminary work.
Phase 2 Development of the model.
Phase 3 Validation.

6.2.1 Preliminary work

This phase included all the preliminary work required to prepare the initial version of the model. The major activity of this phase was reviewing the available literature, and extracting relevant data. The information collected concerned the design process, design activities, design constraints and information input. [For details see section 6.6 Literature Survey].

6.2.2 Development of the Model

This second phase focused on developing the model. A detailed design process model was produced taking into account the data extracted from literature and combining models prepared by [Schaffer, 1977], [Voldeda, 1977] and [Bishop, 1984].

In order to obtain comments from industry on the model, a more simplified model showing the logical flow of activities starting from defining the need for a project to the user occupation and satisfaction of the project was produced.

Over 60 copies of the model were sent to consultants, 17 replies were received. The data collected in this survey concerned influences, constraints, objectives and activities of the design process. The data was used to advance the model from its initial to its final form.

Development of the model was an ongoing process as the model evolved, during which the model changed its form to incorporate changes suggested at each reply of the postal survey. This process of
continuous refinement initially resulted in a high rate of change, but as the replies progressed, the rate of change decreased.

This stage of the model was based on two sources of data: literature review and the postal survey within the industry. [See item 6.3.1 for industry comments on the model]

6.2.3 Validation of the Model

This phase was the last stage of the investigation where the final version of the model shown in Figure 6.1 was specifically validated and agreed upon by three selected consultants. In each interview, one of the questions asked was whether the person interviewed agreed or disagreed with the current form of the model. Additionally, they were asked to suggest ways to make the model better, more complete, or more representative of the processes depicted and no further amendments were necessary.

The three consultants interviewed agree with the basic concepts portrayed by the model. Of course, these comments by themselves do not prove the validity of the model, but they do express a qualitative approval of its completeness and representativeness. People in the industry have a practical orientation and for them the validity of the model is measured by the extent to which they perceive its applications as useful.

The overall consensus was that the model was somewhat idealistic but good and complete. They agreed with the implications and provided clarifying comments.

The model developed in this investigation achieves the three objectives mentioned earlier in section 6.2.
1 It describes the main processes and stages, their output and the principal relations between them.

2 The system portrayed by the model contains several important implications in:
   - assisting to understand the complexity of the process;
   - providing common ground on which to integrate design and construction.

3 The model, properly modified, applies to a diverse range of situations and serves as a foundation for future studies.

6.3 Analysis of the Results

This survey was most productive. Respondents were most co-operative and helpful, and generous in contributing their knowledge and experience.

Comments and remarks on the model were transcribed in a summarised form. This was not easy, because of the unconstrained nature of the interviews. These answer transcripts were then analysed, and all the responses to each stage were brought together. The points of agreement were then apparent, as were the differences. The comments are summarised at section 6.3.1.

6.3.1 Industry Comments on the Model

The main comments on the model from industry could be divided into:

General

a- The flow chart assumes all actions are linear without parallel actions or conditional branching, whereas project developments is a highly interactive process with many activities occurring in parallel. This is particularly evident in projects which are
constructed under several parallel contracts as each contract package usually has its own independent path through design, tendering and construction. It is felt that this is too simplistic to give reasonable results.

b- The flow chart on its own probably is not the best form of presentation. A very simple flow chart supported by a detailed description of the processes that go on within each activity might do better. This approach would also give our model greater flexibility, allowing it to be representative of more than one type of project.

c- The model is directed towards residential and commercial development in UK. Other types of projects in UK and international projects are organised in a very different way. To make a universal model, it might be better to go for a statement of principles. The flow chart is too rigid.

The integral logic of the chart presented is adequate to illustrate a very simple relationship path; there is little which indicates the variety of patterns of events under which contracts can be carried through from concept to completion.

The variations in contract type available to a client these days are numerous and to gather them together under one "representative" single track flow chart is to over simplify the complexities of the situation. As a check list, it would be quite adequate for most needs and therefore probably does illustrate the main activities of the alternative methods available for dealing with them, such as Design and Construct, project Management, Contract Management, etc.

The flow chart assumes traditional separate design and third party construction and takes no recognition of Design and Build, Design and Management, Management Contracting forms of construction.
d- "Professional advisors were involved too late in the process model sent". This criticism seems to have a broad support among consultants.

One consultant advised that the RIBA Code of Conduct for professional architects has changed recently and they are now acting in a much more entrepreneurial way and this could be reflected in our chart. They should be approached as early as possible in the briefing stage. The RIBA suggest a two stage appointment in fact with early work being paid on a time basis and production work as a scale fee. This consultant emphasised that the early input is usually provided without any additions to the scale fee agreed for the project.

e- Insufficient emphasis given to the need for engineers and architects to report formally to the client at the end of established stages in the design process.

f- The emphasis in the flow chart seems to be on building projects rather than heavy civil engineering.

g- Many consultants agreed that flow charts are useful documents. But the construction industry is not very willing to use them. RIBA plan is still an excellent chart but hardly anybody uses it in a business like way.

They questioned the purpose or users I intend my flow chart to serve, and one of them added "Whatever or whoever they may be I think you will find considerable resistance to it. In essence I find it far from user-friendly. This is partly because it is long, cumbersome, unappealing and unbalanced (compare the 600 length of briefing stage with 200 of construction stage); partly because many potential users will not understand (or at any rate know what to do with) general terms such as needs, problems, data, approval."
h- Consultants agreed that success in construction process model depends on having the right relationships between the parties. One of them added "In that case surely the flow chart should be geared to the parties, the artifacts they produce and the way the parties and their products interrelate. I do not agree with you that this cannot be shown on a static flow chart though you may (as you hint) need more than one chart."
He went on saying "I think I would like to see your chart developing and facilitating the methods in use. These are at least accepted. The problem is that they are not used very well. If you can sort that out then you will have made a real contribution"

i- The flow chart does not show the parallel activities and the iterative re-design process that is part of the normal procedure. A major difficulty in the construction industry is not the preparation of project plans but their implementation. Saying what needs to be done is relatively simple, ensuring that it is done is more difficult. Anything that can be done to add to the implementation of project planners would be of great value.

j- The flow chart represents the process reasonably accurately, providing that is how the client wants to procure his building. Therefore, it appears reasonably sound.

Particular

Briefing stage

a- Before a project programme can be drawn a decision must be made on the management approach.

b- The brief stage lists various participants but has no action to appoint any one. Parties are required to do work, are they paid?

c- Defining the job well at the briefing stage is of crucial importance. A consultant who undertook much of their work for
international aid agencies, who put a lot of emphasis on defining the job well at the briefing stage, said "When we become involved the agency has usually completed some preliminary appraisal work which results in a set of Terms of Reference for a major appraisal which follows would include all your items from "Review Probable Sites" to "Brief Report.

This stage is of crucial importance as it is here that the major decision on whether to proceed with the project is made.

It is likely that this stage will include a comparison of alternative outline designs together with the chosen design presented in slightly greater detail. It will also include a statement of the major design criteria that will be used. It may therefore include the first two activities of your design phase. The results of this work would appear in the form of a "Feasibility Report" which can run to many hundreds of pages.

Following the feasibility report we would either start detailed design or have a second level of project definition which is sometimes called "Functional Design". This would comprise general arrangement drawings for each structure. This would approximate to your scheme design.

We would always try to minimise any changes following the functional design phase and if possible would hope to have all design complete before construction starts. We appreciate that this is rather different to the situation on many commercial construction projects."

**Design stage**

a- Following the conceptual design a period for detailed discussion with the client to ensure his full understanding of the concept should be allowed to minimise his (the client) variations.
b- The design would appear to omit the seeking of Statutory Authority Approvals i.e. planning permissions, foul and surface water disposal, availability of gas, water, electrics.

c- No reference to topographical and sub soil surveys.

**Tendering stage**

Advertisement and pre-qualification of bidders can be done in parallel with the design stage.

**Construction stage**

There is no mention of nominated sub-contractors. Their procedures will start in the design stage.

**Commissioning stage**

Surely the test of water tightness should be in the construction stage.

**Summary of the Comments**

The people surveyed agreed with the basic concepts portrayed by the Model. The overall consensus was that the model was somewhat idealistic but good and complete. All designers interviewed agreed with the basic concepts of the model and provided clarifying comments and many useful suggestions. People in the industry have practical orientation which helped in developing the model to its final stage as presented in Figure 6.1 at the end of this chapter.
6.4 Design Process Model

The final version of the design process model is shown in Figure 6.1 which is presented at the end of this chapter. The model has the following characteristics:

1. The construction process can vary enormously, depending upon the size and nature of the project being undertaken. Therefore this model is written in general terms.
2. The purpose of producing this model was to increase our understanding of the design process, and to highlight exactly, the locations of constructability problems.
3. Each project is unique and it is hard to produce a typical model which encompasses all situations.
4. The model assumes that the design team is appointed first, and designs the building, tender documents are prepared as the basis of which a contractor is chosen, and he constructs it. This is only one way of procuring a building and there are many others. Construction Management, Management Contracting, Design and Build and Fast-tracking, where clients wanting buildings on a much shorter time scale, or wanting one person responsible, would not have the same type of model and the relationship between the design team, the client and the contractor varies.
5. Many of the activities shown in the model will run in parallel.
6. At all key stages the client will require time to consider the design team report before committing himself to the next stage.
7. Practical design principles and recommendations from the contractor's point of view were incorporated into the design process model at the detail design stage as shown in Figure 6.1. These principles if implemented would help junior engineers working within the traditional system, to overcome the problems identified by contractors such as overcomplexity and lack of consideration of the method of working.

The design process Model could be divided into the following five separate stages:
A Briefing stage
B Design stage
C Tendering stage
D Construction stage
E Commissioning stage

A Briefing stage

To provide the brief for the project team; establish the budget cost and determine the outline development plan on the selected site so that the design team can correctly interpret the clients wishes and provide cost estimates.

Inception or project identification

To prepare general outline of requirements and plan of future action. This step is done by the client with or without help. It is an interactive process.

- Appoint consultant.
- Specify owner's needs and requirements, define objectives, variables and constraints and the range of their limits.
- Programme, it may be possible for the client to set an overall target date at this stage. Anything more will be conjective.
- Data collection, including technical and non-technical investigations.
- Interpretation and analysis of data.
- Potential limitations and needs in terms of scope, quality, cost & schedule.
- Market studies.
- Discussions with government/Local Authorities.
- Evaluation of impact of project on client's business.
Feasibility or project preparation/development

To provide the client with an appraisal and recommendation so that he may determine the form in which the project is to proceed ensuring that it is feasible functionally, technically and financially.

This step is usually done by the client with a small group of key advisors-consultants, contractors, or his own staff. The aims are:

- Establish the viability of the project.
- Agree on the brief covering the scope of the project, technical requirements, cost plan, programme for implementation strategy.
- Negotiate agreements with sources of finance and end user;
- Develop alternatives.
- Select from the alternatives the concepts and the range of their limits.
- Site considerations.
  - Appraisal
    - Site selection
  - A broad outline of cost.
- Decide to proceed.
- A broad outline of project programme.
- Review economies of project in light of cost estimates and make any adjustments.
- Select design team.
- Decide the management approach; project policy, procedure and process. If time is the essence consider special means of overlapping design with construction & ordering long delivery plant & machines, such as Management contract, Construction Management, Conventional contract.
- Delivery methods.
- Control methods.
- Problem statement (Brief report) could include all above with sketches at scale 1:1000, 1:1500, 1:2000 or 1:3000 illustrating the layout and principles of the project.
- Review funding proposals and find alternative funding sources.
- Perform technical feasibility analysis of project.
- Plan the design process.
  - Scope of work
  - Sub-section split
  - Master programme
- Update cost estimate.
- Study of impact of project on environment.
- A plan of implementation.
- Review/agree the brief.

Participants

- Client
- Project Management Team
- Architect, Engineer, Quantity surveyor and specialists
- Planner
- User representative
- Public authorities

B Design stage

To develop the detailed design from the material in the brief and establish the method of construction and design cost for the project, in order to obtain the necessary approvals from the client and authorities involved.
Also prepare the necessary production information, including drawing and specifications and complete arrangements for obtaining tenders.

Outline proposals

To determine general approach to layout, design and construction in order to obtain client's approval of outline proposals. An outline
Design Report may be produced which compares a number of design alternatives and makes recommendations for the development of one solution in more detail in Scheme design phase.

- See Statutory Authority approvals i.e planning permissions, foul and surface water disposal availability of gas, water, electrics.
- Functional requirements.
- Sizes.
- Use studies.
- Should consult contractors to obtain an informal check on the feasibility of construction method envisaged or on estimates.
- Special requirements.
- Laboratory tests or experimental model tests may be undertaken
- Consult specialists or manufacturers of plant & equipment.
- Give attention throughout to aesthetic and environmental aspects of the design.
- Budget analysis.
- Detailed site analysis.
- Cost estimate for alternative solutions.
- Report to management and client.

Scheme design

Or conceptual solution (i.e basic concept of the project).

To complete the brief and decide on a particular proposal, including planning arrangement, appearance, construction method, outline specification and cost and to obtain all approvals. The objective of the scheme stage is to solve all the problems in principle. Beyond this stage design becomes more mechanistic. The scheme stage is probably the first time a realistic cost plan and programme can be prepared.

- Site plans showing relationships of components.
- General description of the project.
- Statement of the probable construction cost, level of estimate ± 20%. This will continue in parallel with design and construction. The cost plan is updated (or should be!) regularly.

- Approve cost before progressing to the next stage.

- Drawings and written text expressing all the aspects of the project. The general form and shape of the project clearly expressed with all related systems well thought out and integrated.

- Sketches of drawings of principle plans, sections and character.

- Develop models.

- Consider commissioning needs.

- Update estimate.

- Report to management and client, to ensure the client full understanding of the concept in order to minimise variation. In many cases, each major element in the project will have its own programme from here on.

Brief should not be modified after this point.

Design development or Detail design

Detail design to obtain final decision on every matter related to design, specification, construction and cost.

- A fully developed site plan indicating general size and nature of the project, such as showing building locations, access, circulation, planting, grading and utilities.

- A fully developed architectural solutions with all spaces firmly located and dimensioned and with all sections and elevations;

- All project systems (mechanical, electrical, structural and equipments, fully developed and carefully integrated.

- Start nominated sub- contractor procedure.

- Outline specifications and project manual.

- Cost implications of all design decisions considered and recorded.
- Further statement of construction cost.
- Complete detailed estimate and approve cost before progressing to next stage.

Any further change in location, size, shape or cost after this time will result in abortive work.

Construction documents

To prepare production information and make final detailed decisions to carry out work.

- Drawings
- Specification
- Bill of quantities
- Final cost analysis
- Instructions to tenderers
- Condition of contract
- Forms of agreement between Employer and Contractor
- Develop tendering procedures
- Report to management and client to proceed to the next stage

Participants

- Client
- Project Management Team
- Design team
  - Project manager
    - Architect
    - Structural, Mechanical and electrical Engineers
    - Quantity surveyor
    - Specialist
- Planner
- User representative
- Public authorities
C Tendering stage

To develop the tendering procedure and to obtain tenders from contractors and negotiate for agreements on costs.

- Advertisement to bidders. Taking place in parallel with latter part of design stage.
- Pre-qualification of contractors or select tenderers. Taking place in parallel with latter part of design stage.
- Issue tenders.
- Tender bid period.
- Evaluate and analyse tenders.
- Review construction times make any adjustments to design and get agreement of contractors before awarding contract.
- Review financing arrangements.
- Award of contract. There are usually many awards occurring at different times.

Participants

- Client
- Project Management Team
- Public authorities
- Construction Team
- User representative

D Construction stage (Site operations)

To plan, co-ordinate and control site operations in order to construct the required project in accordance with the requirements of the production documents within the cost figure and time limit of the contract and to specified quality.
Project planning :- To establish the programme and to make arrangements to commence work on site. This would include: -

- **Contractor's activities**
  - programme;
  - site organisation;
  - a manpower plan;
  - a plant and equipment plan;
  - a material delivery plan;

- **Supervisors activities**
  - programme;
  - site organisation;
  - administration;
  - office management.

Operation on site :- To follow plans through to practical completion of the building. This includes :-

- **Contractor's activities**
  - all temporary and permanent construction works and the supply of all built-in furniture and equipments; the co-ordination of sub-contractors; general supervision;

- **Supervisors activities**
  - quality Control (Inspection and supervision);
  - performance verification;

  - submittals (samples, shop drawings, payment certificates, variation orders, process claims, substitutions supplemental instructions and as built drawings.
  - completion and Maintenance certification.

Completion :- To hand over the building to the client, remedy any defects, settle the final account, and complete all work.
Testing of sections of work prior to commissioning:

Sort out plans for commissioning, training, maintenance and start-up:

Feedback :- To analyse the management, construction and performance of the project. Report on final cost.

Participants

Client
Project Management Team
Designers
Construction Team
Public Authorities

E Commissioning stage

To commission the engineering services and install the loose equipment required to enable the completed project to be brought into operation and to ensure that the project has been completed as specified in the contract documents and all the facilities work properly.

To provide a record of the actual construction, together with operating instructions.

To train staff in the use of the facilities provided.
Commissioning needs must be considered as early as possible in the design process certainly no later than scheme design.
Contractor's activities

- Ensure that the project completed as specified and all facilities work properly.
- Inspect the building thoroughly and have defects remedied.
- Test for water tightness if required.
- Start up, test and adjust the engineering performance and safety of all services.
- Searching for non-operational defects.
- Prepare 'as-built' records.
- Prepare operating instructions and maintenance manuals.
- Final inspection.
- Hand over of project to client.

Supervisor's activities

- Ensure that the project is completed as specified and all facilities work properly.
- Inspect the building thoroughly and have defects remedied.
- Order tests for water tightness if required.
- Supervise the start up, test and adjustment of engineering performance and safety of all services and equipment. This is probably the most important part of the project as it is the time when we find out whether or not it works. Too often the key members of the project team have disappeared by this stage.
- Searching for non-operational defects.
- Ensure the 'as-built' records prepared.
- Ensure operating instructions and maintenance manuals prepared.
- Final inspection.
- Certificate of occupancy.
- Hand over of project to users.
- Final Account.
- Feedback:- To carry out a systematic examination of the
performance of various aspects of the project and monitor user satisfaction in relation to the design brief and feed-back this information to appropriate parts of the system and database.

**Participants**
- Client
- User
- Project Management Team
- Designers
- Construction Team
- Public Authorities

### 6.5 Problem Locations

Chapter three presented some of the problems and difficulties encountered by contractors. The catalogue of the design difficulties presented in Appendix 1, was produced after a detailed collection from different sources mainly contractors and formwork designers. This catalogue proved that design difficulties are prevalent and according to the contractors present in every single contract.

Over 104 design difficulties were recorded. Problems were categorised into areas of drawings, foundations, structural frames, floors, formwork, reinforcement and pipe lines.

Each design problem was studied, analysed to decide the type of difficulties encountered, the exact location in the model (the stage and sub-stage) where these problems occurred. The data presented in Table 6.1 shows category and number of problems versus locations according to the stages of the model. This is how the points where difficulties arise were identified on the process model.
The majority of design problems seem to fall under the detail design stage, which proves the point raised by contractors and agreed upon by designers.

Table 6.1  The Locations of Design Problems in the Model

<table>
<thead>
<tr>
<th>Type of work</th>
<th>No</th>
<th>Problem locations in Model</th>
<th>Designing stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Outline</td>
</tr>
<tr>
<td>Drawings</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundations</td>
<td>10</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Structural frames</td>
<td>13</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Formwork</td>
<td>28</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipelines</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
<td>10</td>
<td>17</td>
</tr>
</tbody>
</table>
6.6 Literature Survey

The construction process is criticised as long, involved and often cumbersome and inefficient and does not work smoothly. Its success depends on having the right relationships between the parties to the process [Hillebrandt, 1984], the biggest proof of that being the long duration the process takes, as can be seen in Table 6.2 [NEDO, 1978] which draws together the information on the length of time required for various phases of the construction process.

<table>
<thead>
<tr>
<th></th>
<th>Conceptual phase Years</th>
<th>Design &amp; contract Documentation phase Years</th>
<th>Construction on site phase Years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Public Sector</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>1-4</td>
<td>1-3</td>
<td>0.5-2 (1-4)</td>
</tr>
<tr>
<td>Health</td>
<td>1-5</td>
<td>0.5-4</td>
<td>0.5-5</td>
</tr>
<tr>
<td>Education</td>
<td>1-4</td>
<td>0.5-3</td>
<td>0.5-2.5</td>
</tr>
<tr>
<td>Other large buildings such</td>
<td>1-7</td>
<td>1-3</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>as lawcourt, civic buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other small and medium</td>
<td>0.5-3</td>
<td>0.5-2</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>buildings such as general</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>offices, telephone exchange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and public libraries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roads &amp; Harbours</td>
<td>1.5-10</td>
<td>1-4</td>
<td>0.5-3</td>
</tr>
<tr>
<td>Water &amp; Sewerage</td>
<td>1-4</td>
<td>1.5-3</td>
<td>0.5-2.5</td>
</tr>
<tr>
<td><strong>Private Sector</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>0.5-6</td>
<td>0.5-4</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.5-2</td>
<td>0.5-2.5</td>
<td>0.5-2</td>
</tr>
<tr>
<td>Commercial</td>
<td>1-10</td>
<td>1-4</td>
<td>0.5-3</td>
</tr>
</tbody>
</table>

Table 6.2 Characteristic time involved in the various phases of the construction process for some types of new work
The traditional approach in building is that the client appoints his principal designer who becomes the client's main adviser. In most building projects it will be the architect who becomes the leader of the team and advises the client on the appointment of other members of the design team and the quantity surveyor who is responsible for cost advice and for drawing up contracts documents. The designer, and often the quantity surveyor, advises on the selection and appointment of the contractor and may decide to nominate some subcontractors.

In civil engineering the position is similar with the consultant engineer in the main design and leadership role. However there is usually no quantity surveyor in civil engineering, the function being performed by the consulting engineer who is responsible for measurement, and valuation.

Largely because of the difficulties of managing large complex projects new approaches have been developed such as:

- **Design and Construct.** In this case the client calls in a main contractor from the beginning and he arranges and leads the team.

- **Project Management** is the overall planning, control and co-ordination of a project from inception to completion by a project manager who may be an extension of the client with a co-ordinating role or he may be the executive manager of the process taking this role over from the chief designer [Hillebrandt, 1984].

- **Management Contracting** whereby the construction process is managed by a contractor's team on a fee basis.
The client having decided which method of organisation to adopt for his construction he then has to choose the designer/project manager or quantity surveyor. The client should appoint his adviser whose first task is to obtain a clear brief from the client to include the function and the range of cost and timing of proposed construction.

The client must also be involved in the approval of design at the various stages and ensuring that designs proceed smoothly.

Once the preliminary brief is obtained, the designer can proceed with obtaining some of the necessary statutory consents.

The first phase in the design of both building and civil engineering projects is the outline design concluding in a sketch design this is usually produced by a senior person in a consultancy who is in direct touch with the client. Then there is the translation and development of the sketch design to a workable project and finally there is the production of the detailed working drawings that enable the designer's documents to be communicated to the contractor. This last part is usually undertaken by relatively junior personnel [Hillebrandt, 1984]. In the case of the traditional process all the main drawings should be ready before the bill of quantities and other tender documents are produced. If they are not available the bill of quantities may not represent the true quantities and there will be claims and delay in setting the final account.

In the traditional process when the design is substantially complete, the quantity surveyor will draw up a bill of quantities in which each of the components in a building are itemised so that the contractor can price each item to produce his tender.

Traditionally tenders are invited for a job and it is usual for the lowest tender to be accepted.
As soon as work on site commences the main contractor takes over from the designer the principal role in the process. It is his responsibility to organise all the site operations by his own team and by subcontractors.

6.6.1 The Design Process

The term design process is the act of working and solving a design problem [Mackinder and Marvin, 1982]. The simple model of the design process most commonly recognised by theorists and teachers in all fields of design and decision making is shown in Figure 6.2

![Figure 6.2](image)

**Figure 6.2** A Simple Model of the Design Process.

This model makes the assumption that a designer's actions can be rationalised in a way similar to that used by a computer which can operate only on the information fed to it.

This model is partially accurate and it is widely employed in describing the basic moves in the design process.
A diagrammatic form of the traditional process for new building and civil engineering works was produced by NEDO [NEDO, 1978].

All previous models were linear and too simplistic to give a complete understanding of design in practice. The designer is continually jumping backwards and forwards between less and more detailed aspects of a design, and using different types and levels of information in the process.

The most commonly recognised and accepted model is the RIBA plan of work [RIBA, 1973] which is a framework of stages describing all the management tasks and design work in a project programme, from the initial contract between client and architect to the point when the building is completed and in use, as can be seen in Table 6.3.

<table>
<thead>
<tr>
<th>Familiar terminology</th>
<th>Plan of work stage</th>
<th>Purpose of work and decision to be reached</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRIEFING</td>
<td>A. INCEPTION</td>
<td>To prepare general outline of requirements and plan of future action.</td>
</tr>
<tr>
<td></td>
<td>B. FEASIBILITY</td>
<td>To provide the client with an appraisal and recommendation so that he may determine the form in which the project is to proceed ensuring that it is feasible functionally, technically and financially.</td>
</tr>
<tr>
<td>SKETCH PLANS</td>
<td>C. OUTLINE PROPOSALS</td>
<td>To determine general approach to layout, design and construction in order to obtain client's approval of outline proposals.</td>
</tr>
<tr>
<td></td>
<td>D. SCHEME DESIGN</td>
<td>To complete the brief and decide on particular proposals, including</td>
</tr>
</tbody>
</table>

Table 6.3 Summary of Plan of Work Stages
planning arrangement, appearance
construction method, outline
specification, and cost, and to
obtain all approvals

Brief should not be modified after this point

<table>
<thead>
<tr>
<th>Working Drawings</th>
<th>E. Detail Design</th>
<th>To obtain final decision on every matter related to design specification, construction and cost.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Any further change in location, size, shape, or cost after this time will result in abortive work

<table>
<thead>
<tr>
<th>F. Production Information</th>
<th>To prepare production information and make final detailed decisions to carry out work.</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Bills of Quantities</td>
<td>To prepare all information and arrangements for obtaining tender.</td>
</tr>
<tr>
<td>H. Tender Action</td>
<td>To obtain tenders and negotiate for agreements on costs.</td>
</tr>
<tr>
<td>J. Project Planning</td>
<td>To establish the programme and to make arrangements to commence work on site.</td>
</tr>
<tr>
<td>K. Operations on Site</td>
<td>To follow plans through to practical completion of the building.</td>
</tr>
<tr>
<td>L. Completion</td>
<td>To hand over the building to the client, remedy any defects, settle the final account, and complete all work.</td>
</tr>
<tr>
<td>M. Feed-Back</td>
<td>To analyse the management, construction and performance of the project.</td>
</tr>
</tbody>
</table>

Ahuja [Ahuja, 1984] divided the design process into conceptual, preliminary, and detailed design phases and gave a list of typical activities as follows:-
Typical Activities of Conceptual Design Phase

- Appoint consultants
- Inspect similar project constructed elsewhere
- Identify sources and obtain information
- Design market and other surveys
- Identify need for project
- Define objectives, variables, and constraints and the range of their limits
- Develop alternatives
- Select from the alternatives the concept best meeting the criteria
- Select site
- Prepare order-of-magnitude estimate
- Select design team
- Study impact of project on environment
- Perform technical feasibility analysis of project
- Find alternative funding sources
- Organise oral and written presentation of feasibility report to the owner

Typical Activities of preliminary Design phase

- Add necessary personnel to design team
- Expand work breakdown structure to design package level
- Target dates assigned to major activities
- Carry out preliminary design
- Conduct required survey, tests, and research
- Prepare a detailed project report
- Select optimum alternative
- Review and freeze design
- Estimate cost at "facility" level
- Perform cash flow analysis
- Report to management and owner
Typical Activities of Detailed Design phase

- Appoint consultants and specialists to project team
- Develop information management system
- Complete detailed drawings
- Develop models
- Prepare bill of materials
- Develop test procedures
- Write and review specification
- Prepare contract document
- Complete detailed estimate
- Complete master network
- Develop work breakdown structure to contract package level
- Invite bids and award contracts
- Procure materials for in-house work
- Pre-order long-lead items for contract work such as non-standard steal sections or designed-to-specifications equipment
- Perform resources feasibility analysis
- Perform economic and financial feasibility analysis

On the other hand the Institution of Civil Engineers (ICE) [ICE, 1979] goes into more detail and divides the construction process into three stages.

1 Investigation and reports

The nature of investigations are:

- Non-technical investigations such as economic aspects and demographic or social factors.

- Technical investigations embrace all engineering investigations, including those by scientists and other non-engineering which assist engineers to resolve engineering and other technical aspects.

The report required at this phase may be some or all of the following:
A- a sector study which assesses the requirements of a particular sector (of a country or activity) in order to identify individual projects for investigation.

B- a pre-feasibility study which investigates whether there is likely to be a viable demand for the subject to be studied, whether the required resources of implementation would be available within acceptable cost limits, and whether or not a feasibility study would be justified.

C- a feasibility (or pre-investment) study which involve preliminary surveys to investigate technical feasibility and economic viability, an estimate of capital and operating costs, and information to enable the promoter to decide whether or not he should try to finance the project. It may include some outline design.

D- a master plan which is a long term development programme, and which generally indicates how construction and expenditure can be phased.

E- an environment impact statement.

F- a project report which develops the preferred solution in detail, especially its technical aspects. This is also sometimes known as the final design report.

2- Design and preparation of contract documents

- Further site investigations
- Laboratory tests or experimental model tests may also have to be undertaken.
- Consult specialists or manufacturers of plant and equipment.
- Give attention throughout to the aesthetic and environmental aspects of the design.
- Consult contractors to obtain an informal check on the feasibility of construction methods envisaged, or on estimates.
This phase would include the Outline design, where more information is given than was contained in the Engineer's report, and the Tender designs where, ideally, detailed designs of all the Works should be completed before tenders for construction are invited. In some cases, however (ICE state), this is not practicable, and the Contract Drawings on which tenders are invited will be supplemented by a series of working drawings issued by the Engineer during the construction period.

3- Construction

The contractor is responsible for constructing and maintaining the Works in accordance with the requirements of the contract documents.

Austin and Neale [Austin and Neale, 1984], produced a framework of the construction process combining five major stages with four major aspects. These aspects can be divided into four main groups.

- Functional: general concepts, operational patterns, department and room programme.
- Location and site: climate, topography, accessibility, infrastructure, legal formalities.
- Construction: design principles, technical standards, availability of building materials, building methods, safety for operations.
- Operational: Project administration, cash flow, maintenance needs, operational safety and health.

The stages can be divided into five main groups-
They [Austin and Neale, 1984] suggested that the examination of each aspect should start during the briefing stage and continue in greater detail during the subsequent stages until each has been dealt with. Each aspect, or group of aspects, will be attended to at different points during the various project stages.

While Al-Sedairy [Al-Sedairy, 1985], divided the development of a large scale building programme into four segments:-

1. Project inception
2. Design
3. Construction
4. Operation and maintenance

He breaks the design process into three critical steps: Schematic approach, Schematic design and Design development.

At the Schematic approach a very generalised approach or concept of the project developed. It encompasses three areas of conceptual thinking: the design concept, the site concept and the systems concept.

The Schematic design further develops the conceptual solution. Through this phase, rigorous testing and checking of the actual design against the conceptual solution and the original programme should be done.

During Design Development further refinement of the schematic design is undertaken. At this stage we should have the following [Al-Sedairy, 1985]:

- A fully developed site plan showing building location and access, circulation, planting, grading and utilities; all fully thought out and interrelated.
- A fully developed architectural solution, with all spaces firmly located and dimensioned and with all sections and elevation
features thought through.
- All building systems (Mechanical, structural, electrical and equipment) fully developed and carefully integrated;
- A set of outline specification;
- Cost implications of all design decisions considered and recorded.
- A confirmation of tentative decisions regarding tender forms

Bishop and Alsop [Bishop and Alsop, 1969] adopted for their study a simple model. Every building project is assumed to be discharged by the execution of functions, each marking the achievement of an identifiable goal. See Figure 6.3

![Figure 6.3 A Simple Design Model](image)

These functions are considered in four groups: design, design realisation, construction and management. By design is meant those functions that use scientific principles, technical information and
imagination, to define a project capable of meeting specified requirements with economy and efficiency. By construction is meant the planning of work, including financial budgeting and control, and the allocation, acquisition and development of resources on site to achieve the completion of a project. All that lies between design and construction has been designated design realisation.

6.7 Conclusions

I have created a model of the design process, investigated the design process and how the design team work and where in the design process the difficulties arise. A design process model was established, and validated after extensive literature search and interviews with designers reviewing their working procedures and practices. The points in the process where design details difficulties arise are identified. [See Table 6.1]

The model provides a general and basic structure of ideas to establish how design and construction can interact and communicate. It increases our understanding of the design phases of a project. The model includes the principal activities and information flow at the design stage.

Many variations are possible on the model produced to suit the special needs of the firm or organisation. Future models in my view should be concentrating on integrating design and construction.

The main achievements of the model are:

- increases our understanding of the design process, by providing a general conceptual framework based on current practices and breaks down the overall process into multiple components;
- assist in understanding the complexity of the process;

- it gives the client, contractor, designers and educators information as to where to tackle the problem of design difficulties.

Finally the model is significant to all, in clarifying the role of all participants and in particular it clarifies the role of construction input during the project phases.
CHAPTER 7: CONTRACTOR'S INVOLVEMENT IN DESIGN

7.1 Introduction
7.2 The Questionnaire
7.3 Summary and Conclusions
CONTRACTOR'S INVOLVEMENT IN DESIGN

7.1 Introduction

The aim of this chapter is to assess the degree of contractor's involvement in the design phase in normal contracts and to find out whether or not there are more design difficulties in contracts where the detail design is completed before award of contract than in contracts where the construction process has been allowed to influence detail design.

This chapter sets out to demonstrate and prove that we have less design difficulties in contracts where the construction process has been allowed to influence detail design.

Specifically I attempted to answer these two questions:

1. If all detail design is complete before award of contract, so that the construction process has no influence on detailed design, do we have greater or more design difficulties than in contracts where the construction process has been allowed to influence detail design?

2. Can we devise measures of influence of construction on design from 'low' where the detail design is complete before tender to 'high' where the contractor undertakes detail design?

This exercise was required for my research to help in formulating and devising a system where a designer post to award of contract can produce the design details with a contractors knowledge on construction. In other words can we get the constructability knowledge to designers without the contractors involvement in the design process itself. To achieve this a questionnaire was used to obtain the views of people within the construction industry on four distinct types of contract which were suggested for consideration, each with varying amounts of contractor involvement in the design.
7.2 The Questionnaire

Engineers, quantity surveyors, builders and architects were asked to consider what effect varying degrees of contractor involvement would have, in their opinion, on selected problems from chapter three. The following problems were chosen carefully because they are clear and simple, from a list of difficulties identified by the contractors surveyed as present on every contracts:

1. poor quality of information provided for construction;
2. inadequate consideration given to the practicality of detail;
3. superficially economic design;
4. poor sequencing of operations;
5. longer construction duration;
6. higher construction costs;
7. inadequate construction quality.

Four distinct types of contract were suggested for consideration of their effect on the problems mentioned above, each with varying amounts of contractor involvement in the design. These four types of normal contracts show a gradual shift of contractors involvement in the design, from 'low' where the detail design is complete before tender to 'high' where the contractor undertakes detail design. These contract types were:

A. All designs complete before tender, no contractor involvement in the design.
B. Detailed design ongoing during the construction process, no direct dialogue exchanged between the designer and the contractor.
C. Detailed design ongoing during construction and dialogue with the contractor.
D. Contractor undertaking detailed design.

Contract types A and B are comparable to the traditional forms of contract. Type C is similar to fast-track construction and type D is
the form presently seen in the USA and the British Property Federation systems.

A total of thirty-five replies were obtained by a research student during an earlier survey [Murgatroyd, 1988]. Twelve were received from the employees of clients and local authorities, twelve from consultants and eleven from employees of contractors.

The answers were recorded in a numeric form. The interviewees were asked to consider the degree of problem which they would anticipate in each of the four contract types. An answer of one to represent no foreseeable problems, an answer of ten to indicate that they would anticipate a definite problem.

Information received was fed into the StatsWork computer package for statistical analysis. The data has been presented in such a way that the decreasing or increasing of level of influence is shown by continuous line. This format has been adopted although it is acknowledged that the relationship between the four type of contracts are not directly connected. Other format were considered eg. Pie chart and the graphical method was felt to be the most relevant in this case.

The results were as follows:

1 Poor Quality Information Provided for Construction.

Table 7.1 shows the mean result from the replies given for each contract type by each discipline and the overall view of all respondents.
When the respondents considered contract type A in which all design was complete before tender, the overall mean reply was 5.43 for the problems foreseen with poor quality of information provided for construction. This indicated that the consensus of opinion was that there was a greater chance of problems with this type of contract.

However, the replies received varied greatly between individual respondents. The client and local authority respondents gave lower than average replies (a mean of 4.417). Conversely, the consultants view this arrangement as far more likely to produce problems in the quality of information provided for construction with a mean of 6.33. This is quite interesting because it is the consultants who provide the information.

In contract type B, more problems were perceived in the quality of information by employees of contractor and clients. The mean values were 5.727 and 5.833 respectively. However, the employees of consultants perceived a reduction in the problems encountered with this contractual arrangement. Overall the mean value was 5.93 despite the difference of opinion expressed by the consultants.

For type C contracts less problems in the quality of information were
perceived by all respondents. The overall mean value fell to 3.42.

When respondents considered contracts in which the detailed
design is undertaken by the contractor, all disciplines replied that
there were less foreseeable problems in the quality of information.
In this case the contractors gave the lowest mean of 2.727 and the
consultants gave the highest of 3.41.

The mean reply from all three disciplines is illustrated in graphs
7.1, 2, 3, 4 and 5.

![Graph 7.1](image1.png)

**Figure 7.1** Consultants Mean Reply on Quality of Information
provided for construction.

![Graph 7.2](image2.png)

**Figure 7.2** Contractors Mean Reply on Quality of Information
Provided for Construction.
Figure 7.3 Clients Mean Reply on Quality of Information provided for construction.

Figure 7.4 The Industry Overall Mean Reply on Quality of Information provided for construction.
2 Inadequate Consideration Given to the Practicality of Detail

Table 7.2 shows the mean values of the replies given for each contract type by each discipline and the overall view of all respondents.

<table>
<thead>
<tr>
<th>Contract type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants</td>
<td>7.167</td>
<td>6.667</td>
<td>3.583</td>
<td>2.000</td>
</tr>
<tr>
<td>Contractors</td>
<td>6.182</td>
<td>5.182</td>
<td>2.545</td>
<td>1.727</td>
</tr>
<tr>
<td>Clients/LA</td>
<td>4.833</td>
<td>4.500</td>
<td>2.667</td>
<td>2.500</td>
</tr>
<tr>
<td>Overall</td>
<td>6.060</td>
<td>5.450</td>
<td>2.930</td>
<td>2.070</td>
</tr>
</tbody>
</table>

Table 7.2 Industry Mean Reply on the Consideration Given to the Practicality of Detail
For contract type A, the overall mean result was 6.06. This indicated that all of the disciplines felt problems were likely because of inadequate consideration given to the practicality of detail in contracts where design is completed before tender. The consultants produced the highest mean value of 7.167.

For type B contracts, the overall mean value was reduced to 5.45. Again the consultants foreseeing a greater probability of problems, their mean value being 6.667. For type C contracts, the overall mean reduced further to 2.93.

For type D contracts, the respondents foresaw a further reduction in possible problems. The overall mean value was only 2.07.

The results are illustrated below in graphs 7.6, 7, 8, 9, and 10.

![Graph](image)

**Figure 7.6** Consultants Mean Reply on the Consideration Given to the Practicality of Detail.
Figure 7.7 Contractors Mean Reply on the Consideration given to the practicality of Detail.

Figure 7.8 Clients Mean Reply on the Consideration given to the practicality of Detail.
Figure 7.9 The Industry Overall Mean Reply on the Consideration given to the practicality of Detail.

Figure 7.10 A Histogram Showing the Industry Overall Mean Reply on the Consideration given to the practicality of Detail.

3 Superficially Economic Design

Superficially economic designs may occur when savings on materials produce a more costly design due to more costly or longer construction process being required as a result.
Table 7.3 shows the mean reply given for each contract type by each discipline and the overall view for all respondents for superficially economic design.

<table>
<thead>
<tr>
<th>Contract type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants</td>
<td>5.917</td>
<td>5.417</td>
<td>3.500</td>
<td>3.250</td>
</tr>
<tr>
<td>Contractors</td>
<td>4.727</td>
<td>4.909</td>
<td>4.545</td>
<td>3.900</td>
</tr>
<tr>
<td>Clients/LA</td>
<td>4.167</td>
<td>3.917</td>
<td>2.197</td>
<td>2.750</td>
</tr>
<tr>
<td>Overall</td>
<td>4.937</td>
<td>4.740</td>
<td>3.650</td>
<td>3.300</td>
</tr>
</tbody>
</table>

**Table 7.3** Industry Mean Reply on Economic Designs

For types A and B contracts, the overall mean were 4.937 and 4.74 respectively. This decreased to 3.65 for contract type C and further to 3.3 for contract D.

The employees of clients and local authorities were the most optimistic of type D contracts. The employees of contractors perceived type C and D equally advantageous.

The possibility of producing superficially economic design decreased as the degree of contractor involvement in the design process increased as can be seen in graphs 7.11, 12, 13, 14, and 15.
Figure 7.11 Consultants Mean Reply on Economic Designs.

Figure 7.12 Contractors Mean Reply on Economic Designs.
Figure 7.13 Clients Mean Reply on Economic Designs.

Figure 7.14 The Industry Overall Mean Reply on Economic Designs.
Figure 7.15 A Histogram Showing the Industry Overall Mean Reply on Economic designs.

4 Poor Sequencing of Operations

Table 7.4 shows the mean reply given for each contract type by each discipline and the overall view for all respondents when asked to consider the possibility of problems arising from poor sequencing of operations.

<table>
<thead>
<tr>
<th>Contract type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants</td>
<td>6.083</td>
<td>6.833</td>
<td>4.083</td>
<td>2.500</td>
</tr>
<tr>
<td>Contractors</td>
<td>5.273</td>
<td>6.273</td>
<td>3.545</td>
<td>2.455</td>
</tr>
<tr>
<td>Clients/LA</td>
<td>4.333</td>
<td>5.333</td>
<td>4.083</td>
<td>2.917</td>
</tr>
<tr>
<td>Overall</td>
<td>5.230</td>
<td>6.150</td>
<td>3.900</td>
<td>2.624</td>
</tr>
</tbody>
</table>

Table 7.4 Industry Mean Result on Sequencing of Operations
Again, the preferred contract type was type D, producing a mean of 2.624. For type C contract, the mean reply was 3.9 the contractors giving the lower replies with a mean of 3.545. For a type B contract, the overall mean rose quite dramatically to 6.15. This indicated that the respondents felt that problems would arise from poor sequencing of operations with this type of contract. For type A contracts the overall mean dropped to 5.23.

Therefore the degree of contractor involvement in the design process was considered to have a large influence on sequencing of construction operations. The contractor undertaking detailed design was considered to have a beneficial effect on the sequencing of operations, particularly by the employees of contractors as could be seen from the graphs 7.16, 17, 18, 19 and 20.

![Figure 7.16 Consultants Mean Reply on Sequencing of Operations.](image-url)
Figure 7.17 Contractors Mean Reply on Sequencing of Operations.

Figure 7.18 Clients Mean Reply on Sequencing of Operations.
5 Longer Construction Duration

Table 7.5 shows the mean reply given for each contract type by each discipline and the overall view for all respondents. The respondents were asked to consider what problems they foresaw with longer construction durations for each of the four contract types.
Table 7.5 Industry mean Result on Construction Duration

Contract type B was considered the most likely to give longer construction periods. The employees of consultants replying the most strongly against this form of contract, giving it a mean of 6.146.

For a type D contract, the overall mean was only 2.656. Contractor, consultant and client employee alike considered that they were unlikely to encounter problems with longer construction durations with this type of contract. See also graphs 7.20, 21, 22, 23, 24, and 25.

<table>
<thead>
<tr>
<th>Contract type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants</td>
<td>5.583</td>
<td>6.750</td>
<td>4.417</td>
<td>2.750</td>
</tr>
<tr>
<td>Contractors</td>
<td>5.182</td>
<td>6.273</td>
<td>3.909</td>
<td>2.636</td>
</tr>
<tr>
<td>Clients/LA</td>
<td>4.583</td>
<td>5.417</td>
<td>4.667</td>
<td>2.583</td>
</tr>
<tr>
<td>Overall</td>
<td>5.116</td>
<td>6.146</td>
<td>4.331</td>
<td>2.656</td>
</tr>
</tbody>
</table>

Figure 7.21 Consultants Mean Reply on Construction Duration.
Figure 7.22 Contractors Mean Reply on Construction Duration.

Figure 7.23 Clients Mean Reply on Construction Duration.
Figure 7.24 The Industry Overall Mean Reply on Construction Duration.

Figure 7.25 A Histogram Showing the Industry Overall Mean Reply on Construction Duration.

6 Higher Construction Costs

Table 7.6 shows the mean reply given for each contract type by each discipline and the overall view for all respondents. when asked to consider the influence of contractor involvement on construction costs.
<table>
<thead>
<tr>
<th>Contract type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants</td>
<td>5.417</td>
<td>6.250</td>
<td>4.417</td>
<td>3.500</td>
</tr>
<tr>
<td>Contractors</td>
<td>4.000</td>
<td>6.091</td>
<td>4.091</td>
<td>2.909</td>
</tr>
<tr>
<td>Clients/LA</td>
<td>4.917</td>
<td>5.583</td>
<td>4.667</td>
<td>3.667</td>
</tr>
<tr>
<td>Overall</td>
<td>4.778</td>
<td>5.974</td>
<td>4.391</td>
<td>3.350</td>
</tr>
</tbody>
</table>

**Table 7.6** Industry Mean Reply on Construction Costs

The respondents replied favourably for the type D contracts. Contract types A and C gained overall means of 4.778 and 4.391 respectively. Contract type B fared rather worse with a mean of 5.974 indicating that the respondent felt it more likely that there would be higher construction costs in this type of contract, as can be seen in graphs 7.26, 27, 28, 29 and 30.

**Figure 7.26** Consultants Mean Reply on Construction Costs.
Figure 7.27 Contractors Mean Reply on Construction Costs.

Figure 7.28 Clients Mean Reply on Construction Costs.
Figure 7.29 The Industry Overall Mean Reply on Construction Costs.

Figure 7.30 A Histogram Showing the Industry Overall Mean Reply on Construction Costs.

7 Inadequate Construction Quality

Table 7.7 shows the mean reply given for each contract type by each discipline and the overall view of all respondents, when asked what influence contractor involvement would have on the quality of construction.
<table>
<thead>
<tr>
<th>Contract type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants</td>
<td>4.167</td>
<td>4.833</td>
<td>3.833</td>
<td>4.000</td>
</tr>
<tr>
<td>Contractors</td>
<td>2.545</td>
<td>3.909</td>
<td>3.545</td>
<td>4.000</td>
</tr>
<tr>
<td>Clients/LA</td>
<td>3.333</td>
<td>4.583</td>
<td>3.750</td>
<td>3.750</td>
</tr>
<tr>
<td>Overall</td>
<td>3.348</td>
<td>4.440</td>
<td>3.700</td>
<td>3.916</td>
</tr>
</tbody>
</table>

Table 7.7 Industry Mean Result on Construction Quality

All respondents thought the chance of problems occurring would be fairly low. Construction quality was not perceived as a great problem whether the design was complete before tender or undertaken by the contractor.

The least probability of problems occurring with inadequate construction quality was perceived as occurring with contract type A. Type B Contracts were considered likely to give the most problems. However, the variance between the maximum and minimum overall means was only 1.093. Contractor involvement in design was not viewed as particularly influential on construction quality.

See also graphs 7.31, 32, 33, 34 and 35.

![Consultants Mean Reply on Construction Quality](image)
Figure 7.32 Contractors Mean Reply on Construction Quality.

Figure 7.33 Clients Mean Reply on Construction Quality.
7.3 Summary and Conclusions

This chapter assessed the degree of contractor's involvement in the design phase, and found out that there are less difficulties in contracts where the construction process has been allowed to influence detail design.
Contractor involvement in the design process was perceived as favourably influencing the construction process by consultants, contractors and clients alike and they all considered type D and C contracts as least likely to produce problems. The data has been presented in a such a way that the decreasing or increasing of level of influence is shown by continous line.

The results were as follows:

1. **Poor quality of information provided for construction.**

   The consensus of opinion was that there was a greater chance of problems with types B and A contract, for the problem foreseen with poor quality of information provided for construction. For type D and C contracts less problems were perceived by all respondents.

2. **Inadequate consideration given to the practicality of detail.**

   For contract types A and B, all disciplines felt problems were likely because of inadequate consideration given to the practicality of detail in contracts where design is completed before tender. For types D and C, respondents foresaw a reduction in possible problems.

3. **Superficially economic design.**

   The possibility of producing superficially economic design decreased as the degree of contractor involvement in the design process increased from types A to D. Type A and B both fared badly, and Type C and D were considered favourable in this area.
4 Poor sequencing of operation.

The degree of contractors involvement in the design process was considered to have a large influence on sequencing of construction operations. The contractor undertaking detailed design was considered to have a beneficial effect on the sequencing of operations. The respondents felt that problems would arise from poor sequencing of operations with type B and A contracts.

5 Longer construction durations.

Contract types B and A were considered the most likely to give longer construction periods. For a type D contract, respondents considered that they were unlikely to encounter problems with longer construction durations with this type of contract.

6 Higher construction costs.

The respondents replied favourably for the type D and C contracts. Contract types B and A fared badly, indicating that the respondent felt it more likely that there would be higher construction costs in this type of contract.

7 Inadequate construction quality

Construction quality was not perceived as a great problem whether the design was complete before tender or undertaken by the contractor. The least probability of problems occurring with inadequate construction quality was perceived as occurring with contract types A and C. Type B Contracts were considered likely to give the most problems.
The type B contract fared very badly indeed and was considered to give most problems by contractors, clients and consultants, in the area of quality of information provided, superficially economic designs, sequencing of operations, construction duration, and construction quality. The consensus of opinion was that there was a greater chance of problems with this type of contract. This means the industry at least want all designs to be finished and completed before tender, where there will be no chance of a future dialogue between the contractor and the consultants. Type C contracts were considered favourable particularly in the area of construction quality.

It is clearly the view of the people surveyed that we have less design difficulties in contracts where the construction process has been allowed to influence detail design.

A measure of the influence of construction on designs from contracts of type A where the detailed design is completed before tender to type D where the contractor undertakes detail design could be seen.

It is the author's view based on all the available data, that type C contract is the most suitable system for the UK construction industry for the following reasons:
1. The design details are produced by designers not contractors and therefore needs no revolutionary changes in the current practices as the case in type D contract.
2. This type is considered by people surveyed favourably in the area of construction quality and thus taking into account designer's views expressed in Chapter 4.

Therefore type C contract represents the likely optimum input of designer with all design knowledge and the contractor with all the construction knowledge.

This will help in recommending a system where designer post to award of contract can produce the design detail with a contractor's knowledge on construction [See Chapter 8].
CHAPTER 8: FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction
8.2 Research Findings
8.3 Conclusions
8.4 Recommendations
8.5 Recommendations for Implementing the Research Findings
8.6 Further Research
8.7 Contributions of the Thesis to Knowledge on Constructability
8.1 Introduction

Concern about the state of the UK construction industry has resulted in many reviews of the current practices of the industry. These reviews have identified potential areas for change, such as design and contract procedures, the organisation of design of construction, construction methods and client's responsibility [Nahapiet and Nahapiet, 1985].

The concern about the industry has been further emphasised by the findings of international comparisons of construction performance, in particular the comparison studies with the US construction, where the findings show it to be better than that of the UK in terms of speed and cost of construction. [NEDO, 1976], [RICS, 1979], and [LAING, 1979]

This chapter presents the research findings and recommendations that if implemented will bring designers and contractors closer together. Finally it presents the conclusions of the thesis and recommendations for future studies.
8.2 Research Findings

This research provides better understanding of the design and construction processes and presents:

- the structure of the industry and how it tries to operate;
- a catalogue of typical problems caused by design;
- an examination of cost and time implications of these problems;
- a design process model, tested and approved;
- where in the model these design problems occur;
- details of the people causing these problems to occur, how they work and organise themselves;
- who is paying for this problems;
- the information we need to get to designers to solve these problems;
- the means to get to designers this information.

The findings of this work are:

A Findings to match research objectives 1, 2, and 3

1 There can be no doubt that detailed design difficulties do exist. This was exposed by the seminar held at Loughborough (See Section 3.2.1) and confirmed in the survey of contractors and designers detailed in Chapters 3 and 4.

The majority of design problems have been shown to occur during the detail design stage [see Section 6.5]. Out of 104 design problem studied during the research 77 problem fell within the detail design stage.

The survey proved that the detail design decisions have a significant impact on the costs and time. In the UK the construction stage has no major influence at the design
stage because the traditional system prevents this involvement. The nature of the difficulties encompass:

- Over-complex designs which are often costly in construction time and disruption.
- Failure of the designs to allow contractors to use commonly available construction systems, or plant, to their best advantage.
- Poor quality of information provided for construction due to lack of communication and coordination between design and construction team members.
- Superficially economic designs are often more costly in construction time due to their complex shapes or processes of construction.
- Poor sequencing of operations forced upon the contractor by the design.

2 Two case studies showed 18% of design detail cost and 20% and 35% of construction time could be reduced, if designers take construction into account while design detailing[see Chapter 5].

3 Design details according to all the contractors surveyed, are drawn in isolation with little thought given to the incorporation of the detail into the construction process and not enough consideration is given to the practicality of a detail, nor to the effect it may have on the construction as a whole [see Chapter 5].

4 The estimators are unable to extract the cost consequences of detailed design difficulties because they are not taken into account during the estimating process as feedback of site experience is insufficient in this area. Estimators are able to cost major conceptual variations, but are not usually involved at a detail level [see Chapter 3].
5 During construction, the planners, engineers, temporary works or formwork designers overcome any problem arising, if possible, before specific costs are incurred, failing to do that, the cost is 'absorbed'. The client's consultants were usually reluctant to become involved in the cost implications of the specified detail as against the contractors preferred method. The contractors often choose to give away some material costs in order to save on plant and labour costs [see Chapter 3].

6 The planners, engineers, temporary works or formwork designers solve the detailed difficulties without specific references to cost. Once the problem was resolved, it tended to be forgotten and was not documented, unless it became the subject of the claim, in which case the cost generally became the prerogative of the quantity surveyor [see Chapter 3].

7 There is still a significant divide between the design and construction function. This divide permeates the education and training of designers and constructors alike and to some extent is maintained by various professional institutions [see Chapter 3 and 4].

8 There is no contractor involvement in the design process under the traditional tendering system despite the recognition that this involvement would create more efficiency and less problems during the construction phase [see Chapter 4].

9 Construction in other developed countries has been shown by numerous other researches to be cheaper and quicker than present practice in the UK [see Chapter 2].
10 Experience was thought by the designers surveyed to be the main source of construction knowledge and has the greatest influence on design decision making. Education and training was another important source as was feedback, particularly cost feedback from previous contracts, and information published by professional bodies [see Chapter 4].

The more experienced the designers, the greater the constructability. The knowledge of good design detailing resides and depends upon in the experience of senior engineers which is not adequately set down for reference. Designers consider the construction requirement by consulting:

- Their own experience from previous work.
- Colleague's experience.
- Contractor's experience.
- Specialist construction consultancy or site experts.
- Users and suppliers.

11 Nine designers out of twelve surveyed [in Chapter 4] confirmed that designers are not in a position to take into account the special characteristics of the future contractors because:

- Time constraints.
- Of diversified construction techniques.
- Competitive tendering method where contractors are unknown at the design stage and hence there is no co-operation with contractors.

12 The emphasis placed on unit rates and on elemental cost approach, by designers and contractors alike, largely because of the nature of the Bill of Quantities has two significant consequences [see Chapter 4]:

195
Such an approach obviates the fact that relatively small dissimilarities in details (to those on which the unit rates are based) can greatly affect the cost of construction, making it more expensive than the assumed rates.

- Even highly constructable designs are not apparent due to the nature of both the building and civil engineering standard methods of measurement, which are unable to reflect high or low buildability in a design.

13 Eleven designers out of sixteen surveyed [in Chapter 4] do not know the true cost of their designs and do not have a cost data base for evaluating designs which reflect construction methods because of:

- Traditional contracting procedures.
- Difficulty to obtain the site feedback.
- Designers evaluate their designs in cost terms using historical data from previous contracts and is not sensitive to construction methods.

14 The survey among designers [see Chapter 4] confirms that there is no real feedback system at the disposal of designers for use in future projects, especially when it relates to costs. Designers do not actively seek feedback information on completed projects for the followings reasons indicated by designers themselves:

- Shortage of time.
- No interest.
- Practicalities of gaining access to the building once the contract is finished.
- The cost of such scheme- who would fund it?
15 Twelve designers out of sixteen said [in Chapter 4] that they attempt to avoid possible problems on site or with budgeting by:

- simply using their experience gained from designing previous projects or their previous work for a contractor;
- knowledge of availability of supplies and reliability of suppliers and of buildability;
- knowledge of standard of site supervision.

16 Designers try to get some standard approach in structural design, and simplification and standardisation are taken very seriously in some practices, in order to achieve ease of construction, time saving and require less resources [see Chapter 4].

17 One designer interviewed put the blame on the contractors, because they keep asking for changes in design details because (as he put it) the problem with the contractors is they have their own shuttering systems and they want the design to suit it [see Chapter 4].

18 Ten designers out of fifteen surveyed consult contractors during the design phase [see Chapter 4]. This only happens:

- When necessary for specialist circumstances and for specialist information.
- If needed, and this depends mostly on the designer's own site experience.
- In Turn-Key type contracts.
19 It was felt by eleven designers out of thirteen [see Chapter 4] that they prefer tried solutions for the following reasons:

- Keeping an economic time schedule for the design.
- The industry wants that. Designers do feel that the policy of their practice is to use tried and tested solutions where ever possible.
- Unless they think of something better.

20 The most suitable projects for applying Turnkey or Design and Build methods are industrial buildings, or those projects which the client is able to define precisely his requirements and performance standards in detail at the time of tender [see Chapter 4].

21 Designers interviewed [see Chapter 4] stated that existing procedures which allowed the integration of design and construction did not produce better results. A consultant believed that contractors in Turnkey and Design and Build projects try to change or specify some details or material which is of lower quality, and hence the client would get a high price for his project, while in a competitive situation the client will get the benefit. It is not necessarily the case that if you make the contractor responsible for all the detailed engineering and for co-operation between the involved parties, that a saving in cost might occur. Someone else is carrying the burden at the end of the day and he must be paying.
B Findings to match objectives 4, and 5

22 A general design process model for the UK construction industry has been produced [Presented in Chapter 6], which provides a general conceptual framework based on current practices. The model breaks down the overall process into multiple components, which provide common ground on which to integrate design and construction.

23 Junior engineers are involved in the detailed design, senior engineers are less involved. But designers organise themselves in a team. The senior engineer (team leader) sees all the drawings. But he does not check everything mathematically. This team is only engaged in one design at a time [see Chapter 4].

The survey shows that the people in charge of the design at it's different stages are as follows :-

<table>
<thead>
<tr>
<th>Outline design</th>
<th>Only senior designers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme design</td>
<td>Only senior designers</td>
</tr>
<tr>
<td>Detailed design</td>
<td>Senior and junior designers</td>
</tr>
</tbody>
</table>

24 Clients pay for the design problems. Designers admit that the client pays and carries the burden if there is additional cost associated with the design details. Designers do not pay while the contractors lose some of their profits [see Chapter 4 and 6].

In Turn-Key jobs, the client thinks that he puts the risk on the contractors, but what would happen later is one of the following:
- Either the contractors have not put all their requirements in the tender resulting in the contractor start moaning or perform in less satisfactory manners.
- Or put in the cost of all the possibilities in the price and client would get a high price for his project.
C Findings to match objectives 6

25 All designers surveyed in both postal and personal surveys think that the enhancement of the cost experience of designers has beneficial effects because as one designer put it "effective budgeting is essential for survival". To achieve that designers suggest [see Chapter 4]:

- Site experience to see first hand the problems that design detailing can lead to, and the general methods of construction adopted by constructors.

- Exposure to the full range of the building route to completion and preferably to its use.

- Design & Construction package contracts.

- Meeting a contractor to discuss a project before the tender documents are issued. However it is not likely that the time and money would be available to do this.

- Secondment to a contractor's estimating department, to study relative merits of rate buildup and costing total resource mobilisation.

- Experience and information dissemination.

26 All designers surveyed in both postal and personal surveys [see Chapter 4] agree that close co-operation between designers and contractors has beneficial effects on the cost of constructing the building. Designers must be careful to distinguish the roles, and responsibilities must be clear.

For better co-operation between designers and contractors throughout the various phases of the design and construction work. The following suggestions were derived from the designer's survey:
- Remove barriers set up by contractual systems. They also believe that there is a conflict of interest between the designer and the contractor. The contractor has emphasis on getting money more than the designer, while designers are professional bodies, they provide their services in a way to protect the client as well as getting their fees. The solution must be by removing some of the barriers in the contracting system.

- Experience of how a contractor will build the designed work.

- Involvement of contractors in the design stage is very difficult as contractors often have varying preferences for methods of construction and therefore cooperation with one contractor may not help due to a competitive tendering situation. This is only possible for negotiated type contracts.

- Involvement of contractors in design phase for specialist projects. Proper communication between designer/contractor during construction phase.

- Co-operation between designers and contractors can only be achieved by awarding a contract before detailed design is carried out.

- Initial meetings between designer/contractor at the conceptual stage.

- Improved communication - not necessarily Turnkey contracts.
  Communication can be improved only through a change in attitude. Many design engineers look down on counterparts in construction, and a similar attitude exists in reverse. This attitude must be changed to improve communication.

- Negotiated contracts.

27 Getting the contractor to do the detail design will cost the client more in time and money to analyse contractor's offers [see Chapter 4].
28 If the construction stage is allowed to influence detail design, contracts will have less design difficulties [see Chapter 7].

29 The most suitable contractual arrangements for the UK is the one in which detailed design is ongoing during construction and the designer enters into dialogue with the contractors. This represents the likely optimum input of the designer with all design knowledge and the contractor with all the construction knowledge [See Chapter 7].

30 If the principles presented in Section 3.4 are implemented better structural detailing should be achieved and significant design modifications made on site should be reduced.
8.3 Conclusions

Taking all the above points into account, my conclusions are:

1 Design detail difficulties definitely do exist and in spite of much research there is still a significant divide between the design and construction functions. The overwhelming impediment preventing designers from considering alternatives is that designers are not in a position to take into account the special characteristics of the future contractors, mainly because of the competitive tendering method where contractors are unknown at the design stage and therefore no co-operation with contractors takes place [See Chapter 3 and 4].

2 Out of 104 design problems plotted on the design process model 77 fall under the detail design phase, in which junior (for actually doing the drawing) and senior designers (for checking) are responsible [See Chapter 4 and 6].

3 Experience, which is highly respected and valued by consultants, has the greatest influence on design decision making, but needs to be improved and made more reliable. Enhancing designers experience of how a contractor will build work as designed would be an important step towards constructability. Training engineers, especially junior ones in construction methods and technologies should be taken very seriously.

4 The cost consequences of these design difficulties from two case studies presented in chapter 5 showed that 18% of design detail cost and 20% and 35% of construction time could be reduced, if designers take construction into account while design detailing [See Chapter 5].
5 All the evidence shows that the client pays and carries the financial burden if there is additional cost associated with the design details. Designers do not suffer a financial loss while the contractors lose some of their profits [See Chapter 4].

6 The overwhelming evidence in Chapter 7 shows that less design difficulties are encountered in contracts where the construction process has been allowed to influence detail design such as the American system where the contractor undertakes the detail design [See Chapter 7].
8.4 Recommendations

To bridge the existing gap between design and construction and to take the points listed in Section 8.2, and 8.3 the following should be implemented:

A Change to Existing Contractual Arrangements

Previous chapters [Chapter 3, 4 and 7] gave the evidence that contractor involvement in design is required and advantageous. However, this is difficult to achieve with present contractual arrangements which separate design from contraction [Vanegas, 1987].

Evidence in chapter 7 shows that contractor involvement in the design stage favourably influences the construction process by promoting an all round awareness of constructability during design. The traditional British form of contract operates in such a way that only when a contract is won do the detailed drawings become available to the contractor, by which time it is usually too late for comments on constructability.

In all the research surveys, contractors and consultants alike agreed that contractor participation in design led to fewer problems. A view was expressed by contractors in chapter seven, that a design completed before tender is preferential in theory. However, in practice no design was 'complete' in the sense that errors, misjudgements, accidental omissions, conflicts between the documents and lack of foresight occurred.

The emergence of nontraditional arrangements over the last two decades, which primarily seek to involve contractors in the design stage are evidence on the developments in the design and contract procedures used in the UK [Dunican, 1984]. The available practices include Construction Management (Fast-Track), The American
System and Design and Build.

Improvement in the UK construction industry could be achieved by different work practices from the ones currently in use [RICS, 1979]. Therefore it is necessary to find a system where alternative design solutions are actively encouraged, with the saving shared between contractor and employer, without introducing a complete revolution in the existing practices and procedures. The system must put the contractors very much in control of the working drawings and even the design content of the detailed construction. Two systems are suggested by the author based on the findings of the research:

1. **Add a Redesign Stage**

A new stage called the Redesign stage could be added to the model shown in Figure 6.1, directly after the tendering stage. The new model will then consist of six main stages as shown in Figure 8.1 below.
Figure 8.1 The new proposed construction process

In this system tenders are still based upon drawings and bills of quantities as is the case in current practice were the designer is expected to provide fairly detailed drawings. The details which show how the design will be constructed could be arranged between contractor and designer at this new stage. The new drawings produced must be reviewed and approved by the architect and engineer. The emphasis is towards allowing the contractor to decide upon the working details best suited to the method of construction. This is a major variation from normal practice, where the designers tend to design details and the contractors are left with little say.
2 Conforming and Tag Bids Method

The bidders submit two prices one called conforming bid and the second called the tag bid. The first bid price conforms with all the drawings, and requirements of the engineers on which comparison could be carried out between contractors.

The tag option is a bid on which the contractor says how he can execute the same job using his own available resources, ideas and construction methods. For example he has a pre-cast yard and he wants to make use of it. Therefore he asks the client to change from cast in situ to pre-cast concrete using available resources. The saving in such methods could be divided between contractor and client.

But the most important thing is that the engineer would only look into the tag price if the conforming bid is the lowest.

In this system the question of design responsibility will rest with the contractors and designers as a joint responsibility, and therefore there is a high degree of competence and design quality. This means that the responsibility has not transferred from one party to another, but it is spread between contractors, sub-contractors and designers.

In this system tenders are based upon drawings and bills of quantities as is the case in the traditional UK system. The designer is expected to submit drawings with the usual level of detailing, the contractor and sub-contractor are required in the tag bid to produce drawings, which show how the design will be constructed. These drawings must be reviewed and approved by the architect and engineer. Once again the emphasis is towards allowing the contractor to decide upon the working details best suited to the method of construction. This is also a big difference from normal practice. This system is shown schematically in Figure 8.2.
In general the tag bid places a great deal of reliance upon the sub-contractor, because the greater part of all works will be undertaken by sub-contractors, and the documentation should be structured to cope with this eventuality.

The only difficulty I anticipate with this system is that it will take a client longer and will cost more to analyse the contractors offers, than at present.
B The Use of Computers

1 Computer aided design

The use of computer aided design (CAD) systems has implications for the constructability of designs. CAD can improve the situation by allowing the rapid appraisal of alternatives and a measure of iteration previously unavailable.

Of particular concern is the use of 'standard' details. A drawings library, supplied on floppy disc, consisting of product drawings and their constructional detail, could be produced. Such a system with the potential for standardising good constructable details, offers at least the benefit of savings on drawing time.

It is general practice for designers to use details from manufacturers catalogues, and so in effect allow the manufacturer to design the detail for them. It is unlikely that all details will be suitable for all situations, and so an uncritical approach in practice can lead to some of the difficulties commonly encountered during construction.

A computer system would make it much easier to include extra details, hence a much more critical attitude needs to be adopted with more careful appraisal of the details. In practice this may well not happen, and so if such detail libraries are not to become a liability they should not only be 'manufacturer approved' but also construction approved.

There is an outstanding opportunity to establish libraries of good practical details which conform to the ideas of good practice in the industry. The details in these libraries should be appraised for their constructability, durability and cost implications. Otherwise, there is a danger of standardising poor details in a way that will make the current difficulties much worse.
2 The use of expert systems

The existing software used in supporting designers in their work does not help specifically in the areas of constructability or cost, with most structural software being confined to numerical analysis and graphical output. In the more refined systems these allow user interaction with the main analysis module so that any resultant solution is user-influenced. It is our contention that integrating a Computer Aided Design with a knowledge-based system brings to the analysis the experience and knowledge of construction methods and cost to provide a practical solution.

Wager [Wager, 1987] claimed that many researchers think that future expert systems will be integrated to form parts of suites of computer programmes rather than huge stand alone 'experts', and another way of implementing such a system is as a front end or back end to more sophisticated suites of programmes.

Previous studies have established excellent FORTRAN programmes for structural analysis. Although it still remains to implement all these tasks together in the design process within an expert system framework.

My proposal is to integrate a Knowledge-based system within a CAD programme for a structural design, wherein both numeric computation and knowledge-based problem solving are together applied to perform the structural design.

The big advantages of using such an integrated system are that this system is not limited to numeric manipulation and computation, but also can pass on ideas and judgements from experience, advice on construction method and cost implications.
This integration should demonstrate the possibility of carrying out a realistic consultation between the user and the expert system for selecting a suitable structure type; providing the user with the proper consultation and advice concerning site experience, construction method, constructability and cost; and, then designing it, giving several options to select reinforcement required in accordance with the code of practice and finally providing the user with reinforced details.

The basic structure of this kind of integration is shown in Figure 8.5. The programme is divided into two basic sections, the Selection or Decision making and the Design of flexural reinforcement of a structure.
C Training and Supervision

Consultants surveyed admitted that training was a problem, particularly in the small practices. Senior designers reported that much of their time was taken up by administration, leaving little time to supervise their junior engineers or technicians.

In the catalogue of design detail difficulties (Appendix 1), it was
possible to correlate the difficulties with the junior designer perpetrating them at the detail design stage. Therefore much of the effort should be centered on the type of staff who create the details and the supervision they receive in their work. Some effort should also go into examining where in the design office the knowledge of 'good design, easily constructed' is accumulated or resides. This was largely an experienced based knowledge acquired over many years. One problem with this was that the more experienced staff did less detailing.

The problem of producing good, constructable designs was viewed by both contractors and designers as a training and education problem. Few university courses include the study of production topics in their courses for civil engineers.

Membership of the Institution of Civil Engineers (ICE) only requires a designer to spend one year on a site, and in many cases that is spent on the Resident Engineers staff and therefore one step removed from involvement in the actual construction. Technically, a member of the Institution of Structural Engineers is not obliged to spend any time on site. The situation in the ICE could be improved with the post Chilver [Chilver, 1981] requirement for engineers to attend so many days on training courses before being able to qualify for the Part 2 stage.

It is therefore recommended that a joint venture works between industry and academia should be carried out to design and develop education and training modules to raise the level of competence within the junior design staff in issues of constructability. This could be achieved by:

- Educating design engineers in the preparation of tenders and construction methods. This would lead to an awareness that some of their details were expensive.
- Establishing in the undergraduate course the subject of 
  construction management and construction technology, 
  standing equally alongside the other subjects 
  which McCaffer [McCaffer, 1987] believes are relevant to the 
  needs of our major employers.

- The introduction of the subject of constructability and the 
  research findings and recommendations to design, 
  construction, and construction management post graduate 
  courses.

- If a variety of construction courses, identifying production 
  aspects were made available for design engineers, it would be 
  a positive step at a time in their careers when they most need 
  it and when to some extent they are a captive audience.

D Enhance designers site experience by adopting the followings:

- Design engineers spent a greater part of their 
  training working for contractors to gain site experience to 
  see first hand the problems that design detailing can lead 
  to, and the general methods of construction adopted by 
  constructors.

- Exposure to all the stages in the design and construction of a 
  project and preferably exposure to its use after completion.

- Secondment to a contractor's estimating department, to 
  study relative merits of rate buildup and costing total 
  resource mobilisation.
8.5 Recommendations for Implementing the Research Findings

To produce less design difficulties and achieve easier, faster and cheaper construction and to reduce significant design modifications made on site, the following are required to be implemented:

1. By the industry as a whole to develop and implement the contractual systems suggested in Section 8.3. A to facilitate the participation of contractors in the design process.

2. Implementing the practical design principles presented in Section 3.4 for better detailing by designers. These principles cover pipe laying and concrete structural elements.
8.6 Further Research

Future research work should concentrate on the following *eight* directions:

1. Further work is required to implement and put the findings of this research into practice. The recommendations for better structural detailing presented in Chapter 3 section 3.4 need implementation and testing in a real life environment to establish that these recommendations could reduce design detailing problems. For better results this work should be carried out as joint ventures between industry and academia.

2. To develop educating, training, and supervising modules to raise the level of competence within designers and contractors alike. A significant source of these detailed design difficulties would appear to exist in the training and supervision of junior engineers.

   It was thought by the contractors and designers surveyed that the conventional methods of training design engineers prevented them from gaining knowledge of construction methods and it was, therefore, important that these methods be changed.

3. Developing and implementing the contractual systems suggested in Section 8.3A and B to facilitate the participation of contractors in the design process.

4. Developing a drawing library of good practical details to be used by designers which conform to the ideas of good practice in the industry.
5 Developing expert systems and Integrated CAD with expert systems packages, to help in solving the problems related to constructability and construction method. The future development of integrating expert systems with existing CAD programmes should be carried out as joint ventures between industry and academia.

The implementation of such a system could be done in two ways:

a as a front or back end to the sophisticated CAD suites of programmes;

b or applying some new techniques such as blackboards. "The black board is a location within the computer memory in which information that is stored within an expert system is posted so that any other expert systems or programs can refer to it if it needs the information contained there to reach its goals" [Levine, 1985].

6 All future construction models and guides should be specific to one kind of structure or function such as hospitals, schools, hotels, highrise buildings, roads, pipe works, rather than the general model in order to be of more practical use to the industry.

7 Effort should also be given to producing a specific integrated design and construction models for the UK construction industry. These models should show clearly the integration between design and construction as a total system where the construction team and the design team are working together from the beginning to the end of the project. The best way of fulfilling this point is by conducting research in conjunction with contractors and consultants.
Future productivity studies should take constructability into account, in particular the question of directing the blame at the operatives when production is low.

The wide range of possible areas for future research clearly indicate the importance of constructability. This concept will have a strong impact in future construction industry practices.
8.7 Contributions of the Thesis to Knowledge on Constructability

This research provides an insight into the design and construction processes used in the construction industry and offer an opportunity to link investigations in these two disciplines. The author's background in construction and in coordinating designs in a large scale project helped in blending different aspect of these two disciplines.

1 It also provides a better understanding of constructability and the influence of design decisions on site operations and the impact the design has upon the construction process.

2 This study will promote awareness amongst designers of the implications of their designs upon construction process, and recognise significant aspects of design which would enable the contractor to provide the client with better value for money.

3 It is significant to all in clarifying the role of all participants and in particular it clarifies the role of construction input during the project phases and allow a better interaction of the two disciplines.

4 This thesis increases our understanding of the design process, in particular the detail design phase, and provides a general design process model for the UK construction industry. The model produced, provides a general conceptual framework based on current practices to establish how the process work. The model breaks down the overall process into multiple components, which:

- allow the development of better management approach and research strategies; and,
- provides common ground on which to integrate design and construction.
**This study:**

- included interviews with contractors and designers, the basic data and recommendations of chapter 3 and 4 and a model, all of which if implemented by designers as a guide for detailing should reduce design detailing problems;

- quantified the cost to the construction community (Contractor, client, designer) of poor or badly designed details [see chapter 5]. This cost evaluation of design details will give the client an idea of the cost implications of not implementing the research recommendations. It also makes the designer aware of these implications of design decisions taken by him;

- identified where in the model, constructability problems arise and by whom. It gives the client, contractors, designers and educators information as to where the problem lies; and,

- devised measures of influence of construction on design from 'low' where the detail design is complete before tender to 'high' where the contractor undertakes detail design.
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APPENDIX 1: CATALOGUE OF DESIGN DETAIL DIFFICULTIES

1 Drawings
2 Foundations
3 Structural Frames
4 Floors
5 Formwork
6 Reinforcement
7 Material
8 Pipelines
CATALOGUE OF DESIGN DETAIL DIFFICULTIES

The examples provided by contractors covered nearly all aspects of building and civil engineering. A total of 104 examples have been included in this appendix and have been grouped under the following categories, drawings, foundations, structural frame, floors, reinforcement, formwork, materials, and pipelines.

1 Drawings

Twenty three examples of difficulties encountered by contractors were cited during the survey of which eleven were recorded in detail.

Drawings are the medium through which the designers intentions are communicated to the site, but it was considered by some of those interviewed that they were not always suitable for site operatives to build to. Drawings were frequently criticised for poor quality which generally meant a lack of clarity and content. A particular complaint was poor cross referencing of drawings. Some of the examples given included the following:

- From a set of tender drawings and a specification, a contractor stated that it was not clear whether the walls were meant to be pre-cast or in-situ.

One Design and Build contractor argued that they aim to produce a high standard of drawings (both in draughting and content), in the belief that it is reflected in the quality of the job on site. The feeling of all of the contractors doing Design and Build contracts was that they produced fuller detail than consultants, taking into account construction methods, what the site can or cannot do, special load conditions that they should be aware of, providing notes on the fixings of details, and the workmanship side of construction. Much construction method goes into the drawings, often with specific construction drawings. The result is that the work should flow
better, and orders can be placed at an early stage.

In fairness to the independent designers (consultants/architects) it must be said that the D&B contractor has decided on, and is detailing for, a specific method of construction. The independent designer does not have this luxury, he may detail what he wants, but under the standard contract not how to do it. However, it would seem that there is still room for improvement, by giving more consideration to the needs of the production cycle.

Formwork designers in particular complained about the general dimensioning and clarity of drawing. Two formwork designers working for separate contractors cited cases of obtaining essential concrete dimensions from the M and E drawings.

Because of the last recession and the need to reduce their overheads, many contractors have all but eliminated their design staffs with the result that much formwork design is sub-contracted. For the sub-contract designer the situation is made even more difficult, as they are usually only sent the general arrangement drawings, and sections, that the contractor feels are relevant. It is rare for them to be sent reinforcement drawings, and usually the drawings sent to them are copies of the contractor's drawings, sometimes even copies of copies. As a result the first obstacle for them is to read the drawings which are often patchy and dark. (In this respect contractors carry as much guilt as the consultants they complain about).

Some of the difficulties experienced by the formwork designers are:
- The architects dimensions are frequently not tied in. In one example, a designer displayed a set of drawings which he claimed, were an extreme case, where he had to obtain a complete set of concrete dimensions from brickwork details shown on the architects 'small detail drawings'. To quote the designer "It took hours of working around the drawings to find all the required dimensions".
Obviously not all dimensions for an item of work can be included on one drawing. In such cases a systematic system of referencing and clear specific titling of drawings should be used, so that dimensions can be easily located.

The co-ordination of the disciplines that are part of a design and their drawings is crucial to the smooth running of a contract, so D&B firms offering a fixed price for contracts often spend large amounts of money trying to coordinate their designs.

For the structural engineer the principal problems in allowing for services in his design are where to put the holes, what size should they be, and what clashes with what. If the services content is uncertain, it is better to design the structure to be as flexible as possible with this in mind.

Coordination problems that reach the site can cause disruption to the programme, create delays in fabrication, requiring re-ordering of materials and ultimately lead to claims for time and costs.

Not all designers are bad at presenting information, some were praised and some practices were named as being consistently good in their presentation of contract information. One planning engineer told of a particular practice which had gone to great lengths to present a complete package of tender documents for a hospital contract. The result was that the six tenders for the contract were closer than that engineer had ever seen before on such a contract.

It was felt by several contractors that not enough effort was put into giving the right information at tender. Clearly quantity does not equate to quality.

Contractors were rarely found to criticise the concept, but the details of the design. The lack of criticism was frequently because contractors knew that they were all tendering on the same 'costly'
basis. Their dislike of detail is partly because detail drawings either arrive after a tender is won, or the implication of a detail were not realised in the rush of tendering. Whatever the case, the contractor is still committed to a price.

Frequently contractors stated that they could see where savings could be made but knew that unless they could show a substantial saving (to cover their design costs, the Engineers checking costs, and subsequent changes to his details) their proposal would be rejected.

On the whole contractors who tendered for design and construct work tended to be more critical. Their approach to the concept was very keen because in a tender situation the concept can win or lose a contract.

2 Foundations

The complaints collected regarding foundation design were fewer than expected, but twelve were cited of which five were recorded in detail.

Individual pad foundations, especially if closely spaced and numerous (Figure A1.1) are not necessarily a cost saving, if individual areas excavated in isolation, rather than stripping the site to a reduced level in one operation.
The cost of construction for figure A1.1 may involve:
- Individual excavation for each pad.
- Shuttering and reinforcement.
- Reduced access for plant whilst also making the site untidy, spoil may fall on the reinforcement before and during casting the foundations.

Usually the contractor will choose to excavate to a base level, right across the site, and have a flat excavation. This allows clear access, with faster and easier working. There is then the extra cost of backfilling the areas between pads with imported hardcore, up to the formation level of the ground slabs.

A more cost effective design in many instances would be a flat slab or raft. This allows the contractor to bulldoze out a flat excavation, and quickly blind the base with concrete so that the ground is sealed especially in bad weather.

A similar principle applies in constructing a service reservoir for instance where additional thickening of ground slab may be required at the column positions (Figure A1.2).
Figure A1.2a  Additional Thickening of Ground Slab at Column Positions of A Service Reservoir

Alternative details are shown in Figures A1.2 b, and A1.2c

Figure A1.2b  Flat Raft Alternative.
Figure A1.2c  Upside Thickening Alternative.

Figure A1.2  Ground Slab Details.

From the construction aspect the best detail is (b), it is cheaper and easier for the contractor to give away the concrete at the edges.

Example
Tender document were received showing a foundation designed as piles supporting very heavy ground beams, between which spanned the ground slab (Figure A1.3).
Figure A1.3 Piles Supporting Heavy Ground Beams Foundations.

Having driven the piles the contractor would then have to excavate for the beams, fix reinforcement, cast the beams (in two parts), strike the shutter, backfill the trenches around the beams, and prepare the ground for the formation of the slab.

The contractor suggested a flat slab set on the piles, in place of the beam and slab arrangement. From the construction point of view the contractor could place the piles, blade out a flat excavation, bring the piles up into the slab, and cast the slab. This meant that more piles were required and hence more concrete, but without formwork costs. The contractor had estimated the saving to be approximately 20%.

A detail shown in several text books on foundation design, and which according to most contractors, should be avoided is shown in Figure A1.4. The difficulty arises from permanent material reduced at the expense of additional labour and plant time.

Any savings in concrete are quickly lost in the cost of shuttering, reinforcement and the time required to build this detail, for instance a smaller concrete detail requiring more formwork and labour for fixing, striking and placing concrete.
3 Structural Frames

Eighteen examples of difficulties with frame designs were cited and nine significant examples were recorded.

The aim with any building (especially low-rise buildings) is to get the roof on as quickly as possible, so that the structure is weather proofed. Any vertical structural elements therefore, will lie on the critical path of operations. These elements should be detailed so that they can be erected as quickly as possible.

The requirements will vary from structure to structure depending on whether the emphasis is on vertical or horizontal construction, column spacings, shape of works or sophistication of the plant and technology used. However, certain principles emerged from discussions with contractors:

- Structural elements (i.e., trades) should not be mixed, particularly at any one level. If a frame is designed in in-situ concrete then that should support the structure and not structural masonry.
- Vertical elements should consist of columns with a minimum of concrete wall construction. Columns can be erected quickly and cheaply, walls take time and can delay critical operations. Non-structural walls should be eliminated.

- Where concrete walls are necessary for lateral stability, these should be unperforated. Wherever possible openings should be put through non-concrete (non-structural) walls which are constructed off the vertical critical path.

There are several problems with openings in concrete walls.

a Reinforcement fixing is less straightforward.
b The fixing of the box-out sections to the formwork take extra time and cost more.
c Compaction of concrete under a square box-out is difficult to achieve and often leads to a poor finish requiring remedial work (Figure A1.5). If a hole is required, a circular one lends itself to a better finish.

![Figure A1.5 A Square and Hole Box-out Details.](image)
Other principles emerging from discussions with the contractors were:
- Non-load bearing or non-structural walls should be made out of masonry.
- Slabs should be of flat soffit rather than 'formwork' section, because the basic savings are the cost of formwork and the time for its erection.

A ground slab detail as shown in figure A1.6, was presented as an example of poor operational sequences. The block work was detailed as overhanging on the floor slabs. Therefore the floor slab had to be constructed before a start could be made on the inner block work. Structural walls should stand on the foundations but very often adjacent walls are designed standing on the floor slab. This leads to structural discontinuity - Brickwork done out of phase, see Figure A1.6

Figure A1.6 A Ground Slab Detail.
Another example of poor operational sequences in a reinforced concrete semi-basement was presented. The original design shown in Figure A1.7, of a reinforced concrete semi-basement with insitu roof slab. The slab would not span the full width of the basement so a support beam was placed at approximately one third of the span. The beam was supported on columns with brick infill panels (non structural between them). Access was via the central staircase, the walls of which were brick, with a concrete half landing.

Figure A1.7 Poor Operational Sequences in a Reinforced Concrete Semi-basement.
The effect was to divide the basement into two rooms and a corridor area, with return walls at the staircase.

The sequence of work would have to be:
- cast floor slab;
- cast roof slab, strike formwork;
- build brickwork panels and staircases at time in programme.

In the event, it was then decided that the two centre columns were not needed as the brick returns were stable. By adding concrete padstones they could support the steel beam, thus saving the cost of the two columns. But at what cost to the construction?

The steel over beam was then supported on steel columns and brick walls, and the insitu half landing was supported by the brick stair walls, so the brickwork had become a structural feature.

This meant that the roof slab could not be placed until the brick return walls had been placed. To erect the steel columns first, then build the brick returns, then lift in the steel beam, required two visits by the steel erectors and attendant craneage expenses. The architect agreed to let the contractor build the brick work corners first, a process which required the brick work to be raked down Figure A1.8, thus breaking the building specification.
The programme was slowed down further because the corners could not be built until the flight of stairs and half landing had been constructed.

The construction process now become:
- cast floor slab;
- cast concrete walls;
- construct staircase, bringing brick work up two halves, place half landing;
- rake back brick work to corners;
- erect columns and fix beam;
- deck out and cast slab;
- bricklayers return to complete brick work.

A relatively minor knock-on effect would be that the arrangements of the falsework and its removal from the basement would be less straightforward because of the presence of the brick walls. The contractor opted to build to the sequence forced upon him by the design. The alternative was to replace the steel columns at his own cost. Disruption claims from contractor outweighted the savings made by omitting the columns.

An example of mixing of trades and performance of details was given. When roofing a warehouse the steel work contractor (structural frame) should not supply the guttering, that should be the responsibility of the roofing contractor. In that way there can be no excuse if the roof leaks, because the roofing contractor is completely responsible for the integrity of the roof.

A mixture of structural elements at any one level will create problems. Design and Build contractors in particular stress this, and ensure that it does not happen to their design.

4 Floors

Five examples of design difficulties were encountered with floors although two significant examples were recorded in detail. These related to the use of flat soffits in formwork and the consideration given to services during the design of floor slab.

Whenever possible flat soffits should be used in preference to beam and slab floors. There are several advantages:
- simplicity of formwork because there are no changes in level to be accommodated. Savings in cost;
- faster erection and turnaround of formwork;
- the design and installation of services is simplified so fabrication costs are reduced.

A distinction is made between a flat slab and a true slab. As well as being heavier flat slabs are more difficult to design, largely due to the shear forces around the column head. Detailing for these can often cause problems when fixing reinforcement [See section 5 on reinforcement]. In addition, with a flat slab holes cannot be inserted, and usually the holes are required at column positions—the very place where they cannot go. If a large number of holes are required then a flat slab cannot be used.

One situation where flat slabs can be used to advantage is in multistorey developments where all the services are taken into vertical risers and false ceilings, and do not come down at the columns. In this case holes are not required in the slab.

What are the benefits of flat soffits? From pure engineering choice, beams and slabs initially appear to be more economical in terms of actual materials, because there is less concrete, less reinforcement, and it is easier to design. However, with the cost of extra formwork (material and construction), the slower speed of construction, contractors preliminaries resulting from the extra time involved, and loss of rental on extended contract time, the more economic solution is often to use more concrete in the structure.

Example

The roof slab of the Pumping hall in a Low lift Pumping station in a sewage treatment plant, was designed and constructed as a system of beams and slab, because it was thought to be economical in material terms compared to the flat soffit option. (See Figure A1.9)
However, the consequences of that to the contractor were:
- the complex shape;
- the extra formwork used and form wasted;
- delay of at least one month.

Figure A1.9 A Roof Slab Detail in a Sewage Treatment Project.
**Example**

The roof slab of a Pumphall in the pumphouse of a water treatment project was designed as a flat soffit. The contractor was satisfied, because the work was easier and cheaper (see Figure A1.10)

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**Figure A1.10** A Roof Slab Detail in a Water Treatment Project.

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Formwork costs and savings are discussed in more detail in Formwork section No 5.

If a slab and down stand beam is necessary then wide shallow beams are preferable for construction. If the down stand can be kept to 150mm or less, construction can still be simplified. Table forms may still be used, the heads being able to accommodate a 150mm drop, and still be slid out. If the beams are deeper than ordinary proprietary decking, then standard supports must be used, which takes longer to erect and strike. Wide shallow beams will also accommodate services better.

**Services Aspects of Flat Soffits**

It has already been stated that from the start, the services design should proceed in parallel with the structural design to minimise any conflict between the two.

The services content is increasing in all buildings. Several contractors complained of the lack of space generally allowed for services. Even when placed in ducts insufficient space was allowed, congestion being so bad in some cases that the only way of placing the services was in a strict order. This has severe implications for maintenance. As one contractor said of the services on a particular project ".... it will virtually mean dismantling parts of the building to get to them."

When one looks at it in terms of cost more than half of building cost could be in services alone. This is particularly so in buildings with pharmaceutical or chemical applications. One contractor quoted a project for ICI where the building cost was £3.5M and the services content £8M.

With an increasing services content therefore the number of obstructions should be reduced as possible to keep the cost of installation and maintenance down.

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With a flat soffit design many bends in trunking and conduits are eliminated. The result is easy site construction and reduction in manufacturing costs and time.

To some extent when discussing 'ease of site construction', it is an intangible that an estimator could not put a figure to. But when the interactions of a building's elements are considered, the savings become very significant.

It should be borne in mind that in many cases the structure is of secondary importance when related to some of the items it houses. If the overall costs are to be reduced, the structural engineer cannot design his structure in isolation.

Example
An example of a good coordination between the structural and the services engineer was cited in a Water Treatment Scheme, which produced a successful design of services for that project. All the electrical cables from the generating station to the pumphouse were fixed and passed through a cable tunnel connecting the two buildings at below ground level (See Figure A1.11).
The cable tunnel was connected to the cable gallery inside the pumphouse where all the cables were supported by cable trays distributing cables to the electric motors below and the switch room, control panel and air conditioning unit above.

In addition many bends in trunking and conduits were eliminated because of the flat soffit design as mentioned in example Figure A1.10.
5 Formwork

Twentyeight examples of difficulties with formwork were collected during the survey, ten of them were recorded in detail.

Formwork is a very significant cost item and contractors engaged upon 'Design and Build' work give serious thought to minimising the formwork requirements of their designs.

A rough indication of the costs of producing reinforced concrete is shown in Table A1.1. [Illingworth, 1984]

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Table A1.1 A Rough Indication of the Costs of Producing Reinforced Concrete.

The figures in brackets indicate the percentage of total cost items i.e columns, beams etc. The table seeks to give a general picture of how the costs are distributed.

The arguments in favour of flat soffits are borne out when one observes that for a beam 56% of the cost lies in reinforcement, 33% in the formwork and only 11% in the concrete. It must be
emphasised that such tables of cost are only general as every
structure is unique.

It is possible to take two similar structures and with just small
changes in the dimensions of the structural elements make one
much more buildable than the other.

Illingworth has detailed several factors in the cost of a form.
1 The amount of repetition possible.
2 The complexity in shape.
3 The extent of falsework support needed.
4 The degree of mechanisation possible to avoid high labour
content.
5 The surface finish called for.

All of these are directly influenced by the design, not just in building
work but in all concrete structures.

When contractors were asked if designers worked to minimise
formwork costs, all of these aspects were adversely criticised in the
course of the survey.

1 Amount of Repetition Possible

Putting falsework costs aside, the material cost of formwork lies in
the plywood carcase to the shutters. The cost to a contract of the
ply will be calculated on the number of uses the estimator expects to
get from it. The lower the number of uses the higher the cost of
each concrete pour.

If there is little standardisation or repetition of concrete elements
then the site will use significant quantities of plywood for each pour.
This is costly in material, labour and time.

A designer must constantly bear in mind the 'big picture' of his
structural analysis. For instance, as one progresses up a building the
loading that the columns are required to carry reduces on each floor. Hence a smaller concrete section is warranted, from analysis. But construction economics argues against that, for the above reasons.

Repetition of structural elements isn't the only aspect. Flexibility within a design which allows for repetition of shutter panels is also important. If an element is designed so that a shutter does not have to be cut dead to height or length, but can 'fly past' the end or top of the element, then that can offer a great deal of scope to the contractor.

**Example**

Many consultants design the lift shafts of buildings as the bracing. However, as a temporary works designer will point out, that becomes the critical item on the construction of the floors. The four walls of the shaft form a nice box, but boxes are not easy to build. The construction is slower, access is difficult for men and materials, and the next floor cannot be started until the walls (lift shaft) are completed.

Considering the shutters themselves, the main difficulty is that the inner shutters all have to be cut to the correct lengths.
Concrete

Shuttering to walls

A) Plan view of lift shaft (striking pieces not shown)

Section A-A

B) Inclined joint in formwork panel to allow striking

Figure A1.12 Lift Shaft Shuttering.
With a full box the problem of the detail shown in Figure A1.12 A occurs, with the shutters having very specific dimensions and hence restricted use elsewhere. As a box it must have either a mechanical striking piece, or an inclined striking joint, in order to remove it. (See Figure A1.13 ). With such an inclined joint its use in other places is limited. With detail shown in Figure A1.3 B, only two walls are formed in the concrete, because the shutters are able to fly past the stopends. With this kind of detailing large formwork panels can be made and used in a variety of locations.

Formwork economy can be listed in the following order.

- Straight walls can be built quickly.
- 'L' shaped walls can still use fly past shutters, but beware of starter bars coming out perpendicular to the faces of two such adjacent walls (see reinforcement section).
- "U" shaped walls are more difficult.
- A complete box should be avoided where possible as it takes too long to build with 'L' bars in the top of the wall (see reinforcement).

Forming corners, or returns, in concrete is expensive both in material and in greatly increased labour costs, particularly in non-repetitive circumstances.

Walls with 'L' shaped bars cast into the tops of them, (to pick up roof or floor slabs), can similarly limit shutters, in the vertical plan. (See Figure A1.14)

Again, this detail means shutters have to be cut to definite length.
Clearly there will be many situations where such details are necessary and cannot be avoided, but whenever possible consideration should be given to the alternatives to allow maximum flexibility of the formwork.
Multi-storey buildings offer large scope for standardisation of basic structural elements, but savings can be made on all concrete structures, if repetition and standardisation are utilised.

2 Complexity in Shape

Complex shapes seem to arise out of the belief that the minimum amount of material means the minimum cost. When dealing with concrete this is hardly ever so.

Figure A1.15 shows one of two wing walls to a bridge abutment. The stepped section was not detailed to carry brickwork cladding as is sometimes the case but merely to act as a retaining wall.

Figure A1.15 Two Wing Walls to a Bridge Abutment.
The saving in concrete, over a wall section 500mm thick, was calculated to be 4.5 m³. However, the wider section would have allowed the contractor to erect his formwork as two full shutters, a quick and easy process.

To cast the wall as designed it would be necessary to:

a- erect a single pour shutter with a large boxout on one of the shutters to form the stepped shape; or
b- cast the wall in two pours (See Figure A1.16). The first pour would form the lower section the full width of the combined sections and the second pour would form the thinner area.

Figure A1.16 Casting Wall of Figure A1.15 in Two Pours.

The shutter in this would then be struck on the stepped side, and a second sloping shutter placed on the the step.

Because the formwork designs required the use of standard formwork panels, both cases would require make-up pieces to be constructed by the carpenter in those areas not covered by the
rectangular panels.
A third option would be to cast the wall in one pour, a continuous 500mm thick section, thus giving away 4.5m$^3$ of concrete. It is an indication of the cost of formwork that contractors will consider doing so in some circumstances. This would simplify the steel work as well as the formwork. A straight wall would also make for a much simpler sequence hence savings in time as well as materials.

Example
A retaining wall section which occurs quite frequently is illustrated in Figure A1.17. Presumably the design takes advantage of the reduced earth pressures higher up the wall.

![Diagram](image_url)

**Figure A1.17** A Retaining Wall Section.

Again a contractor has two options, either one pour, utilising a large box-out or void former (A) or, as the contractor elected to do three separate pours as in (B). The first requires the use of expensive formwork, the second the loss of time.
By making small saving in the cost of concrete, the additional cost involved in this design include:

1. Formwork-forming box-outs and erecting the shutters.
2. Additional reinforcement costs. It is highly unlikely that any reinforcement has in fact been saved, but the fixing time will have been extended.

There are the additional problems of pouring the concrete through a narrow opening in the top of the wall, and in the case of a one pour wall, of adequately compacting the concrete, particularly below the lower box. The contractor is left with three small shutters to strike and erect. A section such as this destroys any such time saving formwork designs. It reduces what could have been a very smooth operation to one that is fragmented and high in labour and materials content.

With a full section the contractor could have formed large easily handled panels, which would be simple to strike and transport to the next wall. With a very long section of wall, a traveling shutter could be designed giving added ease of handling and minimum erection and striking times.

Example

Lift shaft in a high rise buildings. Formwork designers state that lift shafts are costly and may cause delay to the construction programme especially if they are complex. See Figure A1.18
Figure A1.18 Lift Shaft in a High Rise Buildings.

Formwork designers recommend avoiding this kind of design detail because they make the formwork difficult to design, and erect, and invite the use of special formwork details in order to conform with the design details required.

The main problem with this detail is that the edges of the corners were not straight, this made it difficult to dismantle the shutter between the edges, and a special detail was required.

Another example of a complex shape of lift shaft of an office building in Glasgow was presented by a formwork designer. Again it can be seen the corners are not straight as in Figure A1.19
Figure A1.19 A Complex Shape of a Lift Shaft of an Office Building.

Example

The design of a retaining wall in a Sewage Treatment Plant was similar to that shown in Figure A1.17. The contractor changed this detail to a different shape as shown in Figure A1.20. The contractor used additional concrete, but he gained the following.

- Easier and faster formwork; using a climbing system designed by RMD.
- Easier steel fixing.
- Less formwork used.
- No box-out used.
- Easier casting and compaction. Less pours, because the formwork erection was not limited by the shape (the steps) of the wall. The contractor utilised the steel shutter to the full by
casting to the maximum height allowed by the manufacturer. This also meant that less construction joints and hence less water stop bars.

- Less kickers required, actually only one kicker was required which was the first one.

Figure A1.20 A Retaining Wall in a Sewage Treatment Plant.

For the cost implications of this case please see Chapter 5.

Example

The section shown in Figure A1.21 is another fairly frequent design encountered on certain types of bridge abutments.
The contractor is faced with forming a box-out in the back wall shutter, or erecting a straight shutter and using the extra concrete (in this case approximately 50 m$^3$). According to the formwork designer the contractor elected to box-out his shutter.

Complex shapes usually have complex fixing and this can often create difficulties in obtaining the correct cover if there is any error in the bending of the bars.

Even civil engineering works with their one-off nature can benefit from standardisation within the contract, and perhaps even between contracts.

Considering the number of motorways commissioned by the Department of Transport some form of standard could have been promoted. But the opposition to this is that nobody wants a uniform environment with identical structures everywhere.
The call for standardisation creates a vision of 1960s tower blocks. If true originality was the rule in all design, one would heartily endorse such excuses (because often this is what such arguments are). A close inspection will reveal that many engineering structures are similar in concept and form. The differences often lie only in the dimensions and frequently such differences are small.

Example

On winning a motorway contract a contractor asked if he could use the specialist formwork he had used on a previous contract for casting the bridge column. The bridge columns on the new contract were only 50mm smaller in diameter. For the contractor it was worth the cost of the extra concrete to save on formwork costs. (The new contract incidentally, although of similar size did not require the detailed finish that the shutters provided. Thus in theory the client gained at no extra cost).

Many road bridges have been designed such as to require special one-off shutters, never to be used again. Several contractors commented on concrete box bridges, where every design used a different sized box, with often only small differences between them. It was thought that there was only one case where a shutter from one bridge had been converted for use on another (The Trent Bridge to Ely Bridge), and a systematic approach, standardisation and aesthetics need not be incompatible, nor over expensive.

Example

One motorway bridge used a concrete box girder design, with eleven spans, consisting of six box sections (3 on each carriage way) See Figure A1.22.
Section of boxes

Figure A1.22 Concrete Box Girder.

The deck was a skewed. The box section had a 3 edged chamfer to the corners, and the webs were of variable thickness. At the time of our conversation the Chief Engineer stated that he was in the process of trying to assess what is happening in the 3 dimensions.

In two dimensional drawings, often details of separate elements are shown in section and seem to be quite reasonable but problems arise when considering the intersection of elements.

For instance: when using concrete box beams, consideration should be given to the use of permanent formwork. For a span of 600mm or less, asbestos sheet or old ply is acceptable. Up to 1200mm in span permanent formwork (such as, metal decking) is economical. Spans greater than 1200mm may require propping and so it then becomes cheaper to leave an access void and use ordinary formwork.

Example

One case was quoted where ordinary formwork was used for the top soffit. On striking the formwork, the problem was not taking everything down the box, but at the diaphragm where everything
had to go through a 450mm square hole. It cost approximately £3/m² to strike the shutter and get it out.

3 Extent of Falsework Support Needed

A significant proportion of the cost of any in-situ concrete structure can lie in the falsework supporting the formwork. The larger the structure the more significant the falsework costs particularly in the field of bridge works.

Example

A six span viaduct that had been designed as a continuous deck, used a novel stressing system that, to quote the contractor "........... saved half a ton of stressing cables", by stressing the whole bridge as one rather than as several elements. In order to do this however the deck had to be supported so false work to all six spans had to remain in place until the operation was complete. The cost of this far exceeded any savings in stressing cables or anchorages.

Example

One of the questions that was asked of formwork designers working for proprietary suppliers was, do designers produce designs that exploit the full potential of the proprietary systems? They agreed that this rarely happened, often a falsework designer is made more expensive for the sake of 50mm on the span between building columns.

Major improvements can gains are to be made on multi-storey buildings, particularly when using trough or waffle floor slabs. A study of the available brochures showed that all of the main formwork suppliers have equipment based upon a 300mm module of
components. Figure A1.23 shows typical examples of trough and waffle arrangements.

(a) Trough Arrangement.

(b) Waffle Arrangement.

Figure A1.23 Trough and Waffle Arrangement.
The trough floor is usually designed with a rib beam formed along the line of the columns, usually in both directions (although the troughs span only in one direction). This takes the form of a thickening of the slab over the column lines. This may occur with waffle slabs but the usual thickening features in a special area over each column position.

So, for the trough designs there is a solid line of concrete along the column lines and for waffles a solid area over each column position. See Figure A1.24.

Figure A1.24 Area Around Each Column Position in a Waffle and Trough Design.
If the thickening, dimension X in Figure/1.24 is made the width of one, or two troughs(or waffles), then it is a simple matter to erect the decking and simply leave out the appropriate number of troughs or waffles. This approach makes the deckign operation much easier, but the real saving lies in the falsework below.

Trough or waffle systems are usually supported by a grid of four-legged units.

For the average slab the four leg support grid will be 1800x1800mm. Therefore if the following conditions are satisfied:
- column spacing is a multiple of 300mm; and
- the thickening over the beam is a multiple of a trough/waffle sections, then the false work system can start at one end of the structure and be erected through to the other end, as basic grid units with no interruptions Figure (A1.25).

![Multiple of 300](image)

Figure A1.25 A basic Grid Support for Slabs.

However, should the column spacing be a non-standard dimension ie 5000mm then the thickening will also be non-standard.

This will probably necessitate the use of a makeup piece at column, and hence a break in the standard grid pattern. (See Figure A1.26)
If a standard system in fill beam is not the right size to carry the make up piece then it must be formed out of timber. Therefore, the line of the falsework grid is broken at each column position, to start again at the other side of the column. This incurs the cost of one extra prop at each column, and a time consuming make up piece has to be built. This process inflates the price of the formwork per m².

Most formwork suppliers offer formwork design as part of their service. One supplier in discussing this problem said that often contractors will ask for a price for formwork while formulating his tender and to a floor slab. Without details of column spacings and a detail drawing, the supplier can only quote a 'good' rate (bearing in mind that represents his 'tender' for the work). When the contractor wins the contract and sends the detail drawings to the supplier to actually design to, the problem is revealed and the actual cost of formwork can increase in some cases by up to 50%, and that is without the cost of the make-up piece which is the responsibility of the contractor (the price quoted by the supplier is only for the hire of the equipment). Hence, if a column bay required four prop positions on a straightforward design, to add an extra prop would increase the falsework cost by 25%, plus the cost of any make-up pieces.

Figure A1.26 Make-up Piece at Columns.
Example

For an ordinary thick slab, formed on ply decking the position is similar, however the dimensions of a sheet of ply must be borne in mind, that is 4'x8' or 1200mm x 2400mm. Using a system grid again.

The decking beam sizes may be 2400, 1800, 1600 and 1200mm long, thus giving the maximum distances between props. The infill beams which span between the decking beams to support the ply deck, may be 600, 900, or 1200mm long. The maximum width of ply that can be supported is therefore 1200mm.

To maximise the use of the ply, whole sheets should be used wherever possible to avoid wastage due to cutting.

To minimise the falsework costs, the span should again be based upon a multiple of 300mm. If this is not done, this would necessitate a make-up piece between the columns. For example in Figure A1.27 the span is 5000 mm.

![Figure A1.27 Make-up Piece Between Columns.](image)
A 200 mm wide timber make-up is therefore required, with one extra prop in the span, to support it.

To return to trough and waffle slabs, one designer stated that quite frequently extra props and make-up pieces are required for the sake of only a few millimeters. In one drawing that was examined, the column spans went as shown in Figure A1.28. At 5035mm the column spans were only 65mm short of a 300 module span and an efficient falsework design.

In this particular case, examination of the general arrangement showed that the outer columns of the building were placed on the line of the inner block work.

![Figure A1.28 More Efficient Dimensions of Column Spans to Minimise False Costs.](image)

Hence masonry dimensions dictated the column positions. Almost certainly in the case of brick clad buildings this will be the reason for such odd concrete dimensions that the formwork designers complain about.

In most cases, it would be better to have the greater efficiency in the brickwork operation—but then design is a process of compromise. However, the formwork designer who provided the above example
went on to cite cases of very efficient building design, also brick clad, which were based on column grids of 3.6 x 7.2 or 4.8 x 4.8m. The examples demonstrate that two similar buildings differing only in their columns spans by a few millimeters, can have very different elemental costs, or unit rates, for the construction of their floor slabs (Figure A1.27)

If one considers the average multi-storey building, and if for the sake of a few millimeters a reduction in false work costs of 14-25% could be affected, then it must be worth the designer giving some thought to these aspects of his design.

4 The Degree of Mechanisation that the Design Makes Possible to Avoid High Labour Content

Structures with simple and repetitive elements may make it economical for the contractor to invest in a more mechanised system of production. traveling wall forms for structures such as long retaining walls or large reservoirs, give very low striking and re-erection times and costs. Slip forming, or climbing formwork can be used on suitable structures. On simple multi-storey buildings the opportunity to use table or flying forms for slab decking

Table forms are intended for identical cells in a structure where the number of re-uses, without modification of the span, is greater than 10-20 times. If the cells vary in width, it is better not to use table forms but a proprietary system of props and beams.

Labour is one of the highest cost elements in any construction operation. Any design which allows a proprietary system of formwork erection to be fully exploited, and so reducing erection time, is acting to reduce the overall construction costs.

Using table forms for instance the labour time per m² of formwork per man can be reduced to 3-10 minutes.
Example

Office Building- Glasgow
This example shown in Figure A1.29 was given by a formwork designer who was in charge of designing the formwork for an office building. He could not recommend a Table form or Flying form because the columns on the outskirts of the building were larger than the inner columns. Added to that the problem of the Stand down around the edges of the slab. Both problems made the use of flying form difficult and costly, because the makeup pieces between the two adjacent flying form would have been very large and hence outweighed any advantage of using the flying form.
Figure A1.29 Office Building Design.
5) Type of Surface Finish Specified

A high quality finish will require an expensive ply such as weisa-form, as against ordinary plywood. In order to keep the unit cost down, therefore, it is essential that the maximum number of uses are obtained from such materials if construction costs are to be kept low.

Features finishes are expensive to form, and should be kept to areas where they are appropriate such as public area, and even then with discretion. (A sawn board finish in an urban environment quickly collects dirt and looks very messy). It is important to bear in mind that the more complex the finish detail the more there is that can go wrong.

One type of finish which is universally disliked by contractors is the 'F3' finish as specified in the Department of Transports specification for road and bridge works [Department of Transport, 1976]. It is generally felt that it is over used and often inappropriate.

The specification for the F3 finish specifies no internal ties or embedded metal parts. Without a through tie to resist the wet concrete pressures, the structural integrity of the shutter must be maintained by an external support system. This support must be substantial in order to keep the formwork rigidly in place.

(a) Formwork Design Based on F3 Finish
(b) Formwork design Based on F4 Finish

Figure A1.30 Comparison of Formwork Design Based on F3 and F4 Finish.

Figure 30 shows a comparison of formwork designs prepared for the same contract. One was based on the specified F3 finish, the other on F4, still a high quality finish but allowing internal ties to used. The structure in question was an approach road and bridge where the bridge piers varied from 3m-13m in height. The 'Soldiers' for the F3 panel were made of 15 m long standard beams, braced in pairs, size 914 x 419 x V13. Each panel (2 soldiers and shutter) weighed 20 tonnes. The largest pier was 10m long x 1.5m thick x 13.4 high. This of course, was a fixed height shutter designed for the tallest pours but with the same shutter panels being used for the smaller piers. With design for the F4 finish design using a proprietary panel system and tube bracing to the soldiers, the shutter size could be built to each pour by simply adding more panels and soldiers to the top. Clearly a much easier shutter to handle.

Another example of a motorway bridge pier, of 8.5m high,10m long and1.5m thick, which made more complicated by a tapering design in all three planes.

The soldier in the centre again comprised a two of 914x419
Universal Beams. The waleings were 533 x 210 Universal Beams in pairs (each 15.350 m long).

While in a different example of a substantial F3 shutter, where the problems were aggravated by the fact that the column is circular. A tie across the diameter would have been enough to hold a standard shutter, as it was the hoop stresses had to be contained at the bolt holes in each frame. The end result is undoubtedly aesthetic, but at what cost?

The contractors complaints do not entirely derive from a sense of altruism and the clients best interests. In an attempt to gain an edge over other tenders a contractor may well price an F3 structure as F4 and hopes that once on site, 'common sense will prevail'. Usually it is the specification that prevails, perhaps quite rightly so. If the tender drawings are clearly marked F3, then the contractor takes a risk in not pricing for such. What may worry a contractor more will be the effect such a specification has upon the program. The question remains though, as to whether specifying such a finish warranted for the multitude of places it is found is justified the notes for guidance on the specification for road and bridge works" [Department of Transport, 1976] issued by DOT are quite clear. Under NG1402:
" Dust..... F3 finish is very costly and should only be used for small areas. F4 is appropriate where large areas are required to have a first class appearance ....."

It then goes on to advocate the use of surface features in which to place and disguise the tie holes, suggesting vertical grooves, stating that "The holes are practically indiscernible and an economical design of formwork ensues. Engineers are urged to be flexible in their requirements for surface features, bearing such facts in mind."

Clearly, the DOT is conscious of the costs involved. But what constitutes a "small area"? Does a 13m high pier to a bridge over a series of railway lines qualify?
6 Reinforcement

Another problem area reported by contractors was reinforcement, with some thirty examples cited during the survey.

As concrete construction is a feature of both building and civil engineering works, it was anticipated that the contractors would have something to say about it. The fact that nearly every one of them complained about reinforcement detailing as a frequent, and often major problem, was something of a surprise. As each contractor was doing work for a variety of consultants and architects, the implication was that a large number of designers were less than practical or economical in their reinforcement designs.

In 1970 the concrete society produced a small booklet entitled "Please be practical-detailing for easier construction reinforcement" [The Concrete Society, 1970]. Some of the material from that publication is presented here because during the course of the interviews with contractors they complained about each one of the problems presented in it.

It was pointed out, that there are three points for the reinforcement detailer to bear in mind, from which all problems stemmed.

1. Reinforcement must be bent and fixed.
2. Formwork must be erected and struck.
3. Concrete must be placed and compacted.

Simplicity of shape will produce savings. Complex bar shapes, which save on steel will cost more to bend and fix. In addition complex shapes are more prone to errors in bending and these will create fixing problems and ultimately delays.

Reinforcement should be detailed for flexibility in order to compensate for inaccuracies by other trades.
Example

Figure A1.31 Reinforced Detail of a Parapet.

The shape in Figure A1.31 was detailed at all levels of a multi-storey structure including ground level, the parapet was cast on blinding, the accuracy of which caused fixing problems. If the level of blinding is high, the reinforcement will not fit or will reduce the top cover. If the contractor makes the blinding deliberately low, then the reinforcement will require blocking up to the correct level.

This was a precise detail which relied on in precise operations for its success, which included the bending operation by the steel fixer.

Example

The height of a concrete kicker was specified and 'U' bars were detailed to sit on top of it (Figure A1.32a). This was an economical easy to fix detail, providing the kicker was precisely located.
Normally the steel fixer would set the two end 'U' bars to level, tie a supporting bar through them and then drop the remaining bars into place (Figure A1.32b). This worked when the kicker was low, if it was too high then the top of the precisely detailed 'U' bar was too high, and the cover was reduced. The fixer then had to crop the bottom of the 'U' bars so slowing the fixing operation.

(a) 'U' bars Detailed to Sit on Top of the Concrete Kicker.

(b) Temporary Support to Fix the 'U' bars in Detail (a)
To make the detail more flexible, the legs of the 'U' bars could be made shorter, and the bars from the base longer, to allow for minimum lap plus some extra to allow for adjustment, as in (c).

The message from this example is that construction materials are not suited for factory like precision, because good details have to be flexible.

Three contractors made the same point that most detailers do not detail with economy in mind. As far as possible where straight bars are used, stock lengths of reinforcement should be used. A bar detailed at 10m means that 2m are wasted. Most consultants do not do cutting schedules for reinforcement, normally the contractors would do that. Having drawn up such a schedule the wastage is very apparent. Recommending full length bars for economy of materials and economy of fixing, should not be taken as a fixed rule. Other factors should also be taken into account, for instance the specification and any restrictions it may place on the size of bays poured, as for instance in a reservoir roof slab shown in Figure
A1.33. If the bay size that the specification allows are small and 12m bars specified, it means that the contractors would have to deck out a large area beyond the bay poured, in order to support the 12m long bars lapped into the bay.

Consideration must be given, therefore, to methods that may be forced upon the contractor, as well as economy of material.

Unfortunately there are certain areas where a detailer is blamed if he does and blamed if he doesn't. Contractors will often re-detail reinforcement to suit the most economical pour sequences, but this can vary from contractor to contractor, even between construction managers within a company.

Some agents prefer to cast stub columns and hence require laps; others prefer to cast columns in one lift. One cannot please everybody and even the design departments of two Design and Build firms said they were occasionally caught out by this.

However borderline this case, the principle still holds- long bar lengths do require support and should be related to pour heights.
An example of a detail to avoid this was cited by a consulting engineer from a detail which was actually sent to the site:

A multi-storey frame and the column reinforcement was lapped so that it started 150mm below the floor slab, as shown in Figure A1.34.

Figure A1.34  A Multi-storey Frame and Column Reinforcement.
This meant that the full-height column reinforcement was waving around during the construction of the floor slab. If reinforcement is lapped it should be above the column kicker as shown in (b).

**Example**

Slip forming or climbing formwork, are the reverse of normal pours. Reinforcement should be detailed to match pour heights (plus the necessary laps of course). Reinforcement in site construction is quite heavy, perhaps over 200 Kg/m$^3$, and gets very congested towards the top of the structure.

Feeding in 12m long bars becomes very difficult particularly when most of it is waving around above the pour. For practical reasons the contractor is forced to put in more bars and more laps to support the system. One contractor estimated that as much as 20-30% extra steel may be required to support the detailed cage. For the contractor this is money given away.

With a structure such as a silo, the contractor would wish to stagger the reinforcement such that the fixers can work around the periphery fixing steel, with the concrete gang following behind pouring concrete. This way a spiral staircase effect is created.

The aim, therefore, is still to make maximum use of stock lengths of reinforcement (12m), but by detailing the reinforcement in 4m or 6m lengths, always bearing in mind the height of the concrete lift.

**Standardisation, Repetition and Prefabrication**

Steel fixing is a labour intensive operation and, as with the other aspects of construction discussed, offers major savings in the right circumstances.
Reinforcement should be detailed in such a way as to allow prefabrication assuming that the contractor will have enough room on site for a prefabricating operation which is not always the case.

Beam and slab floors lend themselves to prefabrication. The beam cages can be fabricated at ground level, then lifted and dropped into place, with continuity and splice bars placed insitu through the column and beam junctions Figure A1.35.

![Figure A1.35 Column and Beam Junctions.](image-url)
There is one important aspect to prefabricating such reinforcement and that is to allow generous cover, particularly end covers.

It is no good prefabricating cages if when they are placed, there is insufficient cover, so that the cage has to be taken out and prefabricated it again. Tolerances must take account of the variations which might occur.

Example

A contract for a postal sorting office was designed with slab and beam floors on a large grid of main beams. As detailed, reinforcement was taking three weeks to fix each floor. The contractor redetailed the reinforcement for prefabrication, on the above principles, at his own cost. He was then able to fix the same reinforcement in four days.

Example

One contractor described a design and construction contract in which they prefabricated a structural mesh of 25mm diameter bars.

These were welded in a factory and transported to site, and simply craned into place. (The problem with such a mesh is that the size is limited by the transport available, and the maximum width allowed of loads on the roads. In this case the materials were limited to 3.6m wide).

For such an approach to work it has to be the right situation. A multi-storey building where all the spans and all the bays are the same for instance. When it does work though, the slab reinforcement is placed very quickly.
Example

On a multi-storey building development, the floors of which were designed as flat slabs, shear reinforcement was provided in stepped lines, outward from the column until the shear resistance is adequate Figure A1.36.

Figure A1.36 Plan of the Top Mat of the Reinforcement Showing Shear Reinforcement

In this particular case the shear reinforcement was a link detailed as in Figure A1.37. An added complication was that the main bars in the top and bottom mats were at different centres.
Figure A1.37 Shear Reinforcement Links.

In order to facilitate fixing of the shear links, additional bars had to be detailed at the client's cost. There were in fact 680 of these shear links at each column position. The steel fixers were paid on the basis of the tonnage of steel fixed. It takes a long time to fix a tonne of 10mm links. At the time of that contract, the cost of fixing reinforcement was approximately £60/tonne, these particular items were working out at approximately £600/tonne.

This had not been anticipated at the tender stage, and a claim was submitted for extra costs.

Another contractor mentioned a similar detail, although on his contract there were only about 300 such links to each column head.

A large number of small bars are a problem whenever they are detailed, because they take a considerable time to fix.

One contractor suggested castellated links to replace the small individual links as in Figure A1.38.
This was still not an easy or quick detail to fix. A drop panel at the column head may solve the shear problem but of course loses much of the advantage of a completely flat soffit.

It is clear why design and construct firms tendering for contracts tend to steer clear of flat slabs.

When detailing for shear stress, contractors will advocate open links rather than closed links, for practical reason. One design engineer working for a contractor says "every body knows that these days". It may be widespread practice, but judging by the number of contractors who stressed this point it is not yet a universal one. Threading bars into a cage formed of closed links is slow and requires space. On a congested or small site, insitu fixing becomes very difficult.

The design of non-structural self-supporting reinforcement was cited as another problem. The top reinforcement to a slab particularly needs support but it is not the only place in a structure that may require chairs, or spacers to keep it in position. Designers, it was said, often get around this by saying that the contractor should ensure that reinforcement is fixed in position. A common practice may be not to detail chairs on a drawing, but to include the appropriate detail and numbers in the reinforcement.
schedules. Few contractors will closely examine the reinforcement drawings at tender. They tend to assume that the reinforcement is billed, and so they price on a tonnage.

If the reinforcement for chairs or spacers has not been billed then they are faced with designing and supplying the chairs themselves. If designing for prefabrication, it is important to ensure that the subsequent cages are still adequate for handling and lifting. This may require spacers for wall reinforcement see Figure A1.39

![Figure A1.39](image)

**Figure A1.39** Spacers for Wall Reinforcement.

**Example**

Care should be taken when detailing corbels or concrete ribs

![Figure A1.40](image)

**Figure A1.40** Concrete Corbels Detailing.
Depending on their diameter, all steel bars have a minimum radius to which they can be bent.

The company, for which one Chief Engineer worked for, had just been employed to carry out remedial works to a fairly new structure. A substantial number of the ribs to columns had cracked and spoiled, largely due to a similar detail shown in Figure A1.40.

**Example**

The detailing of reinforcement should not be viewed in isolation. It can complicate the erection and striking of formwork, making the formwork more costly.

The detailing of large in-situ culverts and pedestrian under passes or walkways were a subject of complaint by several contractors. The worst detail is that shown in Figure A1.41, using two 'U' bars

![Figure A1.41 'U' bars Detailing in a Large In-situ Culverts](image)

The formwork has to be manhandled down the length of the culvert. A slightly better detail is 'L' bars with splice bars across the top see Figure A1.41.
If the gap between the 'L' bars is not wide enough though, the forms are trapped again. In both these cases the formwork must be cut to an exact height, allowing also for a splay perhaps to the base of the wall. As discussed in the section headed 'Formwork' this restricts the potential uses of the shutter panel, and so increases the formwork costs.

A potential problem with 'L' bars cast into a wall, as in Figure A1.42 is the difficulty of maintaining the correct cover to the soffit. Once they are cast in, there is no adjustment. The steel fixers must, therefore, ensure that the bars are well supported during the concrete pour, so that they do not slip.

For the designer the best solution is to have fixity at the corners hence 'L' or 'U' bars. This allows a thinner section to be used for the roof. For the contractor the best solution is a simply supported or propped slab. Figure A1.43 has the advantages that it can utilise more flexible shuttering (b). It does however mean a thicker roof section, hence greater materials cost, although, the simplified construction and reduction in production cost should outweigh this. Any concrete box can be viewed in the same light.
Figure A1.43 More Flexible Detailing of Culverts.
Example

Contractors when designing for production will try to avoid starter bars sticking out of walls or columns, wherever possible. The classic case is landings in stair walls. One contractor stated that the detail in Figure A1.44a appeared frequently.

![Starter bars from walls for in-situ landing](image)

(a) Stair wall (b) Figure A1.44 Landing in Stair Walls Detailing.

In such a situation it would be better to design the staircase to span in one direction only as in (b). Such elements should never be tied-in to adjacent walls.

If starter bars must be used in walls a 'good' detail would use bars that could be bent by hand. In this way they could be bent down parallel to the shutter face, and pulled out again after the pour is completed. A similar but neater solution would be the use of a proprietary system of cast-in trays such as Halfen slots, which can be nailed to the face of the shutter. A 'bad' detail would use high yield 'U' bars projecting through holes in the shutter.
Bars protruding from formwork make striking of the shutter difficult and reduce the number of times it may be used. In addition the bars themselves can get bent or broken. The costs and extra time incurred could be balanced against the use of screwed couplers cast into the concrete face, for large diameter bars. Figure A1.45 shows a flat surface for formwork and greater flexibility of shutter use, where a pre-cast staircase fixed to an insitu landing is one of several alternative details using couplers.

![Diagram of wall, in-situ landing, pre-cast staircase, and coupler](image)

**Figure A1.45** Use of Flexible Shutter and a Pre-cast Staircase, Fixed to Insitu Landing Using Couplers.

**Example**

An example of reinforcement congestion was of the junction between the outer wall and the inner central dividing wall in a reservoir. Congestion of reinforcement, was made worse by the complexity of its shape, which became construction difficulty. It was not only the fixing of the reinforcement that was made complex, but the actual pouring of the concrete into a congested steel cage, and, frequently the impossibility of inserting a vibrator to compact the pour.
Example

Often the structural engineer is presented with a design from the architect or civil engineering designer and told to make the section work. The analysis may well show it to work, but only by having very congested reinforcement.

A design approach will give an economical section, using minimum concrete and with adequate reinforcement. The result, however, is often this:-

Large diameter bars at close spacings can effectively produce a 'Curtain of steel' in walls or slabs. Another consideration is the size of aggregate to be used in a concrete mix. It is important for the concrete to surround the bars, hence the aggregate should be able to easily pass between the bars. If it cannot do so the result will be segregation and a poor finish.

Allowance should be made for site fixing. In terms of structural requirements the detail is correct and the general spacings probably just acceptable. The designers clearly do not intend to have congested areas, where there are groups of 3 or 4 vertical bars with little or no space between them. (The bars are lapped and clearly pairs of bars have moved together).

With thicker sections the bar spacings would be wider, and more able to take up construction errors and still allow space for concrete flow and the achievement of a desirable finish.

The final aspect of congestion is, of course, compaction of the concrete. It is essential to have sufficient access for a vibrator to compact the entire pour.

The major difficulty with poor reinforcement detailing is its potential to cause aggravation, disruption and loss of time. As mentioned before, reinforcement details are rarely priced for in a tender.
7 Materials

Ten examples of difficulties arising from material were collected, four of which were recorded in detail. Designers were criticised by contractors for one main reason in this area: The problems associated with the use of modern technology such as the use of water-proofing or tanking treatments.

The cost of many construction projects is often inflated by the use of extravagant materials. If it becomes necessary to reduce the capital cost, they are often first thing to go.

With many civil engineering projects, particularly those with a large amount of earthworks, materials are a major part and as such are critical to cost.

If the specification calls for a particular aggregate or a fill material is specified which is in short supply locally, then transporting it from other areas will result in high haulage costs.

An example given by one contractor was the design of an embankment, which was in a flood area so the specification stated that 'no sand' (which was locally available and cheap) could be used to avoid erosion of the embankment. The designer had to detail a rock and gravel embankment, the material for which had to be transported in from a more distant source. An alternative could have been to use a soft sand core with a fabric protection and a hard shoulder, thus utilising the cheaper material.

Ground replacement materials pose similar problems. In some cases the contractor's suggestions may be accepted, although those interviewed generally considered it difficult to convince the engineer that a change in specification was warranted. That the designer is protecting his clients interests (and perhaps his own as well) by not being too readily swayed from tried and tested methods is not altogether a bad thing. However, it was stated by several
contractors that designers were perhaps too conservative and not up to date in their knowledge of current methods and technologies.

However, for the designers, it would appear to be a case of "blamed if you do and blamed if you don't". One contractor criticised the specification of a particular water proofing compound, which proved to be useless for the task detailed. Like many of these things it required very specific conditions for its application. The cold, damp, wintry conditions which it was applied on site were not at all suitable.

Another contractor, having criticised designers for their conservatism then went on to say that the only way to ensure a water proofed basement was the old way of using asphalt, indirectly admitting that they too were conservative. Clearly there is a time and a place for innovation and the exercise of discretion.

Many of the problems from materials were laid at the door of the product salesmen, who were often considered to make promises that were not justified. Contractors felt that if a designer wanted advice on a product, or process, he would be better asking the contractors who could also advise on the practicalities of a product.

On the subject of water proofing, water bars were singled out for criticism by a number of contractors. A centrally placed waterbar was considered to be is probably the best way to make a watertight joint - if it is constructed properly. Unfortunately that is usually quite difficult under site conditions and if is not formed properly the result can be worse than no water bar at all.

For instance.
There is a problem of getting concrete under or behind the waterbar and compacting it, largely due to air pockets which form under the bar. Problems which can easily occur are illustrated in Figure A1.46. In the first case of detail (a), having cast the first pour there is the problem of preparing the joint face. The result could be a leaking joint, used in a wall pour detail (b) it often gets wrinkled or torn. Junctions can be particularly difficult. Contractors generally prefer to stay away from water bars, except perhaps for the surface type which can be securely held in place by nailing to the shutter or laying on the blinding (See Figure A1.47). However, even this can have its problems.
When working on a drawing to a scale of perhaps 1:50 a water bar on top of a wall kicker would be a smudge 3mm long. A backstop water bar of the type detailed, is actually 320mm long, a fact that the designer appeared to have overlooked.

A 75mm kicker was detailed, but the length of water bar extending below the construction joint was 160mm, taking it well into the footing and below the top mat of reinforcement. This of course was impossible to actually fix. The simple answer was to raise the height of the kicker, unfortunately the 'U' bars, detailed to stand on the top of the kicker, made that impossible also, unless the contractor
cropped the ends of all the 'U' bars (See Figure A1.48).

Figure A1.48 Back Stop Waterbar Detail.

The contractor who described this example and whose work load included situations when waterbar might be detailed, preferred to put his faith in a well constructed construction joint. Another contractor who was very active in the field of service reservoirs and treatment works, avoided all but surface waterbars when using in house designs, for quality control and the practical reasons mentioned. In the final analysis the water tightness of a structure is the responsibility of the contractor, and the more complex the detail the more difficult it is to ensure that watertightness.

This is not to suggest that waterbar should never be used, as they are very good under the right conditions (such as expansion joints in water retaining structures, or sliding wall joints in the walls of circular tanks). However it is not necessarily the most practical or economical way to water-proof construction joints in a basement or water retaining structures.
In other words, some care and thought should given when a water bar is specified, bearing in mind the fixing difficulties and the care required to ensure a good quality detail that will perform as required.

**Example**

In a Water treatment project, a weather or waterproofing system for roofs was designed as in Figure A1.49.

![Figure A1.49 Weather/Water Proofing System for Roofs.](image)

This design failed to allow the contractor to use commonly available construction systems and materials to their best advantage.

The contractor was forced to use the detail shown in Figure A1.49. This meant using a new detail with no previous experience and also meant using a new material which had never been dealt with before such as the solar shield. Importing procedures for this material took a very long time, delay in completion was inevitable.

The detail included importing the bituthene which cost a lot of hard currency for the country.
Comparing this with the detail in Figure A1.50 where all the materials were available in the country as well as the experience to perform the job satisfactorily.

![Diagram](image)

**Figure A1.50** Alternative Weather/Water Proofing System for Roofs.

**Example**

One of the problems faced by a contractor was fixing of steel access ladders to the brick walls in a water treatment project. All of the brick walls were designed as cavity walls, using nonstructural brickwork, as a result, they could not support the heavy steel ladders. The designer had not taken this into account and therefore no special details were prepared. This problem was only discovered after the brickwork was finishing.

The contractor solution was to remove the bricks at the fixing locations, replace them with special expanding cement, then bolt the ladder to this.

The implications of this were:
- time delay and work disruption;
- additional cost for removing bricks and replacing them with special cement.
Three examples of difficulties encountered by contractors were cited during the survey.

The main problem the contractors argued was that the Contract Documents were not complete at the time of tendering. The drawings did not show the line profiles or location of services. The available details were a schedule of pipe lengths, diameters and a plan showing the network as a whole. This meant that the contractor did not know the exact profile of the network at the time of tendering, and hence he did not know the exact amount of excavation required, the type of de-watering system suitable.

The second problem is the lack of co-ordination producing conflicting information. This is the biggest problem facing pipe laying in cities where location of existing services are not incorporated in the drawings. Ideally this operation should be dealt with before laying the pipes and even before starting the detail design.

The problem is that existing services have either not been located accurately or not been located at all before laying the pipes and on many occasions nobody even knows about their existence.

In reality every single drawing had to be changed at least four or five times before construction, and at least two or three times after construction had started. Table A1.2 shows the number of changes to drawings experienced in real life projects.

Changes during pipe laying, cost time and money and disrupt progress plans.
Table A1.2  Number of Changes to Pipeline drawings during Construction

This author's experience in pipe laying confirms the above difficulties, and in particular services obstructing pipe laying. In many cases the contractor damaged existing services, not shown on his drawings. Figure A1.48 illustrates the problem.

Figure A1.51  Pipe Laying Obstructed by Existing Services.

The consequences of case such as this are:

- stop the work, this means up to twenty labourers, one excavator and one crane would be idle;
- ask the designer to study the case and prepare a new detail;
- have the damaged service repaired and prepare for the legal consequences;
- wait for the new design revision, this would include taking site measurements, designing a new profile and getting new approvals;
- the new drawing usually requires the removal of pipes (10-20) that are already laid to satisfy the new slopes as shown in Figure A1.52;

**Figure A1.52** New Pipeline Profiles to Avoid the existing Services.

- extra resources required to support the service while laying the pipes beneath it;
- extra excavation;
- additional services increase the number of air valves and washouts required per 1000m and this means more R.C. structures and fittings are required increase cost and take more time to finish when compared with ordinary pipe laying.

In some extreme cases, complete routes have to be changed because of the services, which has meant removing all the pipes laid previously.
To solve this problem a contractor has adopted a new approach by:

- Asking all local authorities and service agencies to supply their services drawing which should show clearly the locations of the services.
- The formation of a small gang lead by an engineer called the 'Trial Pit Gang'. It's main task was to manually uncover the services along the suggested route of the pipe line and make the exact measurements. Also to make trial pits across the route at 50m intervals and on all crossroads.

Example

An example of sewer crossing in an overseas water supply scheme.

The Transfer lines 2 No.1600mm OD Ductile Iron pipes connecting the North reservoir to the South reservoir and the Feeder line 1 No.1400mm OD Ductile Iron pipes crossed a 2500mm OD concrete sewer as shown in Figure A1.53.
Because there was no proper co-ordination between the different parties involved, and while the contractor was laying pipes in accordance with the drawings, a large concrete structure was discovered at the same level as the pipeline.

The designer decided to lay pipes under the sewer. This was the only solution available. [There was no room to lay pipes above the sewer because there would be no earth cover to the pipe]. The new detail replacing the straightforward pipe laying included the following.

- Two additional air valves for every single pipeline.
- Two additional wash outs for every single pipeline.
- Four additional concrete thrust blocks for every single pipeline.
- Concrete surround to the three pipes.

Figure A1.53 A Big Sewer Obstructing Main Pipelines.
- More excavation below the water table, requiring additional de-watering systems.

It took the contractor an additional four months to complete this short distance, employing:
- 30 workers
- 2 Excavators
- 2 cranes
- 4 deep wells systems, 4 submersible pumps and a set of wellpoint system

The additional cost of this operation was £500,000.

The main difficulties for the contractor were the following.

- The sewer was in use, so any damage would have caused a great problem to the contractor and inconvenience to the people living around. This made the construction very slow, digging under the sewer for each pipe, laying it and then casting concrete around it.

- The excavation was very deep in a very confined area inside a residential quarter. Despite using intensive de-watering systems some soil collapses did happen. Added to that was the problem of quick sand encountered while constructing the washout structures which were the deepest.

- Additional R.C structures were complicated and took a long time to complete especially under these conditions.

Had the designer collected the data properly and co-ordinated his efforts with the local authority, this problem would not have happened and would have taken the contractor no more than 2-3 days, because pipe laying would have been straightforward without bends, thrust blocks, air valve or washouts.
APPENDIX 2: QUESTIONNAIRE FORM FOR BRITISH DESIGNERS VIEWS
QUESTIONNAIRE FORM FOR BRITISH DESIGNERS

VIEWS

PLEASE TICK OR ANSWER WHERE IT APPLIES, IN AS MUCH DETAIL AS POSSIBLE, ALL INFORMATION WILL BE TREATED AS STRICTLY CONFIDENTIAL AND WILL ONLY BE USED FOR RESEARCH PURPOSES.

1. As a designer do you work on more than one project at a time, and at several stages of the design process?
   • YES/NO

2. Which factor has the dominant influence on design decision making?
   • Experience
   • Written information
   • Manufacturer's product & technical literature
   • Written in-house design guidance

3. If you are a member of a design team, do you have any knowledge on the impact of your design on site processes?
   • YES/NO

   If YES do you know the true cost?
   • YES/NO

   If NO is it because:
   • The difficulty to obtain the site feedback you need.
   • The conventional contracting procedures, mean that there is, almost inevitably, a barrier between the site and the designer.
   • Not to the advantage of the contractor to promote extensive feedback, particularly when it is cost information.
4 Do you think that the contractors themselves know the true cost of construction? YES/NO

5 If you have worked on a project where the eventual users were not known before design work start and the brief was extremely well considered. Has this case ..........

* limited the designers?
* Gave the designers a wider role and drawing their attention to their responsibilities to the client?

6 If you are a member of a design team, where a new ideas were put to the team. What will be the reaction?

* Accept because architecture/design is an art and must progress or survive. Keeping in mind that mistakes are inevitable in creation work.
* Predict and evaluate the likelihood of technical failure even if this meant modification to the aesthetic possibilities of the design.

7 Do you consult site expert or contractor during the design phase? YES/NO

IF NO is it because........
* You can not change the traditional system of design & construction.
* No time.
* No need.
* Other reasons ........... PLEASE STATE

8 After finishing a design or before, do you consult additional written information to check design for possible financial consequences of any design defects on large project? YES/NO
9 Is the time spent designing an element in proportion to its capital cost?  

YES/NO

10 What published information do designers use?
* Book and journal publishers.
* Professional institutions - education
* Manufacturer's- product promotion; correct usage of products.
* Manufacturer's associations- promotion of product types; education.
* British Standards Institution - maintenance of minimum standards.
* Building Research Establishment - research results and promotion of better building design.
* Local government - maintenance of planning and building standards.
* Central government - Statutory responsibilities (building regulations); avoiding poor design.
* Agreement Board - Performance standards.
* Practices- avoidance of liability, better design, saving design time.

11 Do you consult other peoples experience as a source of design information?
* colleague
* Consultant
* Manufacturer
* Contractor
* Else
12 What kind of experience are useful source of design information?
   * Experience of how a building put together.
   * Experience of performance.
   * Experience of the processes of building design & construction.

13 In a design team do you attempt to avoid possible problems on site or with budgeting? YES/NO

If YES ........ is it by using:
   * Your experience from previous projects;
   * By knowledge of availability of supplies and reliability of suppliers and of buildability;
   * Else....... Please state.

14 Do you have feed-back information from past projects (collection, storage and use )? YES/NO

IF NO is it because:
   * Shortage of time ?
   * Practicalities of gaining access to the building once the contract is finished ?
   * Not wishing to be drawn into the discussion on management or maintenance issues where out side your influence, in any meeting with the users ?

15 Could you state from your past experience whether feedback on completed projects was actively sought or left to chance? SOUGHT/LEFT

16 In your practice do you have a Research & Development Department? YES/NO
17 Do you have an in-house design guidance?

YES/NO

If YES ....... Why did your practice produce in-house design guidance?

* Economy of design time.
* Avoiding the possibility of liability claims.
* Informing designers of good practice.
* Disseminating and making use of available feed-back.
* Maximising the value of research into design problems.

18 Do you keep a written record of all design decisions, so it can be used later in another projects?

YES/NO

19 Do you think that all drawings and designs work are checked by designer's seniors?

YES/NO

20 Do you think that client responsibility and involvement in some way in the design process is of fundamental importance?

YES/NO

If yes, is it

* In term of direct user information
* Or/and in the analysis and definition of objectives which has not been realised by client or designers at early stages.

21 Are you in a position to take into account the special characteristics (such as the production facilities, professional skills, etc) of the future contractors?

YES/NO
If NO is it because...........
* Diversified construction techniques?
* NO co-operation with contractors?
* Both above?

22 More expenditure is required in order to realise the special requirements of the contractors.

YES/NO

If YES
Is it true to say that the expenditure could have been avoided if the design work had been carried out with the contractor's co-operation.

YES/NO

23 Do you think that the close co-operation between designers and contractors has beneficial effects........
* On the economy of production.
* On the economics of the products (building).

24 What do you suggest for better co-operation between designers and contractors throughout the various phases of the designing and construction work?

25 Do you usually evaluate your designs in cost terms, and what kind of data used in these cost evaluations.

YES/NO

26 Do you think that the enhancement of the cost experience of designers has beneficial effects?

YES/NO

27 In your view how the designers cost experience could be enhanced?
28 As a designer do you have the ambition to create a building of individual Architectural/Engineering value and lay stress upon the aesthetics rather than upon economics of building.

YES/NO

If above is YES ......

Do you see that the cost limit imposed by the client prevents you from fulfilling above ambition?

YES/NO

29 Is it usual that designers are restricted to maximum cost limits?

YES/NO

30 IF above is not the case. Are you as a designer going to incorporate some expensive material, products and details?

YES/NO

31 Is the cost limit imposed by the client on
   * The construction cost?
   * The running cost?
   * The construction cost+running cost (i.e. operating and maintenance).

32 Construction difficulties arising from design details commonly occurs

YES/NO

33 What kind of qualities do designers focus their attention on?

   * The apparent qualities of the buildings.
   * The functional performance or the quality of the building.
   * The effect of design solutions on the 'cost in use'.

321
34 Do you prefer tried and tested solutions?  

YES/NO

35 Is it true that designers feel that the policy of their practice is to use tried and tested solutions wherever possible?

YES/NO

36 In your practice who is actually in charge of the design of the following stages:

- Outline Design  * Junior Designer * Senior Designer
- Scheme Design  * Junior Designer * Senior Designer
- Detail Design  * Junior Designer * Senior Designer

37 Whom do you think bears the financial implications of the designs which do not take construction into account?

* Client.  
* Contractor.  
* Designers.

OPTIONAL

PLEASE FILL IN WITH AS MUCH DETAIL AS POSSIBLE.

YOUR NAME : ............................................
YEAR GRADUATED : ......................................
TYPE OF DEGREE : ......................................
EXPERIENCE : ...........................................
APPENDIX 3: COST EVALUATION
OF ALTERNATIVE DETAILS
COST EVALUATION OF ALTERNATIVE DETAILS

Cost Calculations of Case Study 1, Figure 5.1, Detail A

The aim is to calculate the cost of hours and materials required for each separate operation. The prices represent the net cost of labour, plant and materials without additions for site overheads, nor for off-site office overheads or profits.

1 Concrete

Materials

\[
2 \times 0.5 \times 14 + 2.5 \times 0.625 \times 14 + 0.75 \times 2.5 \times 14 + 0.875 \times 2.5 \times 14 + 2.5 \times 1 \times 14 = 17.5 + 21.875 + 26.25 + 30.625 + 35 = 131.25 \text{m}^3
\]

Use reinforced concrete grade $25 \text{N/m}^2$

Use Wessex price book
Concrete price for walls exceeding 300mm thick = £40.79

Cost of material = $131.25 \text{m}^3 \times £ 40.79 = £5353.6875$

Labour rates

The prices for labour in this section are as follows:
Plain Concrete labourer £3.34 per hour
Reinforced concrete-gang rate of 4 labourers with one carpenter in attendance

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tr>
<td>Crafts man</td>
<td>1x £3.88</td>
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<tr>
<td>Labourer</td>
<td>4x £3.34</td>
<td>= £13.36</td>
</tr>
<tr>
<td>Poker vibrator</td>
<td>3x £1.14</td>
<td>= £3.43</td>
</tr>
<tr>
<td></td>
<td>------</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>£20.66</td>
</tr>
</tbody>
</table>

324
Cost per hour (divided by 4) = £5.17

Rate of casting 10 m³/hr

Pour 1

35/10 = 3.5 hr
Add 2 additional hours = 5.50 hr
Cost of labour = £5.17 x 5.50 = £28.435

Pour 2

30.625/10 + 2 = 5.062 hr say 5 hr
Cost of labour = £5.17 x 5 = £25.85

Pour 3

26.25/10 + 2 = 4.625 hr = 5 hr
Cost of labour = £5.17 x 5 = £25.85

Pour 4

21.875/10 + 2 = 4.1875 hr = 5 hr
Cost of labour = £5.17 x 5 = £25.85

Pour 5

17.5/10 + 2 = 3.75 hr = 4 hr
Cost of labour = £5.17 x 4 = £20.68

Total cost of labour = £124
Total cost of concrete = £124 + £5353.6875 = £5477.68
2 Formwork

Area of shutters= $12 \times 14 \times 2 + 0.1 \times 4 \times 14 = 341.6 \text{m}^2$
One side measured $= 170.8 \text{m}^2$

Forwork generally

Using Wessex figures for ordinary shutter for both cases

<table>
<thead>
<tr>
<th>Making</th>
<th>Net labour</th>
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<tr>
<td></td>
<td>Net materials</td>
<td>£19.43</td>
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<tr>
<td>One use</td>
<td>£26.80</td>
<td></td>
</tr>
<tr>
<td>Fixing</td>
<td>Net labour</td>
<td>£6.14</td>
</tr>
<tr>
<td></td>
<td>Net material</td>
<td>£1.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>£33.98</td>
</tr>
</tbody>
</table>

Add for propping

- Net labour price £0.33
- Net plant price £0.01

Additional for fairface £1.23

Total price £35.55

Cost of formwork = £35.55 x 170.8 m$^3$ = £6071.94

3 Water-stopbar

Servicised rubber water-stop flat dumbell type 203mm wide was used detail can be seen in Figure A3.1
Figure A3.1 Water-stop Detail

<table>
<thead>
<tr>
<th>supply price</th>
<th>Waste factor</th>
<th>Unloading labour</th>
<th>Total unit cost</th>
<th>Unit M</th>
</tr>
</thead>
<tbody>
<tr>
<td>£</td>
<td>%</td>
<td>£</td>
<td>£</td>
<td></td>
</tr>
<tr>
<td>99.60</td>
<td>5</td>
<td>0.11</td>
<td>104.69</td>
<td>9</td>
</tr>
</tbody>
</table>

Extra for junction pieces on flat dumbell type (labour & material)
Take 230mm wide
Flat L
24.60 .02 24.62 Nr
28.88 .02 28.90 Nr

Total waterstop bar length 14 x 5 = 70 m

For every pour we need:
14m length water stop bar
+ 1 Nr Flat L junction piece
+ 2 Nr Flat X junction pieces

Total Nr Flat L junction piece = 1x5 = 5
Total Nr Flat x junction piece = 2x5 = 10

Therefore price = 70x104.69/9 + 5x24.62 + 10x28.90 = £1226.355
4 kickers

kicker area = 0.10 x 14 x 5 = 7 m²
Use £33.98 for making and fixing only
Therefore kicker cost = 7 x 33.98 = £237.86

Add extra work required to fix water stop bar according to the detail shown in Figure A3.2.

Figure A3.2. Extra Work Required to Fix Water-Stopbar.

Labour costs

The prices for labour in this section are as follows
Gang rate of 2 carpenters
2x£3.88 = £7.76
It takes 2 days (16 hrs) to finish this task
Cost of labour 16x7.76 = £124.16
Cost of labour for 5 Nr. = 124.16x5 = £622.5
Material cost

12mm diameter bar of average length 750mm about 300mm centre to centre

Number of bars required per pour = 14000/300 x2 = 94
Total number of bars required = 94 x 5 = 470
Weight in tonnes = 470 x .75 x 0.888/1000 = 0.313 tonnes

12mm diameter longitudinal bar
2 x14 x 5 x 8/1000=.124 tonnes

Use Clips about150mm distance
Number = 14000/150x2x5 = 934
Add waste 10% 1028

5 pence for 1 clip
Clips costs = 1028 x 0.05 = £51.4

Fixing bars

Hot rolled deformed high yield steel reinforcement bars to BS4449 were used.

<table>
<thead>
<tr>
<th>Supply</th>
<th>Waste</th>
<th>Unloading</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>price</td>
<td>factor</td>
<td>labour</td>
<td>unit cost</td>
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<td>£</td>
<td>%</td>
<td>£</td>
<td>£</td>
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<td>-----</td>
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<td>---------</td>
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</tr>
<tr>
<td>F0324</td>
<td>268.07</td>
<td>10%</td>
<td>6.68</td>
</tr>
</tbody>
</table>

Extra for cutting, bending and labelling reinforcing bars

| F0331  | 40.00 | 2.5%     | 41.0   | tonnes |

329
0.313 + .124 = 0.437 tonnes

Cost = 0.437(41.0 + 301.56) = £149.7

Add £1 per meter length (labour & material) for Chamfer

1 x 14000 x 4 = £56

Total cost of kicker = £237.86 + £ 622.5 + £ 51.4 + £ 149.7 + £56

= £1117.46

5 Reinforcement

Hot rolled deformed high yield steel reinforcement bars to BS4449 were used.

<table>
<thead>
<tr>
<th>Supply price</th>
<th>Waste factor</th>
<th>Unloading labour</th>
<th>Total unit cost</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>£</td>
<td>%</td>
<td>£</td>
<td>£</td>
<td>M</td>
</tr>
<tr>
<td>20mm</td>
<td>253.13</td>
<td>10%</td>
<td>6.68</td>
<td>285.12</td>
</tr>
<tr>
<td>25mm</td>
<td>254.34</td>
<td>10%</td>
<td>8.68</td>
<td>288.45</td>
</tr>
</tbody>
</table>

Extra for cutting, bending and labelling reinforcing bars

| 20mm         | 30.00       | 2.5%            | 30.75          | tonnes |
| 25mm         | 30.0        | 2.5%            | 30.75          | tonnes |
Additional cost for fixing will be as follows

<table>
<thead>
<tr>
<th>Net labour price £</th>
<th>Unit Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>20mm</td>
<td>0.10</td>
</tr>
<tr>
<td>25mm</td>
<td>0.09</td>
</tr>
</tbody>
</table>

20mm = £100/tonne
25mm = £90/tonne

Total price for 20mm diam. = £415.87
Total price for 25mm diam. = £409.20

Use 200 Kg/m$^3$
$\frac{127.75 \times 200}{1000} = 25.55$ tonnes

20mm diam. horizontal bars = $25.55 \times \frac{1}{3} = 8.516$ tonne
25mm diam. vertical bars = $25.55 \times \frac{2}{3} = 17.033$ tonne

Cost of 20mm diam. = $8.516 \times £415.87 = £3541.54$
Cost of 25mm diam = $17.033 \times £409.2 = £6969.90$

Amount of dowel bars
The vertical reinforcement was 25mm @12.5
Nr. of bars = 112 in each face
= 224 for both

$40 \times D = 25 \times 40 = 1000$mm
In this case we have five overlaps
$224 \times 1.0 \times 5 \times 3.854/1000 = 4.316$ tonne

Cost $4.316 \times £319.20 = £1377.66$

Total cost of steel reinforcement = £11889.10
6 Scabbling

Rate of scabbling = 2 m²/man/day (From experience)

Area scabbled Pour Nr 1 = 1.000 x 14.0 = 14.00 m²
Area scabbled Pour Nr 2 = 0.875 x 14.0 = 12.25 m²
Area scabbled Pour Nr 3 = 0.750 x 14.0 = 10.50 m²
Area scabbled Pour Nr 4 = 0.625 x 14.0 = 8.75 m²
Area scabbled Pour Nr 5 = 0.500 x 14.0 = 7.00 m²

Total area = 52.5 m²

Use gang of two men

Cost = 26.25 x 8 x £3.34 = £701.4

7 Tanking

Additional areas of tanking on the edges figure 3

There are two edges per pour
Area of additional tanking = 14 x 200 x 2 x4 = 22.4 m²

From Wessex the price for vertical covering = £16.00
Add £2/m² tanking protection

Total cost of tanking = 22.4m² x £18.00 = £403.2

Cost Summary of Figure 5.1

Cost of formwork = £6071.940
Cost of concrete = £5477.680
Cost of water-stopbar = £1226.355
Cost of kicker = £1117.460
Reinforcement = £11889.100
Scabbling = £701.400
Extra tanking = £403.200

----------------------------
£26887.142

Cost Calculations of Case Study 1, Figure 5.2, Detail B

1 Concrete

Quantity of concrete = (0.55 x 12 + 0.55 x 12/2) 14 = 138.6 m³
Cost of materials = 138.6 x £40.79 = £5653.494

Labour Cost

Pour 1

\[4.10 \times (0.55 + 0.29625) + 4.10 \times 0.15375/2]\times 14 = 52.98 m^3

Cost per hour = £5.17
Casting Rate = 10 m³/hr
Casting time = 52.98/10 = 5.298 hr
Add 2 hours = 7.298 hr
Cost of labour = 7.298 x 5.17 = £37.730

Pour 2

\[4.10 \times (0.55 + 0.1415) + 4.10 \times 0.15475/2]\times 14 = 44.13 m^3

Cost per hour = £5.17
Casting Rate = 10 m³/hr
Casting time = 44.13/10 = 4.413 hr
Add 2 hours = 6.413 hr
Cost of labour = 6.413 x 5.17 = £33.15
Pour 3

\[ (3.8 \times 0.55 + 0.1425 \times 3.8 / 2) \times 14 = 29.60 \text{ m}^3 \]

Cost per hour = £5.17

Casting Rate = 10 m\(^3\)/hr

Casting time = 29.60/10 = 2.96 hr

Add 2 hours = 5.96 hr

Cost of labour = 5.96 \times 5.17 = £30.813

Total cost of concrete = £5755.187

2 Formwork

From Wessex book

making

\[
\begin{align*}
\text{Net labour} & : £7.37 \\
\text{Net material} & : £14.43 \\
\hline
\text{Total} & : £20.80
\end{align*}
\]

In this case the contractor used climbing shutters (RMD system), i.e. once the first pour is cast, the shutter could be slid upwards, and therefore no need to disassemble everything and then re-erect.

From experience this could mean 1.5 uses

\[
\begin{align*}
i.e \text{ divid by 1.5} & : £13.866 \\
\hline
\text{fixing} & \\
\text{Net labour} & : £6.14 \\
\text{Net material} & : £1.04 \\
\hline
\text{Total} & : £21.046
\end{align*}
\]

add for propping

\[
\begin{align*}
\text{Net labour} & : £0.33
\end{align*}
\]

334
Net material £0.01  
additional cost for fairface £1.23  
---------
Total formwork rate £22.616

Formwork price = £22.616 x 168 = £3799.488

3  Cost of Water-stopbar

Length of water-stopbar = 14 x 3 = 42 m
Nr of flat L junction piece = 1 x 3 = 3
Nr of flat X junction piece = 2 x 3 = 6
Cost = 42 x 104.69/9 + 3 x 24.62 + 6 x 28.9 = £735.81

Fixing cost

Clips cost = £51.40 x 3/5 = £30.84
Cost of steel bars = £102.768 x 3/5 = £68.511
---------
£99.351

Total cost = £735.81 + £99.351 = £835.161

4  Reinforcement

As in Fig. 1 cost of 20mm diameter bars = £3541.54
As in Fig. 1 cost of 25mm diameter bars = £6969.90

Cost of dowel bars = £1377.66 x 3/5 = £826.6

Therefore the total cost of steel reinforcement for Figure 5.2 = £11338.036
5 Scabbling

Area scabbled Pour Nr 1 = 1.000 x 14.0 = 14.00 m²
Area scabbled Pour Nr 2 = (0.158 + 0.5) x 14.0 = 11.606 m²
Area scabbled Pour Nr 3 = (0.158 + .50) x 14.0 = 9.212 m²
Total area scabbled = 34.818 m²
Use gang of two men, at a rate of 4m²/day;
duration required 34.818/2 = 17.409 day

Therefore cost = 17.409 x 8 x £ 3.34 = £465.166

6 Extra tanking = Nill

Cost Summary of Figure 5.2, Detail B

Cost of formwork = £3799.488
Cost of concrete = £5755.187
Cost of waterstop bar = £835.161
Cost of kicker = £0.000
Reinforcement = £11338.036
Scabbling &Tanking = £465.166
Extra tanking = £0.000

-------------------
£22193.038

Construction Programme

The duration for completing detail A was calculated to be at least 85
days, while in detail B 68 only days.
The aim is to calculate the cost of hours and materials required for each separate operation. The prices represent the net cost of labour, plant and materials without additions for site overheads, nor for off-site office overheads or profits.

### 1 Concrete

**Materials**

\[
(1 \times 2.5 \times 0.50 + 2.5 \times 8/2 \times 0.50) \times 2 = 87.5 \text{ m}^3
\]

Use reinforced concrete grade 25 N/m²

Use Wessex price book

Concrete price for walls exceeding 300 m thick = £40.79

Cost of material = 87.5 m³ \times £40.79 = £3569.125

**Labour rates**

The prices for labour in this section are as follows

Plain concrete-Labour £3.34 per hour

Reinforced concrete- gang rate of 4 labourers with one carpenter in attendance

- Crafts men \(1 \times £3.88 = £3.88\)
- Labourer (standard rate) \(4 \times £3.34 = £13.36\)
- Poker vibrator \(3 \times £1.14 = £3.43\)

\[\text{Total} = £20.66\]

Cost per hour (divided by 4) = £5.17

Rate of costing 5 m³/hr
\[ \frac{87.5}{5} = 17.5 \text{ hr} \]

Cost of labour = £5.17 \times 17.5 = £90.475

Total concrete cost = £3569.125 + £90.475 = £3659.6

2 Formwork

Side shutters = 2.5 \times 3 + 2 \times 3 + 1 \times 3 \times 7 \times 2 = 231 \text{ m}^2

Inclined shutter = 0.5 (1+ 9.34) \times 7 \times 2 = 72.38 \text{ m}^2

Formwork generally
i.e one use for both cases
Use Wessex figures for one use in both cases

2.1 Price for side shutters

<table>
<thead>
<tr>
<th>Action</th>
<th>Net labour</th>
<th>Net materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making</td>
<td>£7.37</td>
<td>£19.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One use</td>
<td></td>
<td>£26.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Action</th>
<th>Net labour</th>
<th>Net material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixing</td>
<td>£6.14</td>
<td>£1.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>£33.98</td>
</tr>
</tbody>
</table>

Add for propping
Net labour price = £0.33
Net plant price = £0.01

Additional for fairface = £1.23

Total price = £35.55

Both side shutter (one side measured) = 231 \times 35.55
for side shutter only  = £8212.05

2.2 Price for inclined shutters

To calculate the inclined shutter cost we need to follow the same procedure as above but with suitable changes for fixing and propping. These two factors have a great effect on the cost and the programme. The rates for fixing and propping are considered to be twice the usual cost.

<table>
<thead>
<tr>
<th></th>
<th>Making</th>
<th>Net labour</th>
<th>£7.37</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net materials</td>
<td>£19.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One use</td>
<td>£26.80</td>
<td></td>
</tr>
<tr>
<td>Fixing</td>
<td>Net labour</td>
<td>£12.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net material</td>
<td>£3.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net labour price</td>
<td>£0.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net plant price</td>
<td>£0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Additional for fairface</td>
<td>£1.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total price</td>
<td>£44.11</td>
<td></td>
</tr>
</tbody>
</table>

Cost of inclined shutter = 72.38x44.11 = £3192.68
Total formwork price = £8212.05 + £3192.68 = £11404.73

3 Kickers and Water-stopbars

Both have same cost effect in both details, therefore they have been excluded from our calculations.
4 Reinforcement

Hot rolled deformed high yield steel reinforcement bars to B.S 4449 were used.

From Wessex prices

The total net price for 20 mm diam. = £515.87
The total net price for 25 mm diam. = £499.20

Above prices include for supply, waste, unloading, bending, labelling, and for fixing.

assume 200 Kg/m³ reinforcement
87.5 x 200/100 = 17.5 tonne
17.5 x 1/3 = 5.83 tonne 20 mm diam.
17.5 x 2/3 = 11.66 tonne 20 mm diam.

Cost 20 mm diam. = 5.83 x 515.87
= £3007.52
And cost 25 mm diam. = 11.66 x 499.2
= 9704.44

Cost of reinforcement = 5416.635
10483.200
----------------
£8828.1941

Cost Summary of Figure 5.3, Detail A

Cost of formwork = £11404.73
Cost of concrete = £3659.6
Cost of reinforcement = £8828.1941
----------------
Total £23892.524

340
Calculations of Figure 5.4, Detail B

1  Concrete

\[(3.0 \times 0.5 \times 2.5 + 3.0 \times 1.5 \times 0.75 \times 3) \times 7 \times 2 = 99.75 \text{ m}^3\]

Use reinforced concrete grade 25N/m²
Use Wessex price book
Concrete price for walls exceeding 300m thick = £40.79

Cost of materials = 99.75m³ x £40.79
= £4068.80
As in example 1, use labour rate = £5.17

rate of casting 10m³/hr
99.75/10 = 9.975hr
Cost of labour = £5.17 x 9.975 = £51.57
Total concrete cost = £51.5 + 4068.80 = £4120.3

2  Formwork

\[(2.5 \times 3 + 0.5 \times 3) \times 14 = 126 \text{ m}^3\]
\[(1.5 \times 3 + 0.5 \times 3) \times 14 = 84 \text{ m}^3\]
\[0.75 \times 3 + 0.5 \times 3) \times 14 = 52.5 \text{ m}^3\]

\[262.5 \text{ m}^3\]

Use the same figures obtained from the Wessex price book
Total price for making, fixing, propping and for fair face = £35.55

Both side shutter (one side measured) = 262.5 x 35.55 = £9331.875

3  Reinforcement

Use hot rolled deformed high yield steel reinforcement bars.
Use Wessex book
Total cost for 20mm diameter, including supply price, waste factor,
cutting, bending, labelling and for fixing

\[ \text{Total cost for 25mm diameter, including supply price, waste factor, cutting, bending, labelling and for fixing} = £409.20 \]

Less in this case, say 150Kg/m³

\[
\begin{align*}
99.75 \times 150/1000 &= 14.96 \text{ tonne} \\
14.96 \times 1/3 &= 4.98 \text{ tonne} \\
14.96 \times 2/3 &= 9.975 \text{ tonne}
\end{align*}
\]

Cost of 20mm diameter = 4.98 \times 415.87 = £2071.03
Cost of 25mm diameter = 9.975 \times 409.2 = £4081.177

\[ \text{Cost Summary of Figure 5.3, Detail B} \]

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of formwork</td>
<td>£9331.875</td>
</tr>
<tr>
<td>Cost of concrete</td>
<td>£4120.30</td>
</tr>
<tr>
<td>Cost of reinforcement</td>
<td>£6152.8</td>
</tr>
</tbody>
</table>

\[ \text{Construction Programme} \]

The duration for completing detail A was calculated to be at least 90 days, while it took only 58 days for detail B.