Integrated planning systems for the construction industry

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INTEGRATED PLANNING SYSTEMS FOR THE CONSTRUCTION INDUSTRY

by

GHASSAN FOUAD AOUAD

BSc, MSc

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

1991

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DEDICATION

To the soul of my father, Fouad, who passed away just two months before the completion of this work.
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ABSTRACT

This thesis reports on a CAD-based integrated model developed to aid the planning of the construction of in-situ concrete structures. The main aim of this model is to automate the planning process of in-situ concrete structures using data generated by CAD systems. In order to achieve this goal, the integration of a CAD system (AutoCAD 10) and a computerised planning system (Artemis 2000) via a database program (dBase IV) has been achieved on an IBM PS2 Model 70 microcomputer. This enables the generation of network plans in the AutoCAD system which are then automatically transferred to the Artemis system for time and cost analyses. Currently, the system can handle concreting, steel fixing and formwork activities associated with in-situ concrete design elements. However, further enhancement of the model is possible in order to automate the generation of most construction activities.

In order to develop this CAD-based integrated planning model, it was necessary to undertake a questionnaire survey on the current status of planning techniques and information technology uses amongst the main UK and US contractors. This survey reveals that many of these contractors are now aware of the benefits that a CAD system can offer to the management and planning of in-situ concrete structures. It was also found that many aspects of information technology such as computer aided design and project management are well within the reach of most of the companies surveyed, and that many recent developments could be used to develop integrated systems as an aid to the planning of construction projects. These findings indicate that the application of such systems could soon become a reality. However, the practicality of these techniques has to be assessed on real life projects which could be the subject of a further research.

The CAD-based integrated model described in this thesis offers many facilities for: modeling, drafting, materials and quantities scheduling, time and cost analyses and reporting which were all integrated and incorporated within such a single system. These facilities which have been fully customised within the developed package are easy to be run as the software is user friendly with pull-down and pop-up menus, and help facilities provided at almost all levels.

This thesis demonstrates that current software and hardware technologies are more than sufficient to establish new approaches to the planning and management of in-situ concrete structures, particularly in the area of computer aided design. Such approaches
can rectify many of the deficiencies found in traditional planning systems. For instance, a CAD-based system could eliminate the re-extraction of information from conventional drawings and documents which could be error prone as an access to the original electronic building model is provided within such a system. In addition, accurate quantities associated with sets of design elements and relevant to the planning process are automatically generated within the system.
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.
ACKNOWLEDGMENTS

I would like to express my gratitude and sincere thanks to my supervisor Dr A.D.F. Price, for his careful supervision, constant guidance, valuable advice, and unfailing support throughout this study. I am also grateful to professor Ronald McCaffer, head of Civil Engineering at Loughborough University and my director of research for his help and support through his popular word "smile".

The author also wishes to thank Dr B. Atkin of Reading University, Mr D Wheeler of O.D.A, Mr D. Wijesundera of Conder Projects, Mr T Wilks of Asta Development Corporation Ltd, Mr A. Hart of Higgs and Hills Construction Holdings Ltd, Miss I. Yeats of Pinn Cowdery Professional Support, Dr J. Allen ex-computer programmer of Loughborough University, Autodesk Ltd, Metier Management Systems, Morris Davy Ltd based in Loughborough, El-Hajj contracting company based in Lebanon, and the planning engineers of the UK and US companies who have participated in this research through useful comments and feedback.

I am also very grateful to my friend Dr J. Tah for his encouragement and help with matters relating to computer programming and for proof reading this thesis. My sincere thanks go also to members of the construction management group (Tony Thorpe in particular), computer technicians (David, Gordon and Steve), to the secretaries (Eileen, Joy, Julie, June, Vera, Laura and Dorothy), to the administrative assistant (David Hately) and to the computer analyst (Barbara Howlett) of the Civil Engineering Department of Loughborough University.

Finally, I would like to thank my mother, brothers and sisters for their love and support and my friends (Faiza in particular) for their help and encouragement, and the Hariri Foundation for their financial assistance.
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<td>CPM</td>
<td>Critical Path Method</td>
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<tr>
<td>PERT</td>
<td>Programme Evaluation and Review Technique</td>
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<td>CAD</td>
<td>Computer Aided Design</td>
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<tr>
<td>IBM</td>
<td>International Business Machines</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
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<td>USA</td>
<td>United States of America</td>
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<td>US</td>
<td>United States</td>
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<td>PMS</td>
<td>Project Management Systems</td>
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<td>PM</td>
<td>Project Management</td>
</tr>
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<td>LOB</td>
<td>Line of Balance</td>
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<tr>
<td>GERT</td>
<td>Graphical Evaluation and Review Technique</td>
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<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>MB</td>
<td>Megabytes</td>
</tr>
<tr>
<td>EGA</td>
<td>Enhanced Graphics Adaptor</td>
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<tr>
<td>VGA</td>
<td>Video Graphics Arrays</td>
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<tr>
<td>HP</td>
<td>Hewlett Packard</td>
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<tr>
<td>DOS</td>
<td>Disk Operating System</td>
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<tr>
<td>RAM</td>
<td>Random Access Memory</td>
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<tr>
<td>DXF</td>
<td>Drawing Exchange Format</td>
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<td>3D</td>
<td>Three Dimension</td>
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<tr>
<td>CIM</td>
<td>Computer Integrated Manufacturing</td>
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<td>DBMS</td>
<td>Database Management Systems</td>
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<td>NEDO</td>
<td>National Economic Development Office</td>
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<td>CICA</td>
<td>Construction Industry Computing Association</td>
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<tr>
<td>UCS</td>
<td>User Command System</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>EST(i-j)</td>
<td>Earliest Start Time of Activity i-j</td>
</tr>
<tr>
<td>LST(i-j)</td>
<td>Latest Start Time of Activity i-j</td>
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<td>EFT(i-j)</td>
<td>Earliest Finish Time of Activity i-j</td>
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<td>LFT(i-j)</td>
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<td>DU(i-j)</td>
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<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
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<tr>
<td>KB</td>
<td>Knowledge Base</td>
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<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
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<td>SOW</td>
<td>Statement of Work</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>OME</td>
<td>Order of Magnitude Estimate</td>
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<td>RIBA</td>
<td>Royal Institute of British Architects</td>
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<tr>
<td>BS</td>
<td>British Standard</td>
</tr>
<tr>
<td>BT</td>
<td>Basic Time</td>
</tr>
<tr>
<td>N/mm²</td>
<td>Newton per Millimetre Square</td>
</tr>
<tr>
<td>Sec</td>
<td>Second</td>
</tr>
<tr>
<td>Doc</td>
<td>Document</td>
</tr>
<tr>
<td>CDF</td>
<td>Comma Delimited File</td>
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<tr>
<td>SDF</td>
<td>Space Delimited File</td>
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<tr>
<td>DIF</td>
<td>Data Interchange File</td>
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<tr>
<td>ASCII</td>
<td>American National Code for Information Interchange</td>
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<td>Text File</td>
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<td>Database File</td>
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<td>ART</td>
<td>Artemis File</td>
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<tr>
<td>IGES</td>
<td>Initial Graphics Exchange Specification</td>
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<td>CADCAM</td>
<td>Computer Aided Design Computer Aided Manufacturing</td>
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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION TO SUBJECT MATTER
1.2 OBJECTIVES
1.3 METHODOLOGY
1.4 OUTPUTS OF THE RESEARCH STAGES
1.5 THE MAIN ACHIEVEMENTS
1.6 GUIDE TO THESIS
1.1 INTRODUCTION TO SUBJECT MATTER

The importance of information technology has only recently been realised and it is now ranked with other important issues and has become an essential requirement for man to exist in this and future societies (Ref 1.7). If construction projects are to be completed on time, within cost and to the required quality standard, then information has to be managed properly in a way that allows data to be stored once in a system and then tracked and retrieved as necessary.

In the past few years, some computer models such as expert systems and simulation techniques have been developed in attempts at automating the construction planning process. These models are not extensively used by the construction industry as they often require large amounts of data input and sometimes lack the flexibility needed by construction planners to account for the unique nature of most construction projects (Ref 1.1 & 1.3). Also, some current construction planning applications and systems are little more than manual formulations of plans. For example, data are fed into the planning system and computations are performed using either Critical Path Method (CPM) or Programme Evaluation and Review Technique (PERT) concepts. However, data related to activity lists, resource requirements and durations are not always automatically generated within the program (Ref 1.5 - 1.6). In addition, as most construction projects involve the participation of different disciplines with little communications between them, the repetition of the tedious task of quantities generating is inevitable. For instance, to associate an activity with a set of design elements, the construction planner is forced to work out new quantities, as no access to the original design model is given. Such approach is error prone, time consuming, and involves information double-handling.

It would, thus, seem logical to devise a new computer model to aid construction planning based on recent developments in information technology, particularly in the area of computer aided design. The model is specifically aimed at assisting the planning of in-situ concrete elements found in modular buildings.

It was well established that available hardware and software technologies were more than sufficient to establish a CAD-based integrated construction planning model provided that the design is given as a collection of basic components. Such approach could ultimately automate the planning process by capturing information generated by the CAD system. This would give the construction planner more flexibility when selecting design elements associated with specific activities, besides the ability to
visualise the design model to account for site restrictions, and equipment and trade interactions.

Communications between the design and production teams within the construction industry have also been highlighted as less efficient than the planning process itself. The integration of computer aided design and project management systems is seen as one solution to the management of the large volumes of data initiated at the different stages of the project. Such integration could prevent data double-handling and corruption which are very common in traditional planning systems. Thus, this research tended to concentrate on the application of information technology rather than the construction planning process.

Recent advances in microprocessor technology, coupled with the decrease cost of hardware and software suggest that it is probably the right time for construction planners to re-appraisal computerised construction planning applications. This research seeks to integrate one of the most powerful computer aided design packages (AutoCAD) with a project management system (Artemis) on a single IBM microcomputer machine, in order to automate the planning process of in-situ concrete components found in modular buildings (concreting, formwork and steel fixing activities).

Finally, it has to be said that the establishment of a CAD-based construction planning model as a part of a fully integrated environment still faces problems and limitations in terms of costs, computing power and organisational structure of the construction industry (Ref 1.2).

1.2 OBJECTIVES

The initial objectives of this research were aimed at developing an experimental CAD-based computer package to aid the planning of in-situ concrete structures using an integrated system approach. An IBM PS/2 model 70 was found to be a suitable microcomputer to run this package. The software incorporated two sorts of databases, a work study database developed by Price et al at Loughborough University (Ref 1.8, 1.9, 1.10 & 1.11) and a company database extracted from the Wessex and Spon (Ref 1.4 & 1.12) building price books for the purposes of timing and costing the different activities of concreting, formwork erecting and steel fixing associated with in-situ concrete elements. These databases will be manipulated within the package to produce a network which can accommodate a wide variety of structural shapes and sizes. The
user will be able to input and adjust several variables, for example, he/she will be able to try several gang sizes and see how his/her decisions influence project duration and cost. This research was also aimed at automating the planning process of the construction of in-situ concrete structures using data generated by CAD systems. This necessitated the integration of a CAD package (AutoCAD 10) and a project management system (Artemis 2000) via a database program (dBase IV). Thus, it was necessary to establish the missing link between these systems which have been incorporated and integrated within the developed software package. This would enable the generation of network diagrams in the AutoCAD system which are then automatically transferred to the Artemis system for time and cost analyses.

To achieve these objectives, it was necessary to investigate the different factors, particularly those of information technology which could affect the development of an integrated computer-based construction planning model. Consequently, the following sub-objectives had to be established:

- the assessment of the current status of information technology in the UK and US construction industries and the applicability of the integrated system;
- the evaluation of micro-based computer aided design and project management systems with the view to designing the intended integrated construction planning application;
- the establishment of the computer software functional specifications;
- the use of these functional specifications in designing, developing and testing a prototype of the software package; and
- the determination of technical, organisational and financial problems which prevent the implementation of fully integrated systems within the construction industry.

1.3 METHODOLOGY

To respond to the above mentioned objectives, the research was organised as illustrated in the concise network diagram shown in Figure 1.1.
Figure 1.1 The methodology of the research
1.4 THE OUTPUTS OF THE RESEARCH STAGES

As shown in Figure 1.1, this research was organised to be implemented in different stages. A summary of the outcomes of these various stages is shown in the following table:

<table>
<thead>
<tr>
<th>NO</th>
<th>PHASE</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Literature review</td>
<td>The production of an up-to-date evaluation of the different construction planning techniques and models.</td>
</tr>
<tr>
<td>2</td>
<td>First contact with industry</td>
<td>The determination of the main limitations of current construction planning models particularly the problems encountered in running project management software applications.</td>
</tr>
<tr>
<td>3</td>
<td>Literature update &amp; visits to computer exhibitions</td>
<td>The establishment of the state of the art in computer uses, particularly in construction and manufacturing.</td>
</tr>
<tr>
<td>4</td>
<td>Suggested construction planning model</td>
<td>Based on the outcomes of phases 1, 2 &amp; 3, a proposed model for the planning of in-situ concrete structures was suggested. This model relies on the integration of computer aided design and project management systems.</td>
</tr>
<tr>
<td>5</td>
<td>Micro-CAD evaluation</td>
<td>A compiled criteria list for the selection of micro-CAD systems suitable for integration has been suggested. The learning of AutoCAD was completed.</td>
</tr>
<tr>
<td>6</td>
<td>Micro-project management software evaluation</td>
<td>Another selection criteria for micro-based project management software was established. The learning of Artemis 2000 took place.</td>
</tr>
<tr>
<td>7</td>
<td>Second contact with industry (questionnaire)</td>
<td>The applicability of information technology in the construction industry was established. In addition, the practicality of integrated systems for building contractors was assessed.</td>
</tr>
<tr>
<td>8</td>
<td>System implementation</td>
<td>The actual programming of the proposed application (5000 lines of programming in AutoLisp, dBase and Artemis command languages).</td>
</tr>
<tr>
<td>9</td>
<td>System testing</td>
<td>The verification of the developed model through demonstrations to experienced construction planners.</td>
</tr>
<tr>
<td>10</td>
<td>System commissioning</td>
<td>The complete version of the developed planning software with its documentation.</td>
</tr>
<tr>
<td>11</td>
<td>Writing-up</td>
<td>The research thesis.</td>
</tr>
</tbody>
</table>

Table 1.1 The outputs of the research stages
1.5 THE MAIN ACHIEVEMENTS

The use of computers within the framework of construction planning has been confined in the past to simple applications of CPM and PERT programs without giving enough consideration to how the data were originated and which sources were used. Such approaches were considered to be inefficient as the construction planner has to produce the construction plan from drawings and documents (data sources) which are not reliable, and very often not available when required. In addition, the traditional approach to the use of CPM and PERT programs involves the input of data (network diagram data) previously generated, most likely on a sheet of drawing paper. These deficiencies have been rectified by developing an integrated planning model which considers data in its electronic format which can be processed when required. Such data are stored once in the system and tracked and used as necessary. For instance, the network diagram is produced as an electronic CAD model which can be passed to a planning system for time and cost analyses. The integrated model has been developed through the coupling of the most appropriate micro-based computer aided design and planning packages, namely Artemis 2000 and AutoCAD 10.

An investigation undertaken among the top UK and US contractors, reviewing their current planning methods and information technology practices, revealed that most of the surveyed companies realise the importance of integrated applications within the area of construction management and planning.

The developed integrated construction planning model offers many potential benefits to construction planners, students, researchers, and software developers for civil engineering and construction. These benefits are explained in detail in chapters five, six, seven, and nine of this thesis. A summary of the major research achievements is included below.

1- The current status of planning techniques and information technology amongst the top UK and US contractors has been established based on a questionnaire survey investigation. The major areas which were addressed are:

a- planning methods and applications;
b- project management systems;
c- CAD systems; and
d- integrated models.
The findings of this investigation can be used as checklists against which construction planners and researchers can select appropriate planning models and software packages. These findings can be summarised as below:

i- CPM technique is still the most popular planning model;

ii- Pertmaster is the most widely used planning software in the UK, whereas Primavera is the most dominant in the USA;

iii- AutoCAD is the most widely used micro-based CAD software in the UK and the USA; and

iv- UK and US contractors have started to realise the importance of integrated applications.

2- The establishment of a new approach to assist in the planning of in-situ concrete structures.

This new approach to planning is based on the concept of coupling powerful and low cost computer aided design and project management systems through database programs which act as repository means. In such environment, the construction planner has been given the power to automate the generation of network diagrams as electronic CAD models which can be passed to the planning package for time and cost analyses. In addition, accurate quantities associated with construction activities are automatically generated as the user manipulates the original CAD building model.

3- The development and validation of the integrated construction planning model.

The integrated construction planning model is a major achievement as modeling and planning can performed within a single system environment. The system has many facilities for: modeling, drafting, materials and quantities scheduling, time and cost analyses, and reporting which were all made parts of an integral model. These facilities can be run by any user as the software has been designed to be user friendly with pull down and pop up menus, and help facilities provided at almost all levels.

Finally, the last major achievement to the work undertaken was the model validation and verification. The developed planning model was tested using modular and integration testing and was proven to be errors and bugs free. The acceptability of the system was approved by experienced construction planners and interested researchers.
and members of staff within the Civil Engineering Department at Loughborough University as the software was designed to have a user friendly interface.

1.6 GUIDE TO THESIS

This thesis contains three main areas of research which can be summarised as: an investigation into current construction planning techniques and models, a study of the impact of information technology on the construction industry, and lastly the design and implementation of an integrated construction planning application. These three main areas are now briefly described as they are treated in the final thesis.

Chapter Two

The current status of planning techniques and information technology in the UK and US construction industries is established in this chapter. The findings are based on a questionnaire survey undertaken among the top 100 contractors in the UK and the top 400 contractors in the USA. The questionnaire results have been used to determine the state of the art in construction planning techniques and information technology practices. The assessment of the acceptability and practicality of the suggested integrated system is also described in this chapter.

Chapter Three

This chapter discusses the impact of information technology on the construction industry, particularly the fields of computer aided design and project management. General information on hardware categories, database management systems, and programming languages are presented. Selection criteria for computer aided design, project management, and database systems suitable for integration purposes are also included.

Chapter Four

This chapter reviews the different construction planning models and techniques developed. Procedural methods (such as barcharts and network diagrams), computer models (such as expert systems and simulation techniques), and the use of computer graphics in planning are fully discussed. The advantages and disadvantages of these models are also covered.
Chapter Five

The traditional construction planning methods and the suggested integrated approach are compared. In addition, the different phases of the proposed integrated system are highlighted. The specifications of the system are also included.

Chapter Six

Having specified the different stages of the integrated system, Chapter Six discusses the modeling sub-system and the first phase of the data transfer sub-system needed for communication between AutoCAD and dBase. The modeling sub-system is implemented within the AutoCAD 10 environment. A thorough explanation of the main features of this package is contained in this chapter. The data transfer sub-system which facilitates the communication means between the different involved applications is fully described. The use of dBase as a repository system for data flow is also highlighted.

Chapter Seven

This chapter discusses the planning sub-system of the integrated application and the second phase of data transfer sub-system implemented within the Artemis package. The developed customised planning package is described in terms of the various options available at the different menus levels. The different tasks of time and cost analyses and reporting are fully discussed. Finally, the most important features of the Artemis package are highlighted.

Chapter Eight

Having described the different sub-systems of the developed application, Chapter Eight investigates the different problems encountered during the development of this application or any other integrated system. These problems have been classified as: technical, organisational and financial and they are considered in details. Recommendations to future software developers are presented in this chapter.
Chapter Nine

This chapter considers the different tests performed to validate and assess the acceptability of the model. Modular, integration, and acceptance testing procedures are all discussed. A case study of an imaginary structure is also included.

Chapter Ten

The conclusions derived from this research are presented in this chapter and recommendations for future research are suggested. In addition, the contribution of this research to the construction industry is discussed. Figure 1.2 illustrates the layout of this thesis.
Figure 1.2  Thesis layout
CHAPTER TWO

THE CURRENT STATUS OF PLANNING AND INFORMATION TECHNOLOGY IN THE UK AND US CONSTRUCTION INDUSTRIES

2.1 INTRODUCTION
2.2 PLANNING IN GENERAL (PART A)
2.3 PROJECT MANAGEMENT SOFTWARE (PART B)
2.4 COMPUTER AIDED DESIGN PACKAGES (PART C)
2.5 THE INTEGRATED SYSTEM (PART D)
2.6 SUMMARY OF THE RESULTS
2.7 SUMMARY
2.1 INTRODUCTION

This chapter sets out to establish the current status of information technology in the UK and US construction industries and assesses the viability of developing integrated systems within the framework of construction planning. The results are based on a questionnaire survey undertaken amongst the top 100 contractors in the UK and the top 400 contractors in the USA (Ref 2.10 & 2.19). 100 questionnaires were sent to the top building and civil engineering contractors in the UK, and 303 companies amongst the top 400 in the USA were surveyed. The degree of response to the questionnaire was higher in the UK mainly due to the location as the research work was undertaken in this country. 33 replies were received from the UK contractors which represented 33% of the chosen sample; whereas in the USA only 42 respondents responded to the questionnaire representing a percentage of 15% of the overall surveyed companies.

The questionnaire was structured in four parts covering the following major areas:

* Planning in general (Ref 2.2, 2.8, 2.21 & 2.13)
* Computer aided design (Ref 2.12, 2.29 & 2.13)
* Project management systems (Ref 2.9, 2.11, 2.20, 2.22, 2.23, 2.30, 2.31, 2.32, 2.33, 2.34 & 2.36)
* Integrated applications (Ref 2.3, 2.14, 2.15, 2.18 & 2.24).

Current practices of these major areas were all covered in the survey. A copy of the questionnaire can be found in Appendix A.

2.2 PLANNING IN GENERAL (PART A)

This section of the questionnaire was aimed at investigating the different planning techniques being used by construction personnel, formed the basis to develop the specifications for an integrated construction planning system. The results are presented below.

Question 1: what kind of work does your company undertake?

It was shown (Figure 2.1) that 94% and 67% of UK respondents undertook building and civil engineering work respectively; whereas 80% and 50% of the US sample were involved in these sorts of work. It was also found (Figure 2.1) that 61% of UK
respondents performed both, building and civil engineering works, whereas only 31% in the USA undertake both types of tasks within the same company. These findings indicate that American contractors tend to be more specialised and execute specific types of projects; this implies that more expertise and resources are dedicated towards either building or civil engineering jobs. Specialisation is an important factor in assessing the suitability of integrated applications as this often involves the commitment of these resources and expertise.

![Figure 2.1 Types of work undertaken by UK and US contractors](image)

**Figure 2.1 Types of work undertaken by UK and US contractors**

**Question 2: what planning techniques are used in your company?**

The main finding was that, 100% of the US and 88% of UK respondents were using CPM (Critical Path Method) techniques for planning purposes. This finding illustrates the strength of CPM as a planning tool and contradicts comments made regarding the suitability of such methods for construction projects (Ref 2.1, 2.4, 2.16 & 2.17). It was also found that bar charts were widely used by the UK and US contractors. Figure 2.2 shows the different planning techniques used by the various surveyed companies.

It appears that the line of balance technique which is mainly used for the planning of repetitive work is not popular in the USA. Also, it seems that heuristic rules are not applied by any of the UK respondents for planning construction projects. Finally,
Graphical Evaluation and Review Technique (GERT) appears to be the least popular planning model in both countries.

For more information on the different planning techniques discussed in this section, you can refer to Chapter Four.

![Bar chart showing the percentage of UK and USA contractors using different planning techniques.](chart.png)

**Figure 2.2 Planning techniques used by the top UK and US contractors**

**Question 3-i: what sort of network diagram do you use?**

Two sorts of network diagrams exist, namely 'on the arrow' and 'on the node'. In the former, the arrows in the network symbolise the activities whereas in the latter the nodes are used to achieve such task (refer to Chapter Four and to references (Ref 2.5 - 2.6) for more information on these techniques).

'On the node' network diagrams are more popular in the UK, with 94% of the surveyed companies use this technique. In the USA, 71% of the top 400 contractors have adopted such diagrams as shown in Figure 2.3.
Question 3-ii: what are the reasons for using a particular network diagram?

It was found that most respondents have considered the following criteria when using a particular network diagram:

* type of work involved
* simplicity of the technique
* flexibility in defining and altering the network logic
* availability of strong computer programs (Processing power and facilities).

Respondents who were using 'on the node' technique have provided the following reasons:
* it is suitable for building works where there are many ladder activities;
* it is easier to be used on a particular computer package;
* it is easier to insert new activities and alter logic;
* it is better for linear construction (highway);
* it can be easily understood;
* more information can be included in the node boxes;
* no dummies are required;
* leads and lags are clearly shown;
* the software package in use is precedence-based;
* precedence plots are clearer than arrows;
* different types of relationships are provided (finish to finish; start to start; start to finish; and finish to start) not only finish to start as in arrows;
* better control can be provided;
* it is easier for data entry;
* it is easily understood by persons without technical CPM knowledge;
* more real world is represented; and
* volumes of reports are reduced.

'On the arrow' diagram was often preferred because:

* it is easier to learn;
* stronger programs are available (Processing power and facilities);
* it is easier to follow path and logic in printed reports;
* it is clearer when communicating with clients;
* it is more frequently taught in engineering/construction curriculum;
* it is a company standard for many years; and
* it is more traditional.

Each type of network diagrams has advantages and disadvantages; for instance, 'on the node' diagrams are easier to analyse manually, where a computer analysis may require a new stage of data input for activity constraints which can be avoided in 'on the arrow' models as they are implicitly included. On the other hand, 'on the node' techniques do not face the dilemma of defining dummies encountered when using 'on the arrow' diagrams. In any case, the decision to adopting a particular technique is highly influenced by the construction planner's personal judgement, preference and familiarity with the technique.

**Question 3-iii:** Some people argue that because CPM and PERT were originated outside the construction industry, their algorithms are not suitable for our requirements. Do you support these views and why?

It was found that 67% of UK and 76% of US respondents did not support the above view. This indicates that the opinions expressed in references (Ref 2.1, 2.4, 2.16 & 2.17) on the suitability of the CPM and PERT techniques for construction projects do not correspond with current practice. The different views given by the respondents are presented in the form of pie charts in Figure 2.4.
The respondents who believed that CPM/PERT techniques were suitable for construction projects gave the following reasons:
* CPM and PERT were originated in an industry similar to construction;
* they are used successfully within industry;
* software utilises the CPM technique already;
* the CPM model is more than satisfactory to analyse projects;
* no other planning algorithm is available;
* the techniques are a means of stating the sequence of activities;
* they are number crunchers and can be used to fit properly;
* they provide suitable means for tracking progress and evaluating the entire project;
* CPM is a planning and organising tool that is flexible enough for use in many applications or industries; and
* scheduling systems can be adopted to many situations. They were developed outside the construction industry, but to construct.

The reasons given by those respondents who partially supported the above views are as follows:

* some projects can not use CPM;
* depends on contract; and
* building is not precisely sequenced as a factory operation and experience plays a much greater role in site planning than pure logic.

Finally, respondents who believed that CPM/PERT techniques are not suitable for construction projects specified the two following reasons:

* the mechanics of making the logic flows correctly is very time consuming; and
* construction does not lend itself to network techniques other in great detail.

For more information on the CPM/PERT concepts, the reader can refer to Chapter Four of this thesis.

*Question 3-iv: how important is the use of CPM to the success of your company?*

![Figure 2.5 The importance of CPM to the success of a construction company](image)

The importance of CPM to the success of a construction company is presented in Figure 2.5. It is clearly shown that many UK and US construction firms consider the CPM technique as an important planning tool which plays a great role in their success.
Question 3-v: do you find CPM calculations difficult?

![Pie chart showing responses to Question 3-v]

85% of UK and 79% of US respondents (Figure 2.6) did not find CPM calculations difficult. The finding of this question, however, can be misleading as most of the CPM calculations are undertaken by computer programs.

Question 4: do you think that computer models such as expert systems and simulation techniques could be applied to construction planning and why?

It was found that 25% of UK and 14% of US respondents were not familiar with the terminology associated with these techniques. This finding emphasises the importance that should be given to training and educating our construction industry personnel on the different aspects of information technology before proceeding with the development of more sophisticated systems. In fact, this research has considered the information technology issue as important as the area to which it will be applied, i.e., construction planning. Chapter Two of this thesis covers this subject in greater details. The pie charts shown in Figure 2.7 indicate the different views of the various respondents in respect to the possibility of applying computer models to construction planning.
Respondents who partially believed that computer models such as expert systems and simulation techniques can be applied to construction provided the following reasons.

* in fairly standard works (warehouses, factories, etc)
* if useful results can be obtained without inputting huge information
* for small developments and temporary works
* if cost can be justified
* for large contracts with large number of sub-contractors
* to model different cranage access and use/reuse of formwork
* as a management tools
* for activity breakdown structure
* for manpower analysis.

People who strongly favoured the use of computer models for planning purposes expressed their views as summarised below.

* what-if scenarios
* similar approaches may be compared and evaluated
* visualisation of project construction can teach many things
* formalisation of the planning process
* to determine problematic scheduling areas
* better approximation of actual conditions and procedures.

Finally, respondents who were not in favour of using expert systems and simulation techniques gave their views as below.

* too many variables in productivity and weather
* too sophisticated
* time available to the contractor is not enough
* planning a contract is an individual operation
* inaccurate.

To summarise, computer models can be used for planning purposes. However, they are not being extensively used by the construction industry as a whole owing to the amounts of input data required and lack of flexibility needed by construction projects.

**Question 5: what sources of data do you use to estimate output rates?**

Most data used to estimate output rates were found to be based on experience and historical records. Also, it was revealed that the use of work study databases was more common amongst British contractors. In this research, two sources of data have been adopted for output rates estimation: one is based on a work study database developed by Price et al (Ref 2.25, 2.26, 2.27 & 2.28), the second is a company database extracted from the Wessex's and Spon's building price books (Ref 2.7 & 2.35). In UK, 21% of the surveyed companies use the Wessex database to some extent to derive their output rate estimates. On the contrary, none of the US respondents was familiar with this system. Figure 2.8 shows the various responses with regards to the estimation of output rates.
Figure 2.8 Sources of data to estimate output rates

Question 6: do you think the generation of network plans from conventional drawings and documents is error prone and why?

Only 15% of UK and 25% of US respondents agreed with the above views. This can be justified by the fact that current traditional planning methods require most information to be generated from these documents and drawings as no other alternative exists which can facilitate such process. The views (Figure 2.9) expressed regarding this matter are now presented.
The following comments were made by the respondents who did not think that the generation of network plans from conventional drawings and documents is error prone:

* the planner should be familiar with the documents and should assemble all the relevant information;
* the process in itself is not error prone. Discrepancies occur through lack of construction experience in the planner drawing the network, and lack of detailed information and failure to address all of the alternative sequences;
* they are the basis of the work scope;
* quantities can be taken and sequences can be determined;
* a well tried and tested procedure; and
* the system is good, but human will continue to error.

People who partially believed that such process could be error prone provided the following views:

* it depends on the quality and quantity of information available from the documents;
* sometimes, consideration is not given to site location or physical restraints on site;
* it depends on the human factor;
* the main source of error is omission or misinterpretation of specifications or phasing requirements;
* it is subject to the accuracy of drawings;
* the production of network relies on a thorough understanding of requirements; and
* subject to many interpretations and opinions as far as methodology is concerned.

Finally, respondents who strongly supported the above views gave their reasons as presented below:

* the quality of information and the skill of the interpreter are always a source of possible error;
* planning is often done in a hurry at the start of a contract before the planner has had time to fully assess the problems;
* from conventional drawings, mistakes can be easily made; items could be missed and volumes and areas can be miscalculated;
* erection sequence is not always clear;
* site conditions are not specified;
* conventional drawings have a history of being error prone;
* descriptive drawings are not very comprehensive, they do not show the whole picture; and
* actual conditions do not relate to modeling techniques.

To conclude, the generation of plans from conventional drawings and documents can be subject to error. However, the use of a CAD-based system which can handle data in its electronic format can eliminate such deficiency.

2.3 PROJECT MANAGEMENT SOFTWARE (PART B)

Question 1: what is the name of the package you are using?

It was found (Figure 2.10) that 88% of UK and 95% of US respondents were respectively using project management software packages.
Pertmaster was also found to be the most popular in the UK, whereas Primavera systems were the most common in the USA. The percentages shown in Figure 2.11 and Figure 2.12 illustrate the ranking of the different project management software packages used by the surveyed companies.

Figure 2.10 The use of project management software packages

Figure 2.11 Project management systems used by the top 100 contractors in the UK
There appears to be a clear dominance by a particular project management software package amongst the top contractors in the US construction industry. Such dominance is not currently present in the UK. However, Pertmaster which is being continuously enhanced can be seen as a major candidate for a UK project management software leadership.

Question 2: when was it acquired?

76% of US and 86% of UK respondents (Figure 2.13) acquired their project management software packages in the last five years thus indicating that the application of these techniques has only recently been made possible, particularly in the UK.
After 1985 14%, Before 1985 86%

(UK) (USA)

Figure 2.13 The period of the project management software acquisition

Question 3: is it available on mainframes, minicomputers or microcomputers?

Most of the project management packages used by the UK and US respondents were run on microcomputers (Figure 2.14). This finding indicates that sufficiently powerful machines can be purchased to perform the required task at a relatively low cost.

Figure 2.14 Types of hardware where project management software packages were run
**Question 4:** what are the hardware requirements?

Some of the various hardware requirements specified by the UK and US contractors have been listed and presented below.

- mainframe/minicomputer (HP 1000, IBM 38)
- microcomputers (IBM and IBM compatibles 8086, 80286, 80386 processors)
- microcomputers (Machintosh plus, SE, II, IIx)
- 512K-640K(memory for microcomputer-based packages)
- 10MB-30MB(hard disk)
- EGA/VGA(graphics cards)
- colour monitor
- plotter, lazer plotter
- printer, lazer printer
- math co-processor.

Refer to Chapter Three for more information on the different terms and hardware requirements mentioned in this section.

**Question 5:** what was the cost of the package(software)?

The costs above 5000 ($ or £) were those of mainframe/mini-based project management systems. However, a cost of up to 5000 was spent by some UK and US companies for micro-based applications. Table 2.1 and Table 2.2 illustrate the finding of this question.

<table>
<thead>
<tr>
<th>VALUE (£)</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-1000</td>
<td>24%</td>
</tr>
<tr>
<td>1001-2000</td>
<td>27%</td>
</tr>
<tr>
<td>2001-3000</td>
<td>15%</td>
</tr>
<tr>
<td>3001-4000</td>
<td>24%</td>
</tr>
<tr>
<td>4001-5000</td>
<td>6%</td>
</tr>
<tr>
<td>&gt;50001</td>
<td>4%</td>
</tr>
</tbody>
</table>

**Table 2.1 Cost of project management software packages in the UK**
<table>
<thead>
<tr>
<th>VALUE($)</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-1000</td>
<td>7%</td>
</tr>
<tr>
<td>1001-2000</td>
<td>11%</td>
</tr>
<tr>
<td>2001-3000</td>
<td>21%</td>
</tr>
<tr>
<td>3001-4000</td>
<td>36%</td>
</tr>
<tr>
<td>4001-5000</td>
<td>14%</td>
</tr>
<tr>
<td>&gt;5001</td>
<td>11%</td>
</tr>
</tbody>
</table>

Table 2.2 Cost of project management software packages in the USA

Some of the expensive systems were operated under the lease option involving a monthly payment to the software supplier. On average, a financial commitment of up to 4000 (£ or $) can be expected if a particular project management software is to be adopted. The system used by the researcher (Artemis 2000) costs £4250 (refer to Chapter Eight).

A comparison between Table 1 and Table 2 indicates that project management packages are relatively cheaper in the UK. However, these figures could be affected by the dominance of a particular package in the USA (Primavera).

**Question 6: how was the package acquired?**

86% of UK and 84% of US respondents acquired their packages after some form of evaluation (Figure 2.15). In this research, a selection criteria for micro-based project management systems suitable for integrated applications has been proposed in order to facilitate the evaluation procedure of these software packages (refer to Chapter Three).
Figure 2.15 Methods of project management acquisition

Question 7: what are the facilities supported by the package?

<table>
<thead>
<tr>
<th>FACILITY</th>
<th>FREQUENCY(UK)</th>
<th>FREQUENCY(USA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity on the arrow</td>
<td>65</td>
<td>88</td>
</tr>
<tr>
<td>Activity on the node</td>
<td>88</td>
<td>78</td>
</tr>
<tr>
<td>Relational database</td>
<td>44</td>
<td>75</td>
</tr>
<tr>
<td>Good documentation (manuals)</td>
<td>88</td>
<td>90</td>
</tr>
<tr>
<td>Good vendor support</td>
<td>88</td>
<td>95</td>
</tr>
<tr>
<td>Interfaces to external programs</td>
<td>65</td>
<td>83</td>
</tr>
<tr>
<td>Customisation facilities</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>High level command language</td>
<td>38</td>
<td>30</td>
</tr>
<tr>
<td>Report generator</td>
<td>91</td>
<td>88</td>
</tr>
<tr>
<td>Graph generator</td>
<td>74</td>
<td>88</td>
</tr>
<tr>
<td>Access to data by passwords</td>
<td>41</td>
<td>38</td>
</tr>
<tr>
<td>Network plot</td>
<td>88</td>
<td>88</td>
</tr>
<tr>
<td>Multi-networks</td>
<td>62</td>
<td>68</td>
</tr>
<tr>
<td>Links to CAD systems</td>
<td>15</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2.3 Facilities supported by project management packages
The major facilities supported by the various project management software packages (per occurrence) used by the UK and US respondents have been presented in Table 2.3. However, some of the answers were incompatible for the same software package. In addition, most of the respondents did not specify the package version which made the analysis of this question even more difficult.

The above figures show that most project management software packages are not linked to CAD systems. Such facility is considered as a must if integrated applications are to be implemented. Primavera and Plantrac systems are now supporting this facility. The author of this thesis has also developed a link between Artemis 2000 (planning package) and AutoCAD 10 (CAD package).

**Question 8: what is the maximum size of network the software can analyse?**

The maximum size of network the software can analyse was found to be a function of the disk operating system and the hardware configurations as specified by most UK and US respondents. However, on average most computer programs were found to be able to support networks with up to 10,000 activities. Wall (Ref 2.33) has indicated that these figures are acceptable when considering project management software packages.

**Question 9: how much training is needed for someone who is familiar with manual CPM calculations?**

The training period specified by UK and US project management users fluctuated between 1/2 day and six months depending on the sophistication of the software program and the familiarity of users with computers. Table 2.4 shows figures of the frequency of training periods required to learn project management software packages. On average, a training period of up to 4 weeks could be required.

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>FREQUENCY(UK) %</th>
<th>FREQUENCY(USA) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2day-1week</td>
<td>56</td>
<td>55</td>
</tr>
<tr>
<td>&gt;1week-4weeks</td>
<td>10</td>
<td>45</td>
</tr>
<tr>
<td>&gt;4weeks-8weeks</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>&gt;8weeks</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 2.4 Training required to learn project management packages**
2.4 COMPUTER AIDED DESIGN PACKAGES (PART C)

Question 1: what is the name of the package?

Computer aided design packages were found to be more popular amongst the US respondents (Figure 2.16). This indicates that integrated systems which require the use of CAD packages are relatively more likely to be implemented in the US construction industry where contractors have more access to these packages than in the UK.

Figure 2.16 The use of CAD systems

Figure 2.17 CAD systems amongst the sample of the top 100 contractors in the UK
The various computer aided design packages (per company) used by UK and US respondents are shown in Figure 2.17 and Figure 2.18.

This survey shows the strength of AutoCAD as a leader amongst microcomputer aided design packages and supports the decision made to adopt AutoCAD in order to develop the integrated construction planning application.
Question 2: is it available on mainframes, minicomputers or microcomputers?

![Pie chart showing types of hardware used to run CAD packages](image)

**Figure 2.19 Types of hardware used to run CAD packages**

A large number (Figure 2.19) of the computer aided design packages used by the UK and US contractors were available on microcomputers. This finding coupled with the fact that most project management were found to be micro-based gives more weight to the concept of developing integrated applications within the microcomputer environment.

Question 3: is the CAD package available on the same computer as the project management software?

In the UK, 40% of project management and CAD packages were available on the same computer, whereas in the USA 72% of the packages supported this facility (Figure 2.20). This finding helps to determine if integration should be established within a single machine or multi-system environment.
Question 4: under what operating system is the package run?

Most CAD packages used by the UK and US contractors were operated under the DOS disk operating system (Figure 2.21). The developed integrated application was also implemented within the DOS environment.

Figure 2.20 Availability of PM and CAD packages on the same computer

Figure 2.21 The disk operating systems under which CAD packages were run
Question 5: what is the cost of the software?

The price of a CAD package was found to fluctuate between as low as £125 and as high as £250,000 depending on whether the system was micro or large machine-based. The lease option described earlier was also found to be operated by some large systems users. Some figures are presented in Table 2.5 on the costs involved when adopting a CAD system. On average, a cost of up to £3000 can be expected when considering the purchase of a micro-based CAD system.

<table>
<thead>
<tr>
<th>VALUE (£)</th>
<th>FREQUENCY(UK)</th>
<th>FREQUENCY(USA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1000</td>
<td>16.6%</td>
<td>6.6%</td>
</tr>
<tr>
<td>1000-2000</td>
<td>16.6%</td>
<td>80%</td>
</tr>
<tr>
<td>2000-3000</td>
<td>33.4%</td>
<td>0%</td>
</tr>
<tr>
<td>&gt;3000</td>
<td>33.4%</td>
<td>13.4%</td>
</tr>
</tbody>
</table>

Table 2.5 The cost of CAD packages

Question 6: what are the hardware requirements?

In addition to the hardware requirements specified for project management packages, the following were identified as possible extra requirements when running CAD systems.

* Tablet
* Puck
* Digitizers
* Extra RAM
* Networking facilities.

Not all of the hardware requirements are compatible, hence it is essential that CAD and project management systems are evaluated against the same set of hardware configurations when considering integrated applications. For instance, a particular type of plotter should preferably be supported by both the CAD and project management programs.
Question 7: what are the facilities supported by the package?

The major facilities supported by the computer aided design packages (per occurrence) used by the UK and the US respondents have been compiled, frequented and presented in Table 2.6.

<table>
<thead>
<tr>
<th>FACILITY</th>
<th>FREQUENCY (UK) %</th>
<th>FREQUENCY (USA) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D drafting</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2 1/2D modeling</td>
<td>30</td>
<td>59</td>
</tr>
<tr>
<td>3D Solid modeling</td>
<td>50</td>
<td>76</td>
</tr>
<tr>
<td>Possibility to attach attributes to symbol</td>
<td>80</td>
<td>82</td>
</tr>
<tr>
<td>Interfaces to external programs</td>
<td>50</td>
<td>82</td>
</tr>
<tr>
<td>Ability to look at the drawing database</td>
<td>70</td>
<td>76</td>
</tr>
<tr>
<td>Good documentation</td>
<td>100</td>
<td>94</td>
</tr>
<tr>
<td>Good vendor support</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>Link to a planning system</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>Bill of materials facility</td>
<td>40</td>
<td>76</td>
</tr>
<tr>
<td>Intercomputer communication(network)</td>
<td>30</td>
<td>59</td>
</tr>
<tr>
<td>Full graphical data exchange(DXF,etc)</td>
<td>60</td>
<td>94</td>
</tr>
</tbody>
</table>

Table 2.6 Facilities supported by CAD packages

The above facilities are crucial key elements in assessing the suitability of a particular CAD system. For instance, the ability to look at the drawing database is an important criterion in manipulating drawings and developing integrated applications. Chapter Three of this thesis discusses the features of computer aided design packages appropriate for integration.

Question 8: what is the learning period required to use the system?

The average learning periods associated with CAD packages exceeded those of project management on average. The training periods (see Table 2.7) specified the CAD users fluctuated between 1 week and 6 months. An average training period of up to 8 weeks
may be involved when learning the basic features of a CAD system (refer to Chapter Eight for further information).

<table>
<thead>
<tr>
<th>PERIOD (WEEK)</th>
<th>FREQUENCY (UK) %</th>
<th>FREQUENCY (USA) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>57</td>
<td>31</td>
</tr>
<tr>
<td>&gt;4-8</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>&gt;8</td>
<td>14</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 2.7 Training periods for CAD packages

2.5 THE INTEGRATED SYSTEM: GENERAL QUESTIONS (PART D)

Question 1: do you foresee any possibility for a CAD system (a CAD-based planning system) to make a starting point for construction planners and why?

A large number of respondents (40% in the UK and 60% in the USA) were aware of the benefits a CAD system can offer to construction planners. The pie charts shown in Figure 2.22 illustrate the views of the different respondents.

Figure 2.22 CAD systems as starting point for construction planners

US contractors were more aware of the benefits that a CAD system can offer to construction management, with 60% of these contractors foresaw that a CAD system
could make a starting point for construction planners, whereas in the UK only 40% agreed with this view. However, the reasons provided by UK and US contractors were similar. These reasons are listed below:

* online network development can be achieved;
* a design specification could be instantly transformed into scheduling data;
* there will be more flexibility in the work layout;
* it reduces data doublehandling and increases value engineering;
* a CAD interface is helpful in the estimating and take-off stage of construction planning;
* cross sections and drawings could be generated as required;
* they can be used as construction sequencing tool; assigning elements to activities and sequencing them simulating field construction;
* it is suitable for design changes;
* building elements can be linked to network activities;
* drawings would become adequately advanced;
* in assisting with quantities take-off and organisation of site from general arrangements;
* better visibility of the plant can be achieved;
* in provision of quantities to determine durations, but the planner must have an input at a very early stage to determine the way the structure is to be constructed;
* the use of overlays could give the planner access to subsets of the overall project as needed and links to quantities generators;
* it is suitable for design and construct practices;
* integrated design, quantification, planning and pricing can be achieved; and
* it eliminates the recalculation of quantities from bill of quantities.

The integrated construction planning application developed by the author supports most of the above mentioned aspects. These aspects will be clarified in the coming chapters.

On the other hand, 33% of UK and 12% of US construction planners who did not believe that a CAD system could make a starting point for them gave their views expressed as below:

* it is easier to flip pages than wait for screens to regenerate;
* massive computing power would be required for systems to be workable;
* CAD systems are too complicated and expensive;
* builders do not use CAD systems to a great extent, although designers do;
* standardisation would become necessary throughout the industry;
* most civil engineering works do not warrant the use of a CAD system at present;
* planners are generally too valuable a resource to use a CAD system; draftsmen should do it;
* CAD systems are not suitable for small to medium-sized companies;
* construction drawings are not available in CAD format and there is no time at the start of a contract to prepare CAD input; and
* the planner requires access to and knowledge of all project information to plan effectively.

Current working practices, the different technical limitations and the financial aspects can be considered as major barriers in developing a CAD-based planning model. However, recent developments in software and hardware technologies and the adoption of new contracting methods such as 'design and build' and 'management contracting' would eventually motivate researchers and practitioners to adopt new approaches to construction management and planning using CAD systems. These aspects will be described in detail in Chapter Eight of this thesis.

**Question 2:** is it possible to establish a version of CIM (Computer Integrated Manufacturing) for the building industry and why?

Only 6% of UK and 21% of US respondents agreed that a version of CIM can be established for the building industry. The term CIM was found to be unfamiliar to a large proportion of the surveyed companies. The different views expressed by the various respondents are presented as follows (Figure 2.23).
Respondents who thought that a CIM system can not be established for the building industry provided the reasons presented below.

* the technology and subsequent use would be too complex. Also, you would need to link every combination of planning and CAD packages
* there are too many variables. Every job has a different site, different client and different design. Also, the technology is not high and does not require sophisticated systems
* work is too irregular
* not enough standards and guidelines
* not cost effective for general construction services
* the industry is too complex and each project is individual. In addition to this, construction methods are extremely variable
* integration of complete systems is in its early stages. Obvious route is integrating bill of quantities/estimating/planning/cost control. This will be difficult as the different disciplines require the project to be broken in different ways
* industry is too fragmented.

On the other hand, people who agreed that a CIM system can be established expressed their views as follows.

* the concept would be the same as for current engineering integrated packages that work successfully
* system building for all types
* if money is available
* for immediate transfer of computer aided design data to manufacturing processes
* the necessary tools already exist (3D solid modeling software, relational databases)
and the understanding of the benefits of such system is continuously strengthened.

To conclude, current tools are more than sufficient to start at least experimenting with the establishment of a prototypical CIM system for the building industry. However, the establishment of a complete system appears to be a long way ahead as this requires the removal of many of the organisational, financial and technical problems which could hinder the development of such a system. These problems will be considered in great details later in this chapter.

**Question 3: do you accept the fact that most construction management data is initialised at the construction stage rather than at the early development of the project?**

It was found that a great deal of UK and US respondents (Figure 2.24) supported the above view. This aspect has been highlighted in this research, as well as others (2.15) who were involved in developing integrated applications. The different views regarding this matter are shown on the following pie charts.

![Pie chart showing the initialisation of construction management data in UK and USA](Image)

**Figure 2.24 The initialisation of construction management data**

The 64% of UK and 40% of US respondents who strongly believed that most construction data is initialised at a later stage of the project gave the following reasons.
* responsibilities are given to managers after drawings and concepts are completed
* in a typical owner-architect-general contractor relationship
* many times, the people building the project had nothing to do with the bid
* contractors can not afford to invest in the design process.

However, the 18% of UK and 29% of US contractors who disagreed with these views made the following points.

* planning takes place in the office first, programmes are compiled for tender documents
* not in design and build
* initialised at the tender stage
* the work breakdown structure, construction sequences and bills of materials are prepared before construction begins.

Finally, respondents who partially thought that construction data is initialised at the construction phase stated that this depends on the stage the construction manager is brought into the project.

To conclude, it appears that UK contractors where 'design and build' practices are less common than those in the USA are more concerned with this aspect of data initialisation.

**Question 4:** for an integrated system to be achieved, designers and contractors should change their way of thinking. Is that correct and why?

The main assumption of the integrated application developed by the author is that, current working practices should be modified if an integrated system is to be implemented. This view was also found to be shared by 61% of UK and 48% of US respondents (Figure 2.25).
Figure 2.25 Changes of the way of thinking by designers and contractors

The respondents who thought that changes are needed expressed their views as presented below:

* we can not have an integrated system with the current approach of involving contractors after the design is substantially completed;
* designers would need to have more experience and give more consideration to construction methods. Tendering and contracting methods would need to be changed;
* nobody likes to change, and building in this country (UK) is still in the stone age;
* closer relationship is required;
* planners need to become involved much earlier in the design process;
* to make an integrated system cost effective;
* the team concept should be embraced;
* designers should consider constructibility earlier in the project;
* designers would accept more responsibility for quantity development and preliminary planning. Obviously, the designer and the planner would have to share the same system you speak of; and
* it is always necessary to change concepts as knowledge is gained.

The respondents who partially supported the above view made the following points:
* it is not a change of ways as each party is following a necessary process. A much earlier coming together is desirable (beneficial to the clients);
* designers and contractors meet clients needs. Therefore, clients need to change their way of thinking;
* a one stop shop approach for a client is more effective than the adversorial approach of client/designer/contractor; and
* the requirement is more important in the compatibility of systems. Data exchange is currently possible via discs and the only thing stopping integration expansion is the multitude of hardware requirements.

Finally, respondents who disagreed with the view that changes are needed gave the following reasons:

* the system should adopt to the current discipline rather than the reverse; and
* every project needs to be broken down into meaningful tasks.

As shown in Figure 2.25, 61% of the UK and 48% of the US respondents felt that both designers and contractors would have to change their way of thinking if an integrated construction planning system was to be implemented. The indication is that, American contractors have already started to realise the benefits that new approaches such as 'design and build' and 'management contracting' can offer to the management and planning of construction projects.

*Question 5: (related to question 4) if yes, would that be possible in the near future?*

It was found that, only 18% of UK and 26% of US respondents (Figure 2.26) foresaw that designers and contractors would change their way of thinking in the near future. Even though these figures are not encouraging, it has to be said that the introduction of new systems in the past was accompanied by some changes among the different departments within an organisation which appeared at first to be impossible to be achieved. For instance, the introduction of project management and computer aided design systems resulted in different changes within the various companies in terms of space, responsibilities, etc.
Figure 2.26 Possibilities of changing the way of thinking in the near future

Uk and US respondents who did not foresee any changes in the near future blamed:

* a backward conservative and greasy industry which is reluctant to accept any changes
* the nature of the industry.

However, people who strongly believed that changes are imminent responded as follows:

* when cheap PC's become available;
* examples such as management contracting are already on these lines;
* Europe can accelerate the process (UK sample); and
* if the proof of effectiveness can be given.

Question 6: do construction planners have to re-extract most information from conventional drawings and documents to devise the master plan?

A large number of UK and US respondents (Figure 2.27) shared the view of the author that most construction data are re-extracted from conventional drawings and documents. Such re-extraction has been considered earlier in this chapter as error prone. In the integrated application developed by the researcher, most if not all the information once stored are automatically extracted from the CAD model.
Figure 2.27 Re-extraction of construction data from drawings

The 85% of the UK and 67% of the US contractors who supported the above view specified the following reasons:

* quantities of excavation and concreting is an example of such re-extraction of information;
* if the information is not contained on the computer and can not be transferred to a planning package; and
* contractors can not trust the summary data produced by others.

On the other hand, the 3% of UK and 10% of US respondents who disagreed with these views stated that such step is required to familiarise themselves with the work to be done.

Question 7: (related to previous question) would you consider these (information reextraction) as data doublehandling?

Only 49% of UK and 41% of US top contractors (Figure 2.28) thought that re-extraction of information from drawings and documents could be considered as data doublehandling. In current working practices, data doublehandling is almost inevitable. For instance, to generate quantities associated with particular construction activities, the geometrical attributes of the involved design elements have to be re-input into the system. This approach has always been recognised as inefficient. As a result,
the integrated application has considered such deficiency and thus information are stored just once in the CAD model.

Figure 2.28 Data double handling by construction planners

Question 8: would it be helpful if a CAD system allowed construction planners to place their components the way they are going to be built on site?

The main benefit a CAD system can offer to construction planners was thought to be the ability to simulate the construction process on the computer screen. Such view was also shared by a large number of the UK and US surveyed companies (Figure 2.29). Some respondents specified that such an approach can be particularly helpful in very complicated sites, eg nuclear power stations.
Figure 2.29 The simulation of the construction process on the computer screen

Question 9: is it important for construction planners to visualise the building model to account for site restrictions and equipment and trade interactions?

Figure 2.30 The importance of the visualisation of the building model
A large number of UK and US construction planners (Figure 2.30) considered the visualisation of the building model and construction site as important. This view was also emphasised by the author during the course of this research.

**Question 10: what difficulties would the construction industry face when implementing an integrated system?**

The different organisational, financial and technical problems which might be faced when implementing integrated systems were found to be aware of by most UK and US respondents (Figure 2.31). Most of the responses regarding this matter were comprehensive, but not detailed. However, Chapter Eight of this thesis covers clearly and fully all of these important issues.

![Figure 2.31 Problems faced when implementing integrated systems](image)

*present method of tendering/contracting*
*design and construction are carried out by separate organisations both with established and proven systems and procedures*
*getting clients to think in 'design and construct' packages*
*wide variety of work types and sizes of companies*
*a complete change of attitudes from the professionals*
*senior management would have great difficulty in appreciating such an approach*
* cooperation of architects who may not understand construction problems
* open communication and combined planning/development effort between the designers and the construction and engineering people
* the building industry is slow to change and accept changes
* owner/designer/engineer/contractor have different objectives and priorities and might not want to share data
* lack of organisational arrangements compatible with integrated systems.

With regards to the technical difficulties facing integrated system, the following set of answers were given by the surveyed companies.

* building is a low technology industry. There are possibilities in areas where there is a greater acceptance of sophisticated computer technology
* creating a standard system
* choosing a system
* adequate CAD input at an early stage to make it work
* compatibility of equipment
* incompatibility of data between systems
* too complex
* lack of qualified people
* standards are not in place, artificial intelligence software is not available and complexity of site conditions can not be handled by present databases
* technical training of the planner (use of CAD system)
* interpretation and presentation of data in useful formats
* lack of integrated computer programs.

Finally, the different financial implications associated with developing integrated applications have been presented below.

* training people in computing
* system purchase
* a significant financial investment to buy a CAD system and teach people how to use it.
2.6 SUMMARY OF THE RESULTS

This questionnaire survey intended to establish the current status of planning techniques and information technology aspects amongst the UK and US top contractors. A summary of the questionnaire results have been compiled and here presented.

1- It was found that 61% of the UK and 31% of the US top contractors undertake both building and civil engineering work respectively. Also, it was revealed that 94% of UK and 80% of US respondents were involved in building works.

2- One of the most interesting finding of the questionnaire was that, 100% of the US and 88% of the UK companies were using CPM as a scheduling and planning tool. Such technique was discredited by many researchers as inappropriate for construction works.

3- 'On the node' diagrams were found to be more popular than those of 'on the arrows', particularly in the UK. The main reason for this popularity appears to be that the former do not require any dummies which can be sometimes confusing, in addition to the fact that more relationships between activities can be defined within this type of network diagrams.

4- 67% of UK and 76% of US respondents did not support the view that CPM/PERT are not suitable for construction works.

5- A great deal of the surveyed UK and US contractors thought that CPM was important for the success of their companies.

6- 85% of UK and 79% of US top contractors did not find CPM calculations difficult. However, most of these calculations nowadays are undertaken by computers.

7- Surprisingly 25% of the UK and 14% of the US surveyed companies were not familiar with terms such as expert systems and simulation techniques. Also, it was found that, only 15% in the UK and 41% in the USA thought that these techniques can be applied for planning purposes.

8- The main sources of data used to estimate output rates by the UK and US construction planners were found to be based on experience and historical records.
9- Only 15% of the UK and 26% of the US respondents agreed with the view that the generation of network plans from conventional drawings and documents was error prone. This finding could be related to the fact that no other alternative exists which can facilitate such task.

10- 88% of the UK and 95% of the US contractors were using project management software packages. Also, it was found that Primavera systems were the most dominant among the US sample, whereas in UK Pertmaster appeared to be the most popular.

11- Most project management software packages were found to be acquired by British and American contractors only recently, specifically in the last five years.

12- A large number of these project management packages were available on microcomputers.

13- An average financial commitment of up to £4000 can be involved if trying to install a micro-based project management system.

14- 86% of UK and 82% of US project management users acquired their packages after evaluation.

15- The major facilities supported by most project management packages included: activity on the arrow, activity on the node, good documentation, good vendor support, interfaces to external programs, customisation facilities, report and graph generators, network plot, and multi-networks processing capabilities.

16- An average training period of up to 4 weeks were required by most UK and US project management users.

17- It was found that 30% of UK and 43% of US respondents were using computer aided design packages. Also, it was revealed that the AutoCAD software was the most popular program among the UK and US surveyed companies.

18- Most of the CAD packages run by UK and US contractors were found to be available on microcomputers.
19- In the UK, only 40% of project management and CAD packages were available on the same computer, whereas in the USA 72% of these packages were installed on the same machine.

20- Most of the CAD packages used by UK and US respondents were operated under the disk operating system DOS.

21- The major facilities supported by most CAD packages included: 2D drafting, solid modeling, interfaces to external programs, ability to look at the drawing database, good documentation, good vendor support, possibility to attach attributes to symbols, and full graphical data exchange capabilities.

22- An average learning period of up to 8 weeks was found to be involved by most UK and US CAD users.

23- 40% of UK and 60% of US respondents agreed with the view that a CAD system could make a good starting point for construction planners.

24- Only 6% of UK top contractors and 18% of US top contractors thought that a version of CIM (Computer Integrated Manufacturing) can be established for the building industry. The term CIM was found to be unfamiliar to a large proportion of the surveyed companies.

25- The view that most construction management data is initialised at the construction phase rather than at the early development of the project was supported by 64% of the UK and 40% of the US respondents.

26- 61% of the UK and 48% of the US surveyed companies shared the view that designers and contractors should change their way of thinking if integrated systems are to be implemented. However, only 18% of UK and 26% of US respondents thought that these changes can take part in the near future.

27- 85% of the UK and 67% of the US surveyed construction planners thought that they had to re-extract most information from conventional drawings and documents to devise the master plan. However, only 49% in the UK and 43% in the US considered this deficiency as data doublehandling.
28- The benefit a CAD system can offer to construction planners in terms of simulating the construction process on the computer screen was appreciated by 41% of the UK and 45% of the US respondents. The visualisation of the building model was, however, considered as more important with 79% in the UK and 72% in the USA regarding this facility as beneficial to the planning of their constructions.

29- The problems which could be encountered when implementing integrated applications were specified by most UK and US contractors as: organisational, financial, and/or technical.

2.7 CONCLUSIONS

In this chapter the author has sought to establish facts on the current status of planning techniques, information technology uses (Project Management and Computer Aided Design Systems) and the applicability of integrated applications amongst the top contractors in the UK and US construction industries. The following is a summary of the conclusions drawn from this chapter.

1- Most UK and US contractors agreed with the fact that new approaches to construction planning should be adopted to take advantages of the recent developments in the hardware and software technologies.

2- A large number of UK and US contractors were using project management systems for the planning, scheduling and controlling of their construction projects. Also, it was found that CPM/PERT planning technique is still the most dominant. With regards to the use of CAD systems, a great deal of the UK and US companies have started to realise the benefits these systems can offer to the management and planning of construction projects.

3- Integrated applications within the framework of construction planning can be developed using available information technology facilities. However, these systems were found to still face problems and limitations in terms of power, money, and the construction industry organisational structure.

4- The need for an integrated construction planning system is imminent (See Chapters Five, Six, Seven, Eight, and Nine).
5- Current available construction planning models should be discussed (Chapter Four) in order to explore the possibilities of developing a more appropriate planning system.

6- Some aspects of information technology should be clarified to construction personnel, particularly those of expert systems, simulation techniques and finally those of hardware and software selection (Chapter Three and Chapter Four).

7- The adoption of new approaches such as 'design and build' and 'management contracting' offers great benefits to the development of integrated CAD-based planning applications.

8- AutoCAD has established its strength, particularly in the USA. The facilities supported by this system are more than sufficient to start experimenting with the development of a prototypical version of a micro CAD-based planning model.

9- The findings of this chapter can be used by researchers and practitioners alike. Researchers can benefit of the most up to date information presented on current status of planning techniques and information technology uses within the UK and US industries, while practitioners can get assistance for the evaluation of their own systems. These findings have been used in the development of the CAD-based planning model described later in thesis.
CHAPTER THREE

THE IMPACT OF INFORMATION TECHNOLOGY ON CONSTRUCTION

3.1 INTRODUCTION
3.2 INFORMATION TECHNOLOGY IN CONSTRUCTION
3.3 COMPUTER HARDWARE
3.4 SOFTWARE SELECTION
3.5 SUMMARY
3.1 INTRODUCTION

Information technology is a general term covering the converging technologies of computers, telecommunications and office automation (Ref 3.16 & 3.19). This chapter assesses the recent information technology developments that are applicable to the construction industry. Important software selection criteria are assessed in order to establish guidelines to software investors. Thus, a review of computer aided design (CAD), database management systems (DBMS) and project management systems (PMS) was performed. This chapter demonstrates that the establishment of a CAD-based integrated construction system relies heavily on the computer software selection stage. Finally, a general discussion of the various programming languages available to computer programmers and analysts and a brief description of the different computer hardware categories is included.

The main findings of this chapter are based on literature review, visits to computer exhibitions, contacts with software and hardware specialists and personal observations and experience gained throughout the use of the Artemis 2000, AutoCAD 10 and dBase IV software packages.

3.2 INFORMATION TECHNOLOGY IN CONSTRUCTION

According to a survey compiled by Consultants Peat Marwick McInlock and the Construction Industry Computing Association (CICA) (Ref 3.9), it has been revealed that on average contractors in UK spent 0.25% of their turnover on information technology while consultants spent 1.5%. Although these figures are relatively small, they show that an increase of 20% on the previous year. However, one problem which should be highlighted is that British companies are developing their systems in isolation, particularly in the area of computer aided design. This warning has come from a working party of the National Economic Development Office (NEDO) (Ref 3.11). The NEDO working party on CAD raised the problem of multiplicity of firms in the construction industry and system incompatibilities. It is the view of the working party that the UK Construction Industry must avoid computerising current applications without looking to eliminate inefficiency, inaccuracy and bad practices.

In this thesis the top 100 contractors in UK and the top 400 contractors in the USA were surveyed regarding the applicability of computer aided design, project management systems and the use of integrated approaches within their companies. A full analysis of this survey can be found in Chapter Two, while Figure 3.1 and Figure
3.2 show a sample of the results drawn by Consultants Peat Marwick Mclinlock and CICA.

![Chart showing the use of project management in the UK construction industry](chart1)

**Figure 3.1 Use of Project management in the UK construction industry (Ref 3.9)**

![Chart showing the use of CAD systems in the UK construction industry](chart2)

**Figure 3.2 Use of CAD systems in the UK construction industry (Ref 3.9)**

At present, information technology is applied to almost every area of the construction industry from design to construction. Mahony (Ref 3.19) highlights seven areas where information technology is applied:
- design
- estimating and planning
- plant and materials control
- project control
- finance
- administration and office automation.

Further details of software packages available for each of the above are presented in reference 3.17.

The main types of software packages used within the construction industry can be classified as:

- word processing
- computer aided design and drafting
- database management systems
- project management systems
- spreadsheets
- accounting
- estimating
- bill of quantities
- structural analysis.

Computer aided design, project management and database management systems will be described in ensuing sections.

3.3 COMPUTER HARDWARE

Until recently, computers have been large and expensive machines demanding substantial environmental consideration in terms of air conditioning and space requirements. Minicomputers and microcomputers no longer present such problems as they are small and can be easily accommodated. In addition, recent developments in the microprocessor technology have reduced the power gap between mainframes, minicomputers and microcomputers (Ref 3.30).

Table 3.1 shows a comparison between the computer and human powers for the task of computing earthwork cross sectional areas and volumes.
<table>
<thead>
<tr>
<th>Type</th>
<th>Equipment Cost (£)</th>
<th>Task Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainframe</td>
<td>7,000,000</td>
<td>0.1</td>
</tr>
<tr>
<td>Supermini</td>
<td>150,000</td>
<td>0.5</td>
</tr>
<tr>
<td>Mini</td>
<td>30,000</td>
<td>2.4</td>
</tr>
<tr>
<td>Micro</td>
<td>3,500</td>
<td>5.7</td>
</tr>
<tr>
<td>Human</td>
<td>45,000</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1 Comparison of processing speed between computers and humans (Ref 3.38)

The different computer hardware categories are now described.

3.3.1 Mainframes

Most mainframe computers could cost up to £6,000,000, but the average price could range between £150,000 and £500,000. These machines are extremely expensive to buy, run and maintain. However, the benefits gained from these machines justify the huge investment. These benefits can be summarised as follows:

1- mainframe computers are capable of fast processing. They have powerful operating systems that allow multiple users to run multiple applications at the same time in different languages;

2- they can support a wider range of programming languages;
3- they have virtual memory capabilities;
4- they can support sophisticated database management systems; and
5- mainframes can be used to solve complex problems such as finite elements, fluid dynamics, etc.

3.3.2 Minicomputers

Most minicomputer cost between £20,000 and £150,000. Minicomputers are mainly used by medium-sized construction companies with volumes of turnover between £5,000,000 and £30,000,000. The advantages of such machines are listed below:

1- they are cheaper than mainframes and require less management;
2- they can support multi-tasking operations; and
3. they have powerful operating systems.

3.3.3 Microcomputers

Microcomputers are usually the cheapest type of computer. Microcomputer cost between £1,000 and £10,000 and are mainly used by small construction companies. However, recent developments in microprocessors chips have promoted the use of microcomputers. 32-bit 486 processor chips are now available and will eventually enhance the quality of future microcomputing devices. The following characteristics can be associated with microcomputers:

1- they are relatively cheap;
2- they can be easily accommodated as their sizes are compact;
3- they can be run by a person who is not a specialist;
4- they are appropriate for applications developers;
5- they can be installed by the user; the author spent less than an hour to set up an IBM model 30 machine;
6- the have low to non maintenance cost;
7- they are friendly and can be used by any casual user; and
8- they are portable and can be used even on site.

On the other hand, microcomputers have their own limitations some of which are summarised below:

1- they do not support powerful operating systems (at the moment);
2- they have memory limitations;
3- they do not allow for full networking; and
4- they can be easily stolen and broken.

3.4 SOFTWARE SELECTION

Although computer hardware costs have come down over the last few years, software costs are still high and form a greater part of the computer application budget, especially on microcomputers. Thus, it would seem logical that a prospective user should consider some selection criteria which would determine the utility of the program to be selected. Such selection process has been found to be the backbone of the construction planning integrated system developed by the author.
3.4.1 COMPUTER AIDED DESIGN SOFTWARE

3.4.1.1 BACKGROUND

The major objective of this research is to develop an integrated planning application suitable for microcomputers. Thus, only micro CAD packages are considered in this section. However, a general description of the historical background of the development of computer aided design systems has been included. These techniques date back to around 1960 when Ivan Sutherland was working in the USA on interactive graphics (Ref 3.24). The early systems, however, were developed by public sectors which could afford the huge amounts of required investments and were only available on large machines (Ref 3.4). In addition, these mainframe and minicomputer based CAD systems can cost from £50,000 to over £700,000 which makes a CAD conversion unaffordable for many companies, especially the small firms. On the other hand, and in the early 80's the micro CAD revolution has taken place paving the way to relatively cheap, powerful and affordable programs. These low cost systems are capable of supporting 80% of the facilities available on mainframe and minicomputer based systems (Ref 3.23) and at a cost ratio which could be as low as 10%. This is referred to as the 80/10 rule.

The reasons for purchasing a low cost micro CAD system are summarised by Goetsch (Ref 3.15) as below:

1- lower initial cost  
2- lower maintenance cost  
3- shorter payback period  
4- fewer facility adaptations  
5- lesser user training.

The big dilemma is still, however, which micro CAD system is to be selected when facing an array of different packages. The next section will cover the selection of a micro CAD system suitable for integration purposes.
3.4.1.2 MICRO CAD SELECTION CRITERIA

The information regarding the evaluation of computer aided design packages are abundant (Ref 3.2, 3.3, 3.15, 3.28 & 3.31). However, this research is aimed at evaluating features important to the integration concept. The sources of data for this evaluation came from promotional brochures, software demonstrations by distributors, reviews from computer magazines, evaluation by professional societies, visits to computer exhibitions, personal observations and experience gained throughout the use of AutoCAD 10. The major features of a micro CAD system which have to be considered when adopting integrated approaches are now described.

1- User interface

A user friendly interface is a key factor in developing integrated applications as it facilitates the interaction between the user and the machine. The following is a list of interfacing elements which a micro CAD system should support.

a- screen menu and sub-menu
   - bar menu
   - pull down menu
   - side menu
b- tablet menu
c- specific keys for functions
d- defaults displayed on the screen
e- command line input
f- separate monitors for text and graphics
g- switches between text and graphics screen
h- small text area on graphics screen
i- on screen help facilities.

The user interface has become a major issue for applications developers. The mental and psychological behaviours of users are now under investigation to establish proper user interfaces (Ref 3.34 & 3.20). Until such investigation is completed there seems to be no ideal user interface. In the integrated construction planning application developed by the author, the user friendly interface was designed around the AutoCAD 's pull down and side menus as a personal preference. In addition, the user is provided with default values to shorten the time consuming input stage, for instance he/she can hit the
RETURN key to accept the default values displayed on the screen. Help facilities are also provided at all levels.

2- Documentation

The micro CAD documentation is another key element in the selection process. It has been revealed that most previous research has not given this area enough consideration. On the contrary, this research highlights the importance of a software documentation and suggests the following items as elements to be considered.

a- software installation guide  
b- hardware installation guide  
c- program manuals and tutorials  
d- software demonstrations  
e- quick reference guide  
f- availability of third party or adds on packages  
g- newsletters and publications  
h- availability of user groups  
i- number and quality of books covering the program.

The hardware installation guide should provide information on the hardware devices supported by the program, these may include one of the following.

a- 86, 286, 386, 486 or any other processors  
b- graphics cards  
c- disk drives  
d- maths coprocessors  
e- plotting devices  
f- monochrome, colour, or high resolution monitors  
g- digitizers.

The author's own experience of the hardware problems faced during this research should not be underestimated. The research work started in 1988 on an IBM/AT machine using AutoCAD 2.6. At a later stage an IBM PS2 MODEL 30 was bought to proceed with the work. This has necessitated the need to purchase a new set of program diskettes as the new disk drive only supported the 3.5" size. The AutoCAD release 9 was then bought. Once again, a new problem has evolved, the release 9 required a maths coprocessor to make use of the pull down menus provided by the new
program. In 1989, the AutoCAD 9 was replaced by AutoCAD 10 to benefit from the new 3D enhancements of the software package. This stage of software upgrading has again necessitated the use of an IBM machine which supported either the 286 or 386 processors required to run the extended Autolisp interpreter incorporated within the AutoCAD package.

3- Vendor support

The micro CAD vendor support is another important criterion in assessing the suitability of a micro CAD system. The observations of the author in this area are now explained.

1- A good vendor support facilitates the programming and customisation phases of the integrated applications. Autodesk, the AutoCAD developers, have shown extreme cooperation in developing the customised planning package. Their technical support section have always dealt with the Autolisp programming problems encountered during the application development. Vendor support is expected by the provision of a hot line, consultation, training and software demonstration.

2- The second major observation is that there appears to be a positive relationship between the number of users and the quality of a product. The AutoCAD package is being developed and enhanced according to users requirements, for example the availability of the UCS command (user specified coordinate) in the latest version of AutoCAD has allowed the author to produce 3D symbols which can be placed in any direction. This facility was not available in previous versions but was included in Release 10 in response to user demand. In addition, a large number of users would encourage the formation of user groups which can enhance the quality of the micro CAD product by sharing experience to avoid common problems and to spread knowledge.

4- Basic facilities of the system

The ideal micro CAD package which meets all user requirements is yet to be developed. However, most current systems can to some extent support the development of integrated applications. The most important basic features which are to be considered when evaluating CAD system have been compiled and are presented below. Items with an asterisk are those currently supported by AutoCAD.
I- Unit types and format

a- imperial
  - yard
  - foot*
  - inch*
b- metric
  - kilometre
  - metre*
  - millimetre*
c- user defined units
d- angular units
  - decimal degree*
  - radians*
  - degree/min/sec*
  - surveyor's units*
e- units format
  - scientific*: 1.55E+01
  - decimal*: 15.50
  - architectural*: 1'-3 1/2"
  - engineering*: 1'-3.5".

The customised package developed by the author uses the metric unit type in its decimal format.

II- Coordinate modes

a- cartesian or absolute coordinate* (to specify a point as x and y values)
b- relative coordinate* (to specify a point as a distance from the last coordinates)
c- polar coordinate (to previous point)* (to specify a point as a distance and an angle from the previous point)
d- polar to origin (to specify a point as a distance and an angle from the origin).
III- Drawing primitives

Drawing primitives, also known as drawing entities, are defined as elements which can be placed in a drawing by means of a single command (Ref 3.5). The following list summarises the various drawing primitives offered by most micro CAD systems.

a- point* (dot, square, circle,...etc)
b- line* (the most fundamental drawing entity)
c- polyline*
d- arc/circle* (several methods can be provided)
e- rectangle
f- double line (useful in drawings involving walls)
g- polygone*
h- ellipses*
i- curves*

j- text* (to add text to a drawing)
k- dimensioning* (to annotate a drawing with its appropriate measurements)
l- 3D entities
   - 2 1/2 D* (the extrusion of 2D elements into a third dimension)
   - true 3D (the input of 3D coordinates is supported)
m- block* (to produce symbols)
n- ruler* (to display ruler lines along the edges of the display)
o- hatching* (to produce patterns)
p- grid* (to display a reference grid of dots of any desired spacing)
q- object snap* (to snap to precise locations)
r- display controls
   - viewports* (to display different views of the drawing on the same screen)
   - regeneration of drawings*
   - zooming* (to increase or decrease the apparent size of items)
   - panning* (to see details that are off-screen)
   - viewing*
s- layering* (to organise the computer model information)
   - maximum number of layers (no limit in AutoCAD)
   - layer setting* (to set new layers)
   - layer freezing* (to freeze specific layers in order to facilitate the drafting task)
   - layer thawing* (to thaw specific layers for viewing and plotting purposes)
   - setting colors and linetypes* (for presentation)
- coding layers with numbers and texts* (for classification)

t- editing
- moving objects*
- copying entities*
- rotating objects*
- scaling*
- arraying items* (to place similar objects in polar or rectangular rows)
- exploding entities* (to explode a block into its constituent parts)

u- inquiry facilities
- drawing database listing*
- distance calculations*
- perimeters
- areas*
- volumes computations.

Siricon (Société D’Informatique et de Recherche pour l’Industrie de la Construction) in Canada have evaluated twelve CAD systems available on microcomputers: AUTOCAD, AUTOCAD AEC, C-CADD, CADKEY, CAD-SOLUTIONS, CADVANCE, DATACAD, DESIGN BOARD PROFESSIONAL, DRAWBASE, PERSONAL DESIGNER, VERSACAD, and VERSACAD 3D. An evaluation matrix of these systems can be found in reference (Ref 3.31).

5- Symbols creation, insertion and manipulation

Most micro CAD systems support the facility of symbols creation. This area should be carefully evaluated as the main assumption for an integrated system is that designs are made of components held within a database. The following features regarding the use of symbols should be investigated.

- choose symbols from tablet/screen menus
- choose symbols by name
- rotate/scale/drag symbols
- insert 3D symbols
- list defined symbols
- insert multiple symbols
- write symbols to disk
- attach attributes to symbols
- edit symbols globally
- edit symbols individually
- pre-defined libraries of symbols for various applications provided within the system
- system capabilities of using libraries of components produced by professional organisations such as RIBA.

The integrated construction planning application developed by the author is mainly based on the idea of placing design elements and their associated construction activities to model both the design and construction phases. These elements and activities are produced as symbols within the AutoCAD 10 environment. A full explanation of the AutoCAD symbols creation procedure can be found in Chapter Six.

6- Customisation

Billsdon (Ref 3.8) believes that a little customised software can substantially increase the benefits to be gained from a general purpose computer aided design system. Customisation is, thus, an important criterion for making the system truly usable. In order to customise a micro CAD system, the following minimum requirements should be met.

- access to external commands such as DOS (disk operating system commands) from within the CAD system
- execution of external programs such as word processors, spreadsheets and databases from within the system
- custom menus
  a- screen side menu
  b- screen pull down menu
  c- screen icon menu
  d- tablet menu.
- help messages
- ability to write command macros
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The non-graphical database is very often used as a link between a micro CAD system and a relational database program to enhance the former capabilities. The following points are worth mentioning in assessing the power of the non-graphical database associated with a micro CAD software.

a- the number of attributes per component
b- the database size limitation
c- the types of non-graphical data
   - text fields
   - numeric fields
   - logical fields
   - constant fields
   - variable fields
c- the editing of components attributes
d- the extraction of non-graphical information into text or database files. It has been found that there is no single database program which can directly read a drawing file
e- the capability to look at the structure of the drawing database and its associated non-graphical information.

In the developed integrated planning application, non-graphical data attached to design elements and construction activities are extracted from the drawing database. These information are then manipulated within the Autolisp modules specifically designed to generate information relevant to the planning process. In addition, these non-graphical data are used to serve as a link to further information kept in a relational database. The idea of integrating micro CAD and relational database systems has been highlighted by many previous researchers (Ref 3.24, 3.34 & 3.4) and is considered at present as an alternative to the non-existing complete project database. This research has again adopted such concept of integration which has proven to be feasible and practical.

9- Communications

The need for different computer aided design systems to communicate with one another is a must if a complete integrated construction system is to be implemented. In the motor industry, many companies have indicated that their system components suppliers should possess compatible CAD systems which can communicate with their own (Ref 3.22). Even though the construction industry still lags behind in this area, in the future designers, contractors, material suppliers and other parties will eventually transfer data
electronically. This will necessitate the use of compatible CAD and other computer systems.

The main data formats which can both support internal information transfer between CAD systems; and external communications between CAD and external programs are summarised below.

- DXF drawing interchange file
- IGES initial graphics exchange standard
- DXB binary drawing interchange
- CDF comma delimited file
- SDF space delimited file
- DIF data interchange file
- DBF database file
- WKS worksheet file.

As the main objective of this research is to integrate the AutoCAD 10 and Artemis 2000 packages, the CDF and SDF data formats supported by both AutoCAD and dBase IV were extensively used in the first phase of data communications. In the second phase, the DIF format was required to transfer data between dBase IV and Artemis 2000.

10- Other factors

Other factors which should be considered when evaluating micro CAD systems can include software cost, training required and maintenance.

The AutoCAD package has been chosen for this research as it has met most of the criteria discussed in the previous sections and for its worldwide popularity. Table 3.2 shows a sample of the results drawn by the CICA (Construction Industry Computing Association) on the micro CAD systems used within the construction industry (Ref 3.10).
<table>
<thead>
<tr>
<th>SYSTEM SUPPLIER</th>
<th>SYSTEM NAME</th>
<th>UK CI</th>
<th>UK</th>
<th>TOTAL</th>
<th>UK CI WS</th>
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</table>

Table 3.2 Micro-based CAD systems used in the UK construction industry.

UK CI = UK Construction Industry
UK = Excluding Construction
UK CI WS = UK Construction Industry Workstations
TOTAL = Worldwide

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3.4.2 PROJECT MANAGEMENT SOFTWARE

Project management is another important area where the position of information technology should be established as the development of integrated applications depends to a large extent on the software facilities of this field. This section highlights the major features of a micro project management system.

3.4.2.1 HISTORICAL BACKGROUND

Project management software has been available on mainframes and minicomputers since the early sixties. Unfortunately the application of such software required the use of data processing staff who knew very little about planning (Ref 3.27), besides the high overhead costs involved. The emergence of the microcomputers in the late seventies along with easy to use project management systems have changed the role of managing projects managers.

At present, there are over 150 micro project management systems which vary in price from £100 to around £5000. In the midst of this huge number of micro-based systems, the prospective user should refer to some sort of selection criteria. Literature on project management software evaluation can be found in references (Ref 3.12, 3.13, 3.32, 3.33, 3.35, 3.36 & 3.37). However, for the sake of a successful integrated system, the following selection criteria adopted by the researcher during system implementation can be used (Ref 3.21).

3.4.2.2 MICRO-BASED PROJECT MANAGEMENT SELECTION CRITERIA

The micro-based project management software selection criteria suggested by the author are mainly based on knowledge acquired during the research period. Promotional trade literature on the following software packages were collected

- Primavera
- Microplanner
- Pertmaster
- Power Project
- Plantrac
- Open Plan
In addition, demonstrations on Primavera, Power Project and Pertmaster were given by software promoters, distributors and specialists. Finally, the observations of the author throughout the use of Artemis 2000 gave him a clear picture on the needs for a project management system appropriate for the development of integrated applications. The major features of such system are now presented.

1- User friendly interface

In integrated applications, the micro-based project management system is mainly used to process data generated by different programs. Therefore, it is of crucial importance to select an easy to use and friendly package. However, the ideal software which can combine power and friendliness is still ahead of being commercially available. Artemis 2000, the package selected by the author has proven its power in the customisation facilities provided within the system. The incorporation of a high level programming language within the Artemis software has allowed the user to develop a more user friendly interface for the customised planning package using pop-up menus and help facilities.

2- Vendor support

Once again the feature of vendor support has been highlighted as it is an important criterion in selecting micro-based project management systems. The author has experienced some lack of cooperation and support from the Metier's Management Systems, the Artemis developers, during application development. This lack of interest can be detrimental, particularly at the programming stage.

3- Documentation

In contrast with other areas of information technology, there is no single micro-based project management software which has an influential dominance. For example, AutoCAD, dBase and Lotus 123 have respectively dominated the markets of micro computer aided design, database management and spreadsheet systems. This lack of a specific micro-based project management software dominance can be partially associated with system documentation. For instance, whereas many books have been dedicated to the teaching of the previously mentioned systems, few if any are available which cover a particular planning package.
4- Basic facilities supported by the system

As mentioned earlier, there seems to be no ideal package which can support all the facilities required by the user of a micro-based project management software. However, the basic features which should be considered when evaluating such systems can be summarised as below.

I- Time management

a- Time control techniques
   - On the arrow network
   - On the node network
   - Barcharts
   - Multi-networks
b- Capacity of networks
   - Maximum number of activities per network
   - Maximum number of activities per project
c- Activity duration
   - Minutes
   - Hours
   - Days
   - Weeks
   - Months
d- Calendar facilities
   - Span
   - Multiple calendars
   - Units
e- Time analysis
   - CPM/PERT calculations
   - Total float
   - Free float
   - Independent float
   - Negative float
f- Network logic
   - Multiple starts and ends
- Time constraints (start to start, finish to finish, start to finish, finish to start)
- Hammock activities

**g- Network updating**
- Activity percentage completed
- Remaining duration

**h- Reports**
- Tabular reports
- Graphical reports
- Standard reports
- User specified reports

**II- Resource management**

i- Maximum number of resources per activity
ii- Maximum number of resources per project
iii- Resource scheduling (time limitation)
iv- Resource scheduling (resource limitation)
v- Resource aggregation
vi- Histograms/Multihistograms outputs

**III- Cost management**

1- Cost tracking (actual v budget)
2- Graphs of budget, actual and cashflows
3- Cost reports.

Some of the available micro-based project management packages can implicitly support most of the above mentioned facilities if a high level command language and a relational database are incorporated within the system. Artemis 2000 is a good example of such software packages.

**5- Relational database**

The concept of a total engineering database which can support both textual and graphical data is still a recent one (Ref 3.34). However, the integration of low cost CAD systems with relational databases is regarded by many researchers (Ref 3.4) as a temporary alternative to the complete database strategy. Therefore, the incorporation of
a relational database within a micro-based project management system is a key criterion in developing integrated applications. Some of these systems vendors have realised the importance of relational databases by providing interfaces to available commercial packages such as dBase and Oracle. Open Plan and Pertmaster Advance are examples of such systems. In this research, Artemis 2000 which is built around the relational model has been linked to the AutoCAD package in order to devise an integrated construction planning application. A full explanation of the features of a relational database is included later in this chapter.

6- High level command language

Most current micro-based project management systems are not provided with high level command languages. The lack of this facility has prevented the development of third party or add-on packages within this field. The absence of such packages has inspired the author to develop a fully customised planning application which can support both time and cost analyses. The high level command language incorporated within Artemis has been used to customise the data transfer phase between the different applications and to develop all the programs required to simplify the CPM and cost calculations tasks undertaken by Artemis. Such facility has proven to be of extreme importance in developing integrated construction applications. Micro-based project management software investors and applications developers should therefore give this criterion enough consideration during the evaluation process.

7- Interfaces to external programs

Some micro-based project management packages are provided with interfaces to external programs to facilitate the task of data transfer between the different applications. The compatibilities of data to be transferred between the various systems should be considered. For instance, a particular system might have interfaces to spreadsheet programs, while another might interface with databases or CAD systems. The Artemis 2000 package adopted by the author can import Wordstar files, besides data in its DIF format. Furthermore, it has links to mainframes and minicomputers which can analyse large and complex projects.

Because of the lack of a data transfer standards, the development of integrated applications might necessitate the introduction of new mediums to facilitate such task. In the integrated application developed by the author, dBase IV has been used for the mere purpose of data communications between the two incompatible systems, namely
AutoCAD and Artemis. The different data formats discussed in Section 3.4.1.2 (item 11) should be evaluated before deciding on a particular system.

To summarise, a thorough and careful evaluation of a micro-based project management software is a key factor in developing micro-based integrated applications. The major features of such software packages have been analysed and compiled in order to establish a checklist against which construction application developers can depend upon when considering the purchase of such systems. Appendix B contains a list of journals and magazines relevant to the evaluation of micro-based project management systems.

3.4.3 DATABASE MANAGEMENT SYSTEMS EVALUATION

3.4.3.1 HISTORICAL BACKGROUND

The early database management systems have come into light in the early 70's. However, their wider application in business and engineering fields have only taken place in the late 70's and early 80's (Ref 3.34). Their importance are now being realised by most computerised construction applications developers because of the great flexibility they can offer to data storage, integrity and consistency.

3.4.3.2 DATABASE MANAGEMENT SELECTION

The key features in selecting a micro-based database management system have been compiled and presented below (Ref 3.1, 3.14, 3.18 & 3.29).

1- Types of databases

i- Inverted list

In the inverted list type of databases, data are kept in sequential files of records. This sort of database is not suitable for applications where data are continually being modified (Ref 3.25).
ii- Hierarchical

A hierarchical database handles relationships between records through the insertion of pointers. In other words, it is an index which grows and shrinks with the addition or deletion of data.

iii- Network

The network model was a reaction to the difficulty of relating information from two different record types kept in different files. In addition this sort of database can cope with more complex association between records. CAD developers are showing much interest in the network database model (Ref 3.25).

iv- Relational

In the relational database model, associations between records are not decided by pointers or computer memory addresses, but through the identical contents in the fields of different records. The main characteristics of a relational database are that (Ref 3.21):

- each database contains a single type of record;
- each record in the database contains the same number of fields;
- repeated group of fields are not allowed;
- each record in the database has a unique identifier known as the key which can be sometimes a concatenation of fields;
- the same field can occur in more than one database; and
- different fields can be joined or linked to form derived databases.

This sort of database is generally suitable to handle the non-graphical information associated with computer aided design graphical symbols.

2- Good user interface, vendor support and documentation (as described earlier)
3- Facilities supported by the software

Micro-based database management system capabilities vary according to their sophistication. However, the basic features which should be looked at when evaluating such systems are summarised below.

a- hardware support

In an integrated application implemented on a single machine, the database management system should support to some extent the hardware required to run both the CAD and project management packages. On the other hand, in a distributed environment the system's inter-communication capabilities such as LAN (local area network) should be investigated.

b- menu/command driven system

c- data types
   - integer
   - decimal
   - date
   - duration
   - text
   - vectors (Arrays)

d- incorporation of a command language

e- security measures
   - password protection
   - electronic device protection (dongle)

f- system capacity
   - maximum number of files open concurrently
   - maximum number of fields per record
   - maximum number of characters per field
   - maximum number of characters per record
   - duplicate entries prevention
In the integrated planning application, dBase IV has been chosen to act as a common interface to facilitate communications between the computer aided design and project management packages. dBase is considered as a leader amongst database management systems in terms of power and flexibility. The great number of data formats supported by the package is of extreme importance in developing integrated approaches.

3.4.4 SELECTION OF A PROGRAMMING LANGUAGE

The number of languages suitable for use with micros has grown considerably over the past few years. Paradoxically, this is making life increasingly difficult, both for existing users and newcomers to computing (Ref 3.7).

Programming languages can be categorised as:

- machine languages;
- assembly languages; and
- high-level languages.

Machine and assembly languages are machine dependent and difficult to write. On the other hand, high-level languages are independent of the computer in use, but a compiler is always needed to translate the language into machine code. The most common programming languages found in business and engineering applications are compiled as below (Ref 3.7, 3.30 & 3.26):

- BASIC: for teaching purposes; slow in comparison to other languages
- FORTRAN: for scientific and engineering computation
- APL: well suited to the interactive environment
- C: to produce compilers and graphics applications
- COBOL: the best language for business applications
- PASCAL: for teaching purposes and for the construction of system software
- PROLOG: ideal for artificial intelligence applications and knowledge-based systems
- ALGOL: well suited for scientific and mathematical projects
- PL/1: to develop scientific and business applications
- LISP: for interactive and artificial intelligence applications
- ADA: can support the construction of large programs

After experimenting with BASIC, FORTRAN, PASCAL and LISP, it has been revealed that an ideal programming language has no existence yet. Whereas some languages such as BASIC are good at processing numbers, others such as LISP are more appropriate to tackle symbols. It is the view of the author that the nature of the computerised application will dictate the choice of a programming language. In this research, Autolisp which is a sub-set of the common lisp language has proven to be a powerful tool in processing symbols produced by the AutoCAD package. Autolisp has offered the ability to manipulate lists of symbolic alpha and numerical data recursively which was the main requirement of the developed application. The different data types supported by Autolisp (Ref 3.6) are:

a- lists;
b- symbols;
c- strings;
d- real numbers;
e- integers;
f- file descriptors;
g- AutoCAD entity names;
h- AutoCAD selection sets; and
i- built-in functions.

The AutoCAD's selection set data types supported by Autolisp have been used extensively during the modeling phase of the integrated application to associate design elements with activities in the network diagram. The data types supported by the program are, therefore, another key factor in the selection process of a programming language.
3.5 SUMMARY

In this chapter the author has considered the overall position of information technology and its impact on the construction industry. The main findings have been summarised as below:

1- British companies are developing their systems in isolation, particularly in the area of computer aided design.

2- Information technology is applied to almost every area of the construction industry from design to construction. These areas include: design, estimating and planning, plant and material control, finance and office automation.

3- There are three major types of computer systems which can be used by construction companies. These systems can be categorised as: mainframes, minicomputers and microcomputers.

4- The software selection criteria for project management, databases, and CAD systems suitable for integrated applications were not clearly specified or covered in great details by researchers of this field. Such selection process has been found to be the backbone for the development of an integrated construction planning system. The major features which should be considered when selecting a computer software include: user friendly interface, good documentation and vendor support, basic facilities supported by the package, customisation capabilities, incorporation of a programming language, communications, and finally whether interfaces to external programs are provided.

5- The selection of a programming language depends on the nature and the requirements of the involved application and the different data types supported by the programming language.
CHAPTER FOUR

CONSTRUCTION PLANNING OVERVIEW

4.1 INTRODUCTION
4.2 PROJECT MANAGEMENT IN CONSTRUCTION
4.3 PREVIOUS WORK
4.4 SUMMARY
4.1 INTRODUCTION

Project management can be defined as the overall planning, control and coordination of a project from inception to completion meeting constraints such as time, cost, product quality (Ref 4.34 & 4.11) and client satisfaction (Ref 4.31).

Modern project management is said to have begun with the Manhattan project during which the atomic bomb was developed. However, it may be argued that the construction of the Tower of Babel and the Egyptian pyramids must have taken considerable thought and organisation, and thus project management could be considered as old as these historical monuments (Ref 4.24).

This research deals mainly with the planning aspect of project management. In this chapter, the different planning techniques developed by researchers and practitioners have been reviewed and classified as procedural and computer models. The drawbacks and benefits of these systems are fully discussed.

4.2 PROJECT MANAGEMENT IN CONSTRUCTION

Construction is an industry where the design and production activities are very often carried out separately (Ref 4.37). The design is normally produced by an architect with the help of a quantity surveyor, a structural engineer and sometimes a services engineer. This process has long been recognised as inefficient as the contractor has little say at the early design stage, often making his/her production job very complex and extremely difficult. Thus, current working practices need to be modified if construction projects are to be managed properly. The full benefits from the development of an integrated project management system can only be reaped if the different disciplines of the construction industry are willing to work together. This, coupled with recent advancements in hardware and software technologies, could eventually lead to a new era of construction project management.

4.3 PREVIOUS WORK

The various planning techniques developed and used by practitioners and researchers have been reviewed and here presented as procedural methods and computer models.
4.3.1 PROCEDURAL MODELS

In this research, barcharts, linked barcharts, network techniques and line of balance are regarded as procedural methods of planning, even though they can be computerised. These methods are frequently used as scheduling tools during the development of computer models such as expert systems. The remainder of this section discusses the various procedural models applied by the construction industry for planning purposes.

4.3.1.1 BARCHARTS AND LINKED BARCHARTS

Barcharts are widely known as Gantt charts after their originator, Henry Gantt (Ref 4.25). This technique was developed around 1917 in the context of the first world war military requirement.

A Gantt chart can be defined as a programming chart which shows the duration of activities plotted to scale against a time base. The only difference between a barchart and a linked barchart is that, an ordinary barchart shows no connections between activities, whereas a linked barchart shows the links between an activity and the preceding one which has to be completed before it can start. The advantages and disadvantages of barcharts have been compiled here presented below.

a- Advantages of barcharts

The main advantages of barcharts are that they:

- are easy to construct;
- are preferred as day to day control tools;
- are useful for calculating the project resources;
- can be produced from PERT/CPM networks;
- are appropriate as means of communication between groups involved in the construction process, especially when colour coding is used; and
- can be used to graphically portray plans, schedules and progress.

b- Disadvantages of barcharts

The main disadvantages of barcharts are that:

- they do not clearly show the interdependences between the project activities;
- planning and scheduling are considered simultaneously;
- barcharts are manual graphical procedures which are awkward to set up for large projects; and
- they can be tedious when updated manually.

4.3.1.2 NETWORK TECHNIQUES

Network diagrams are graphical representations of the actual relationships among project activities (Ref 4.6). These can be produced either on the arrow or on the node. BS 6046:1981 (Ref 4.5) gives a good comparison of the two techniques. The on the arrow approach was adopted by the author when developing the construction planning application which helped to minimise the computer data input stage. Chapter Two gives figures on the current uses of these techniques within the UK and US construction industries. CPM, PERT and GERT are good examples of the network models. These techniques are now described.

a- Critical path method (CPM)

The critical path method was developed in 1957 by Kell and Walker at Dupont (Ref 4.9). Since then, a number of articles were published on CPM, some criticising it as unsuitable for construction projects (Ref 4.4, 4.17 & 4.19), others favouring it as more than appropriate (Ref 4.23). The findings of Chapter Two agree with the latter. The CPM model assumes a deterministic activity network structure, and deterministic activity duration.

Criticism of CPM

Birrell (Ref 4.4) believes that the CPM method was created in the military/industrial environment where low weighting is put on cost control and efficient use of resources. His argument is that, in construction, the project is not of national importance, and every contractor is interested in the efficient use of his resources.

Jaafari (Ref 4.17) has added to the above criticism. In his opinion, CPM scheduling assumes that project activities have fixed time and discrete nature which is unrealistic, especially when repetitive units or linear projects are to be constructed. Another criticism of CPM comes from Neale et al (Ref 4.28) who believe that any network form is a poor communication tool especially on site. Finally, Kavanagh et al (Ref 4.19)
describe CPM as a poor model of the construction process and suggest that site superintendents think of work crews and not activities.

Davis (Ref 4.8), in 1974, surveyed the top 400 construction firms in the USA on the use of CPM. Davis' main finding was that over 90% of these firms use CPM for detailed planning of work prior to start of construction. During this research the top 100 contractors in UK and the top 400 contractors in the USA were surveyed on the applicability of CPM within their firms. It has been found that 100% of US and 88% of UK contractors use CPM. These findings establish the strength of CPM as a planning tool and contradict most of the previously mentioned views.

Advantages of CPM

Mahony (Ref 4.23) believes that one of the major advantages of CPM is that, for the first time logical thinking about the sequence of events which are to take place on site is incorporated within the model. Neale et al (Ref 4.28) regard CPM as a powerful control tool ideal for construction projects.

It is the view of the author that nothing is wrong with the CPM concept when applied to construction projects. It is a fact that most computerised construction planning models developed in the last few years have adopted CPM as their scheduling and controlling tools. Those who are argue against the suitability of CPM should give us more promising techniques instead of criticism which could be related to a lack of knowledge on the CPM concept and its calculations. In the next sub-section, such calculations will be undertaken to clarify ambiguities surrounding this technique.

CPM calculations

The following example illustrates the use of CPM (Activity-on-arrow networks) in a two storey building project (Figure 4.1 and Table 4.1 ).
Figure 4.1 Network diagram (typical example)

<table>
<thead>
<tr>
<th>ACTIVITY NUMBER</th>
<th>DESCRIPTION</th>
<th>DURATION (WEEKS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>FOUNDATION</td>
<td>4</td>
</tr>
<tr>
<td>2-3</td>
<td>WALLS 1ST STOREY</td>
<td>3</td>
</tr>
<tr>
<td>2-4</td>
<td>COLUMNS 1ST STOREY</td>
<td>2</td>
</tr>
<tr>
<td>2-6</td>
<td>STAIRS 1ST FLIGHT</td>
<td>2</td>
</tr>
<tr>
<td>4-5</td>
<td>1ST FLOOR SLAB</td>
<td>4</td>
</tr>
<tr>
<td>5-8</td>
<td>COLUMNS 2ND STOREY</td>
<td>3</td>
</tr>
<tr>
<td>6-7</td>
<td>STAIRS 2ND FLIGHT</td>
<td>2</td>
</tr>
<tr>
<td>8-9</td>
<td>ROOF</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 4.1 Activities of the involved structure (typical example)
The earliest start and finish times of activities are calculated in the forward pass, whereas the backward pass carries out the calculations for latest start and finish times and floats.

**The forward pass**

- **EST** = Earliest Start Time
- **LST** = Latest Start Time
- **EFT** = Earliest Finish Time
- **LFT** = Latest Finish Time

**Activity 1-2**

- EST = 0
- EFT = EST + duration = 0 + 4 = 4 Weeks

**Activity 2-3**

- EST = EFT of activity 1-2 = 4 Weeks
- EFT = EST + duration = 4 + 3 = 7 Weeks

**Activity 2-4**

- EST = 4 Weeks
- EFT = 4 + 2 = 6 Weeks or EFT = 7 + 0 = 7 Weeks (the biggest)
- EFT = 7 Weeks

In theory, two sets of activities can occur (refer to Figure 4.2 & Figure 4.3).

![Figure 4.2 Activities found in the forward pass (1st set)](image)

**Figure 4.2 Activities found in the forward pass (1st set)**

- EFT(i-j) = EFT of ACTIVITY i-j = EST(i-j) + DU(i-j)  
  (Equation 4.1)
- DU(i-j) = duration of activity i-j
\[ \text{EFT}(i-j) = \text{EST}(i-j) + \text{DU}(i-j) \]
\[ \text{EFT}(k-j) = \text{EST}(k-j) + \text{DU}(k-j) \]
if \( \text{EFT}(i-j) > \text{EFT}(k-j) \) then \( \text{EST} \) of an activity starting at \( j = \text{EFT}(i-j) \)

\( \text{EFT} \) of this activity = \( \text{EST} \) of this activity + duration

\( \text{EST} \) of any activity starting at \( j \) = the largest \( \text{EFT} \) of activities aiming at \( j \) (Equation 4.2).

The following table (Table 4.2) illustrates the calculations for the example set before.

<table>
<thead>
<tr>
<th>ACTIVITY NUMBER</th>
<th>EST</th>
<th>EFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>0</td>
<td>0 + 4 = 4</td>
</tr>
<tr>
<td>2-3</td>
<td>4</td>
<td>4 + 3 = 7</td>
</tr>
<tr>
<td>2-4</td>
<td>4</td>
<td>4 + 2 = 6</td>
</tr>
<tr>
<td>4-5</td>
<td>7</td>
<td>7 + 4 = 11</td>
</tr>
<tr>
<td>2-6</td>
<td>4</td>
<td>4 + 2 = 6</td>
</tr>
<tr>
<td>6-7</td>
<td>11</td>
<td>11 + 2 = 13</td>
</tr>
<tr>
<td>5-8</td>
<td>11</td>
<td>11 + 3 = 14</td>
</tr>
<tr>
<td>8-9</td>
<td>14</td>
<td>14 + 4 = 18</td>
</tr>
</tbody>
</table>

Table 4.2 The forward pass calculations
The backward pass

(refer to Figure 4.1).

Activity 8-9

LFT = 18
LST = 18 - 4 = 14 Weeks

Activity 2-4

EFT = 7
LST = 12 - 2 = 10
   = 7 - 2 = 5
   = 7 - 3 = 4 = the smallest = 4 Weeks
As earlier, two sets of activities can occur (refer to Figure 4.4 & Figure 4.5).

Figure 4.4 Activities found in the backward pass (1st set)

LST(i-j) = LFT(i-j) - DU(i-j) (Equation 4.3)

Figure 4.5 Activities found in the backward pass (2nd set)
The latest start time of activities i-j, i-k and i-l is the smallest of:

\[ \text{LFT}(i-j) - \text{DU}(i-j) \]
\[ \text{LFT}(i-k) - \text{DU}(i-k) \]
\[ \text{LFT}(i-l) - \text{DU}(i-l) \]

The LST of an activity starting at i = the smallest (LFT - duration) (Equation 4.4).

Table 4.3 illustrates the calculations of the backward pass.

<table>
<thead>
<tr>
<th>ACTIVITY NUMBER</th>
<th>LFT</th>
<th>LST</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-9</td>
<td>18</td>
<td>18 - 4 = 14</td>
</tr>
<tr>
<td>5-8</td>
<td>14</td>
<td>14 - 3 = 11</td>
</tr>
<tr>
<td>6-7</td>
<td>14</td>
<td>14 - 2 = 12</td>
</tr>
<tr>
<td>4-5</td>
<td>11</td>
<td>11 - 4 = 7</td>
</tr>
<tr>
<td>2-4</td>
<td>7</td>
<td>12 - 2 = 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 - 3 = 4</td>
</tr>
<tr>
<td>1-2</td>
<td>4</td>
<td>4 - 4 = 0</td>
</tr>
</tbody>
</table>

Table 4.3 Calculations of the backward pass

**Float calculations**

Three types of floats are widely known (Ref 4.30):

i- total float

The total float is the time by which an activity can expand without affecting the critical path.
ii- free float

The free float is the time by which an activity can expand without affecting subsequent activities.

iii- independent float

The independent float is the time by which an activity can expand without affecting any other previous or subsequent activities.

Consider any activity i-j

\[ \text{Total float} = \text{LFT} - \text{EST} - \text{DU}(i-j) \]  
(Equation 4.5)

\[ \text{Free float} = \text{EFT} - \text{EST} - \text{DU}(i-j) \]  
(Equation 4.6)

\[ \text{Independent float} = \text{EFT} - \text{LST} - \text{DU}(i-j) \]  
(Equation 4.7)

For activity 6-7 in the typical example:

\[
\begin{align*}
\text{total float} &= 14 - 11 - 2 = 1 \text{ Week} \\
\text{free float} &= 13 - 11 - 2 = 0 \text{ Week} \\
\text{independent float} &= 13 - 12 - 2 = -1 \text{ Week}
\end{align*}
\]

The critical path of this typical project example is 1-2-3-4-5-8-9. This path is the longest sequence of activities between the beginning and end of the project which determines the minimum duration of this project. Activities on the critical path have no floats.

The broken lines used in Figure 4.1 represent dummy activities which consume neither time nor resources, but indicate a sequential relationship. In the typical example, the dummy activity 3-4 signals that activity 4-5 can not start until both activities 2-4 and 2-3 are finished.
b- PERT (Programme Evaluation and Review Technique)

PERT is an acronym for programme evaluation and review technique. It was developed in June 1958 by the US NAVY to control the Polaris missile project (Ref 4.9) (4.21). PERT assumes a deterministic network and a stochastic activity duration by requiring three time estimates:

- $t_o$ : the most optimistic
- $t_p$ : the most pessimistic
- $t_m$ : the most likely

PERT calculates the expected duration by applying this equation:

$$t_e = \frac{(t_o + 4t_m + t_p)}{6} \quad \text{(Equation 4.8)}$$

Where $t_e$ = time expected

Once the activity expected durations are worked out, the PERT calculations are similar to those of CPM. In fact, some researchers use the notation PERT/CPM to refer to any of these scheduling techniques because of their similarities.

c- GERT (Graphical Evaluation and Review Technique)

GERT is an acronym for the graphical evaluation and review technique. It is a network model which can handle complex modeling situations in the sense that it allows for greater flexibility and uncertainty to be included in the structure of the network. GERT combines signal flowgraph theory, probabilistic networks, PERT/CPM and decisions trees all in a single framework (Ref 4.9 & 4.25).

The main advantages of the GERT model can be summarised as:

- the network is given a stochastic structure allowing some intermediate activities not to be performed;
- permission is given for the repetition of an activity; and
- success and duration of an activity control its completion time.
GERT is a useful scheduling technique for projects such as research and development where the future work to be performed is very likely to be uncertain.

### 4.3.1.3 LINE OF BALANCE

This technique was originally developed to help in the planning and control of manufacturing processes. It was then adopted to the construction industry by Trimble (Ref 4.11). The line of balance is mainly used to plan the construction of similar items. A detailed discussion of the Line of Balance method can be found in references 4.20 and 4.14.

Researchers and practitioners interested in this technique can use the Artemis LOB which is an end user solution written in Artemis 2000.

### 4.3.2 COMPUTER MODELS

In the past few years, researchers have developed computer models to assist in planning and controlling construction activities. Most of these systems have adopted CPM as their scheduling tool. Expert systems, simulation and graphics models are examples of these computer techniques. These models are not extensively used by the construction industry as they require huge amounts of data input and lack the flexibility needed by construction planners to account for the unique nature of construction projects.

#### 4.3.2.1 EXPERT SYSTEMS

An expert system is a computer program to simulate a consultation between an expert of a particular field and the non-expert (Ref 4.40). In the field of construction planning, many expert systems have been developed, mainly in the USA. The major systems are now described.

**a- Construction Planex (Ref 4.16)**

Construction Planex is a prototypical knowledge intensive expert system for construction planning. This system was developed by Hendrickson et al in the USA to generate activity networks, cost estimates and schedules. It has been designed to plan modular high rise buildings, including excavation, foundation and structural construction. In this system, the different design elements are identified, then tasks or element activities to install these design elements are assigned. These tasks are then
aggregated to form project activities. The construction Planex uses the CPM technique to handle the scheduling task. The main components of the Construction Planex system are shown in Figure 4.6.

![Figure 4.6 The Construction Planex System](image)

The main limitation of the Construction Planex model is that only precedence relationships derived from physical relationships among building components are accounted for. The interaction of trades and its effect on activity logic is not considered.
b- MIRCI (Management Interface for the Construction Industry) (Ref 4.2)

MIRCI is an expert system developed in the UK by Alshawi et al to assist in generating and scheduling construction activities. The major aim of this system was to develop a facility which automates the establishment of a construction solution from a given design proposal. This system has relied on the integration of expert system technology, database and project management software.

Figure 4.7 shows the layout of the MIRCI system.

![Diagram of MIRCI system](image)

**Figure 4.7 The MIRCI**

The work undertaken by Alshawi has proven that it is feasible to use microcomputer technology to develop an integrated construction planning system. This approach of integrating different micro-based applications has also been adopted by the author of this thesis.

c- GHOST (Ref 4.27)

GHOST was developed at the MIT by Navinchandra et al. It is a prototype knowledge based system for network generation. It takes a set of activities as an input and provides a schedule as an output by assigning precedents among activities. As a start, the system assumes that all activities can be done simultaneously, then according to the
stored knowledge the network is modified wherever activities can not be done in parallel. Currently, the GHOST system does not consider resources and does not support activity duration determination.

**d- RATU-AJ (4.18)**

RATU-AJ is a knowledge-based system for determining durations of site activities. It is based on the Finnish system of production files. The current version of RATU-AJ has been designed for large shuttering and panels. It can handle the durations of the following activities:

- reinforcement
- large shutter erection and removal
- concreting.

This system runs on a MacintoshII microcomputer using, NEXPERT, an expert system shell, and the Microsoft Spreadsheet, EXCEL. The architecture of RATU-AJ is shown in Figure 4.8. RATU-AJ is not currently linked into any commercial planning package. Future plans for this system include the establishment of such link.

![Figure 4.8 The Ratu-Aj System](image-url)
**e-FEPP (Finite Element Project Planning) (Ref 4.33)**

The FEPP was developed at Nottingham University by Sirajudin and Mawdseley. It is a knowledge-based system for the recognition of work required for construction. This model has been implemented under the GEM operating system in Prospero Pascal. A flowchart of this system is shown below (Figure 4.9).

**Figure 4.9 The FEPP system**

In the FEPP system, the site is divided into a grid of rectangular elements; the grid size depends on the details levels. 0.5m is considered the smallest size a construction resource can work in. Once the site grid is established, a stage of work recognition is started. At the moment, a manual interpretation of the drawings is used to determine the elements of work at any level. However, the FEPP developers hope that, in the future a CAD system can perform this task automatically. Following this work recognition stage, a scheduling process is needed to determine the order in which the work must be done and how it will be done using the available resources. This is achieved using algorithmic and knowledge-based procedures.
CONSAS (Construction Scheduling Analysis System) (Ref 4.18)

CONSAS is a PC-based expert system developed by Ibbs et al to analyse construction schedules. Figure 4.10 shows the knowledge structure of the this system. As in the MIRCI, the CONSAS model is based on the idea of integrating database management, project management and expert systems (Figure 4.11). CONSAS can be used to analyse schedule proposals. One module of this system is aimed at evaluating the accuracy of activity duration estimates.

Figure 4.10 The knowledge structure of the CONSAS system
Figure 4.11 The CONSAS model

**PLATFORM (Ref 4.20)**

The platform model was designed at Stanford University by Levitt et al to assist in the updating of the design and construction of offshore drilling platforms. This system was built using the INTELLICORP KEE environment using the XENOX 1108 computer. The architecture of the PLATFORM model is shown in Figure 4.12.
The PLATFORM model has proven the validity of the usage of hybrid artificial intelligence environment for the support of construction scheduling. This approach can also be adopted to generate construction schedules.

**h- MASON (Ref 4.15)**

MASON is a hierarchical rule-based expert system for masonry construction duration estimation developed by Hendrickson et al, in the USA. The estimation hierarchy is shown below (Figure 4.13).

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**Figure 4.13 The hierarchy of the Mason system**

The MASON model does not generate or schedule any construction activities. It only deals with the duration estimation of masonry work.
This model was developed at Reading University by Gray et al. The main aim of the TIME system was to pass the knowledge used by the construction planner to the designer through an intelligent knowledge-based system. Gray has contributed in the sense that he has made it clear how schedulers use heuristic rules to breakdown the construction of any facility into activities based on the type, function and location of the work.

The main limitation of the system is the lack of an object oriented capability for describing the building components. Other works on expert systems in the area of construction planning include these of Warszawski et al at the National Building Research Institute, in Israel, (Ref 4.38) and of Waugh at Stanford University in the USA (Ref 4.39).

**4.3.2.2 SIMULATION MODELS**

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (Ref 4.29). In construction planning, the major simulation models have been compiled and are presented here.

**a- SIREN (Simulation of Repetitive Networks) (Ref 4.19)**

Siren is a computer model which was developed by Kavanagh at the University of Missouri-Rolla to simulate the construction of repetitive structures such as the construction of multi-storey buildings. This model requires the user to input a precedence diagram of the repetitive unit and additional sub-networks of the non-repetitive elements. The computer would then generate the whole network. The model simulates the various crews as they queue to implement their associated activities. The output of the model are presented in terms of working schedule, cumulative cost curve and statistics on crew and equipment utilisation. Siren is run on a remote mainframe which accepts data collected from site and set via an IBM-PC. The architecture of the Siren model is shown in Figure 4.14.
The Siren model needs further enhancements in order to make it applicable, these include:

- the number of repetitive network must be specified;
- the model should allow for certain flexibility in changing the crew size during the project;
- the weather effect on activity cost is not modeled accurately; and
- the system should incorporate a set of rules which would dictate the sequence of work.

**b- PRODUF (Project Duration Forecast) (Ref 4.1)**

This model was developed in Canada by Ahuja et al. It is mainly used to simulate the expected occurrence of the uncertainty variables of the project. The different steps of the PRODUF model are described in Figure 4.15.
The PRODUF model can be mainly used for:
- forecasting probabilistic project completion time;
- determination of criticality index;
- sensitivity of an activity to uncertainty variables; and
- gaming purposes.

The major limitation of this system is that it is only used on mainframe computers.

c- Stochastic Network Model For Planning Scheduling (Ref 4.41)

Stochastic networks can be defined as sophisticated simulation techniques. Whereas ordinary simulation models include some degree of simplification, stochastic networks accept most data describing project activities in the form of a distribution. The stochastic network model described in this section was developed by Gandall et al at the University of California. This system is based on Monte Carlo simulation techniques. The input consists of a time distribution for the activity under optimal condition and a series of time distributions for various problems which lengthen the
activity completion time. The output of the network model is a decision criteria which demonstrate the possible variation in outcomes rather than relying on a single point estimate. Examples of other simulation programs dedicated to construction planning include the Construction Project Simulator developed at Reading University (Ref 4.18).

4.3.2.3 WORK OF SIMILAR NATURE (COMPUTER GRAPHICS)

The use of computer graphics to assist in the planning and controlling of construction projects has been considered very recently (Ref 4.36). In this section, the major computer graphics models developed within the context of construction planning and management are compiled and described as below.

**a- BRIAN ATKIN (Ref 4.3)**

Brian Atkin et al at Reading University have investigated the capabilities a CAD system can offer to the management of construction projects. Atkin's main findings were that:

- CAD systems in the UK are mainly confined to the production of detailed drawings;
- most systems are used as 2-D drafting tools which are not suitable to incorporate non-graphical construction data;
- 3D systems are the most suitable for integrated applications with the necessity for separate databases;
- design practices should be modified to adopt component based approach; and
- the computer technology is available now to develop new approaches to the management of construction using CAD systems.

Atkin et al have configured an experimental integrated system to provide information for management purposes, besides producing drawings. This system is based on the idea of integrating computer aided design and relational database management systems. Details of specifications, costs, durations and resources are stored in the database system which accepts graphical data from the CAD model and relates them to their associated non-graphical attributes. In addition, the graphical data input stage includes a barchart which is used to produce a schedule of durations for the work packages held in the database management system.
Retik et al at the Israel Institute of Technology have developed a model to assist in construction scheduling. The input of this computer graphics-based system consists of a geometrical representation of the structure to be erected and a schedule for the erection of its main components. The program would then output graphical representation of the total schedule, besides reporting the construction status at any given date. The developers of this system have used two interrelated packages, SCHED and DRAW for the tasks of scheduling and modeling. The layout of this system is shown in Figure 4.16.

![Diagram of the Retik Model]

**Figure 4.16 The Retik Model**

The 3-D computer graphics package incorporated within the system enhances the presentation of the project and permits the planner to view his/her structure as it will look during construction.
c.- COMANDS (The Construction Management Display System) (Ref 4.42)

The COMANDS system was developed by Stone & Webster in the USA for an integrated plant model. In this system, the capabilities of a 3-D solids computer model were combined with the efficiency of a computerised cost and schedule database to plan and schedule the construction process.

To use the COMANDS system, the planner should disassemble the model created during design into its base elements which are then assembled in the same sequence as they are going to be built on site. Activities are then associated with these elements. Quantities and durations generated within the system are also related to these design elements.

d.- ACE (Analytical Cost Evaluation) (Ref 4.7)

The ACE package is described by Paul Barton as the nearest thing to a complete PC-based construction management system as it is a conscious attempt to integrate design and production information within the one system.

The package incorporates a 3-D graphics module which allows the user to model the structure on the screen and then a database of components is originated from the design model for pricing purposes. The structure of this database is hierarchical and can be on elemental or activity basis.

e.- BUILDER (Ref 4.22)

BUILDER was developed at MIT by Cherneff. This system incorporates two sorts of knowledge bases, one is used for drawing creation and manipulation, and the other for construction scheduling. The architecture of the BUILDER system is shown in Figure 4.17.
BUILDER can be seen as a serious attempt to generate construction schedules from drawings. Its key characteristics is the object-oriented environment used to develop the system. This environment has facilitated the storage of physical objects such as doors, windows, walls, as well as generic tasks for their construction. The two knowledge bases of the BUILDER system are DRAW and PLANNER. DRAW is a knowledge enhanced CAD system which has been used for drawing creation, recognition and manipulation. PLANNER, on the other hand, has been adopted as a scheduling tool. Its knowledge of construction sequences, estimating data and procedures to produce the project network are combined to develop the construction plan.

The main criticism of the BUILDER model is its crude barchart output which is not suitable for site uses.

f- TIMBERLINE SOFTWARE (Ref 4.35)

In the USA, Timberline Corporation have developed a link, known as CAD integrator, between AutoCAD and their PRECISION ESTIMATING PLUS SYSTEM. The CAD integrator performs take-off directly from AutoCAD electronic drawings. It then moves the information into PRECISION PLUS, an estimating spreadsheet-based
program. Once estimating has been done, information can also be tied directly to PRIMAVERA and Microsoft scheduling products to give more precise job planning. The key features of the CAD integrator are that:

- it automatically takes off 3D dimensions from AutoCAD drawings;
- it allows for specifications transfer from the estimating database to AutoCAD drawings;
- when drawings are changed, estimates are automatically updated; and
- estimates can be inserted into AutoCAD drawings.

Even though this system seems to offer a new generation of computer assisted design and estimating software, Gilleard (Ref 4.12) believes that the experience of the system is currently slight. He states that review work of this Timberline product is under investigation at the Georgia Institute of Technology.

Currently, Timberline supports two construction estimating databases: a general contractor and a residential contractor databases.

\textbf{g- AYMAN MORAD (CAD/CPM INTERACTION) (Ref 4.26)}

Morad et al at Virginia Tech have developed a planning technique based on the concept of integrating CAD and construction planning systems such as critical path method (CPM) in the presence of an expert system. In this model, the construction process is simulated on a graphics display of a super workstation. The system operates by extracting information from the 3D computer model. The execution sequence is then generated using the extracted data and the knowledge rules of the expert system. The generated sequence is used to visually simulate the construction process using the WALKTHRU simulation package. The layout of this model is shown in Figure 4.18.
This model can be seen as a serious attempt to integrate computer aided design and planning applications within a single system. However, the practicality and costs of such models should be assessed as they involve the coupling of CAD, simulation, expert system, databases and planning techniques on a relatively costly piece of hardware.

4.4 SUMMARY

1- Planning techniques can be classified as: procedural or computer models. Procedural models include: barcharts, linked barcharts, network techniques and line of balance. Network and barchart techniques are widely used by construction planners as planning, scheduling and controlling tools. The use of CPM (activity on the arrow network) has been illustrated in this chapter in order to simplify the task of CPM (Critical Path Method) calculations and to clarify ambiguities surrounding this technique.

2- Computer models such as expert systems, simulation techniques and graphics systems have been developed in the past to automate the construction planning process. Most of these have been developed in the USA. These models, however, are not
extensively used by the construction industry as they require large amounts of data input and lack the flexibility needed to account for the unique nature of construction projects.

3- It has been argued that CPM network techniques are not suitable for construction projects mainly because CPM was developed in the military/industrial environment which is completely different from that of construction. However, others who were in favour of using CPM techniques argued that for the first time logical thinking about the sequence of events which are to take place on site is incorporated within such technique and which is needed for construction projects. Evidence of the extensive use of CPM in the construction industry indicates the strength of this technique.
CHAPTER FIVE

TRADITIONAL METHODS AND THE PROPOSED INTEGRATED
SYSTEM APPROACH TO CONSTRUCTION PLANNING

5.1 INTRODUCTION
5.2 THE TRADITIONAL APPROACH TO CONSTRUCTION
   PLANNING
5.3 INTRODUCING THE INTEGRATED SYSTEM
5.4 SUMMARY
5.1 INTRODUCTION

This research considers the traditional planning process as no more than re-initialisation of information captured within conventional drawings and documents. In this chapter, the different stages of this process are highlighted and described, particularly at the construction stage. In addition, the proposed integrated system developed by the author to assist in the planning of in-situ concrete structures is introduced. The functional specifications of this system are also discussed. This model is based on the concept of integrating the most appropriate micro computer aided design and project management packages. The selection procedure of such computer programs are discussed in Chapter Four.

When compared with the traditional process, the proposed integrated system should be regarded more efficient as the information flow is consistent and data corruption is kept to a minimum. In addition, data doublehandling is almost avoided as the initialisation of information relevant to the planning process occurs at the early stages of the project rather than at the construction phase. Most computer models applied to construction planning such as expert systems and simulation techniques have no direct interfaces with computer aided design programs and thus require data generated at the design phase to be re-input manually into these systems. In the proposed integrated system, an access to the design model is provided within the developed package.

5.2 THE TRADITIONAL APPROACH TO CONSTRUCTION PLANNING

The current approach of planning construction projects often inefficient and error prone as most data have to be re-extracted from conventional drawings and documents which can be subject to a great misinterpretation by construction planners when trying to establish a master plan. These factors are considered in greater details in the next sections.

5.2.1 THE PLANNING PROCESS (GENERAL)

The project plan or master schedule is the major outcome of the project planning process, whether at the design or construction stage. Traditionally, planners are equipped with a pile of documents, a roll of drawings, and sheets of papers in order to establish the project work programme. Prentis has identified seven steps in creating the project master plan (Ref 5.10).
**Step 1 - Baseline programme definition**

The statement of work (SOW), milestone schedule (MS), and order of magnitude estimate (OME) documents are produced at this stage. The SOW defines the overall project objectives and it might include cost target, preliminary start and end dates, legal and financial obligations. The MS shows schedule dates for major activities. Finally, the OME is a feasibility estimate based on similar projects, but adjusted for present day prices and the productivity in the area where the project will be performed.

**Step 2 - The work breakdown structure**

Once the statement of work, the milestone schedule and the order of magnitude estimate documents have been issued, the task of breaking the project into manageable pieces can take place. This is widely known as the work breakdown structure (WBS). Bushait has found that the work breakdown structure technique was applied to almost all of his surveyed construction projects and in 90% of research and development projects (Ref 5.2). The WBS technique is considered essential when determining the required activities for constructing the bar chart or the network diagrams.

**Step 3 - Conceptual design/planning**

The conceptual design/planning phase relies heavily on the outputs of step 1 and step 2. For a new system to be installed, requirements such as identification of available equipment, layout drawings, material flow and storage diagrams should be most appropriate. This could only be achieved efficiently and quickly if computers are used. In a traditional environment, the access to a conceptual design is limited and thus the planning process is affected to a certain extent. To rectify this, a CAD system should be used to give planners more freedom in assessing the outputs of the conceptual design stage.

**Step 4 - The budget estimate**

A definitive budget estimate seems impossible at this stage of the planning process because of the conceptual nature of the available information. The budget estimate can be considered as a rough guess based on this information using bid and unit rate prices for material, equipment, tooling and manpowers. Prentis believes that the budget estimate depends on the industry and type of contract. He states that the range of the
budget estimate should be between -10% and +25% of the actual final cost of the project (Ref 5.10).

**Step 5 - The network development phase**

*The network logic*

The network diagram can be developed in parallel with the budget estimating step. The tasks which are to be performed and their logical relationships can be presented in a graphical format (network diagram). In practice, the activities or tasks list come from the decomposition of the work breakdown structure into action levels. The level of activity detail is dependent upon the nature of the construction project. Echverry et al have identified four factors which affect logical relationships among activities (Ref 5.3).

a- Physical relationships

Physical relationships among project components are widely known as natural relationships. The natural dependency among activities is beyond the project planner control. For instance, the concreting activity of a reinforced concrete footing can only take place if the steel fixing activity is finished.

b- Trade interaction

The presence of different elements on the construction site plays a crucial role in determining the proper activity sequencing. For instance, two different gangs might compete for the same space. Interaction between the different trades has always been ignored by both researchers and practitioners of this field. This is justified by the fact that construction planning processes have always relied on traditional drawings. It is the view of the author that only an access to a 3D CAD model would help construction planners to establish the right activity sequencing considering trade and equipment interactions on a computer screen.

c- Resource limitations

A resource dependency is not natural and is caused by activities competing for the same unique resource. This limited resource might be manpowers, materials, money or equipment.
d- Code regulations

Activity logic depends sometimes on the safety requirements. Specific rules and regulations have to be followed under certain circumstances which can affect the activity sequencing.

Duration estimation

The various factors which can affect activity duration estimates have been compiled and presented below (Ref 5.4, 5.7 & 5.11).

- weather
- learning curve
- design changes
- crew interaction
- equipment interaction
- absenteeism
- project complexity
- union regulations
- gang size's pay per hour
- lack of supervision
- lack of true work atmosphere
- poor communication
- drawing approval schedule
- unskilled tradesmen and labourers
- management unawareness.

Trimble believes that it is impossible to select a model which totally represents the output of building operations as the quantitative effects of the multitude of factors which could affect these output data are yet to be known (Ref 5.4). In contrast with Trimble, Price suggests that a model for construction planning and estimating can be established based on the concept of site factors. It is the view of Price, site factors can account for lost production and can be used as a measure of performance. In this research, the model designed by Price et al (Ref 5.12 - 5.15) which is statistically sound has been adopted for duration estimating of concreting, steel fixing and formwork activities of in-situ concrete structures. Some of the tabular data produced by Price were translated by the author into equations using the Cricket Graph package. These equations have been stored within the developed package as methods for concreting, fixing reinforcement
and erecting formwork. In addition, and in order to make the integrated application more flexible the Wessex database has been chosen as another alternative to the work study database developed by Price as it is widely known in the UK construction industry (refer to Chapter Two on the use of the Wessex database within the top 100 contractors in the UK). Other sources for activity duration estimating can include:

- experience;
- historical records;
- simulation models; and
- expert systems.

Traditionally, planners rely on their experience for the estimation of durations as the construction industry lacks recognised standard models. However, construction projects are becoming more complex and competitive, and thus the need to couple experience with scientific approaches is urgent. This strategy has been adopted in the integrated application as planners are given more freedom to use stored data associated with activities durations.

Once the network diagram has been completed, a forward and backward pass may be performed to determine the project duration and to identify the critical path through the project.

**Step 6 - Resource allocation**

Tripathy defines two sorts of resources: consumables such as materials which are consumed in a given task, and non-consumables which are used to accomplish a task without being consumed (Ref 5.17). Examples of non-consumable resources are equipment and labour. The resource allocation job is the actual loading of these resources onto the network activities in order to implement the work programme. Once resource loading has been done, a stage of scheduling based on two approaches can take place. The first is time-limited scheduling where the end date of the project is externally imposed. The second is resource-limited where available resources may not be exceeded.

**Step 7 - The master schedule**

Once the network diagram is produced, resources constraints are met and activities are planned when they can be accomplished, the original budget estimate should be revised.
As a result, a finalised master schedule may now be used as a baseline for the dynamic working environment. The previous steps have been originated for the design stage. Practically, these steps can be followed to devise the construction master schedule.

5.2.2 PLANNING AT THE CONSTRUCTION STAGE

In the UK, the bill of quantities type of contract is a norm. In this type of contract three stages of project planning at the construction phase are widely recognised (Ref 5.7 - 5.8):

- pre-tender planning;
- post-tender planning/pre-contract planning; and
- short term planning.

1- Pre-tender planning

Pre-tender planning allows the estimator of a construction company to build up an overall tender price for the construction of a project. The cost estimate will be based on the proposed method of working and an estimate of the time required to perform the work. Only the main operations of the project are considered at this stage. Pike believes that throughout this process the most important factors which can affect the planning of construction projects are (Ref 5.8):

- access;
- methods of construction;
- construction time scale; and
- materials handling.

The documents available to planners at this stage can be summarised as below.

- tender drawings
- bill of quantities
- specification requirements
- conditions of contracts
- qualifying letters
- site reports.
In the traditional environment, construction planners extract most of the data relevant to the planning process from these documents. The proposed integrated system introduced later in this chapter considers data in its electronic format to avoid misinterpretation of these available documents and drawings.

2- Post-tender planning

The post-tender planning is carried out when the contract has been won. At this stage, planners should give enough attention to the following items.

- site organisation structure
- construction methods
- material schedules
- labour schedules
- plant schedules
- sub-contractors
- services such as electricity
- overall project programme.

In an integrated environment, the above factors can be easily assessed. The site layout can be displayed on the screen to account for restrictions and trade interactions. In addition, the different schedules required for equipment, labour and materials can be automatically generated within the system. On the contrary, the traditional environment is not capable of offering much help in terms of visualisation and automatic quantities generating.

3- Short term planning

Short-term planning is usually done on site and based on the overall project programme with much more details. It is generally drawn up on a day by day basis. In the integrated system, the level of details can be defined by the user (planner). For instance, he/she can group any set of objects and then associate construction activities with these elements.
5.2.3 CURRENT MALPRACTICES

Traditionally, the construction industry operates in a sequential way. For instance, the RIBA job book sets out the plan of work for a building project as a sequence of the following tasks (Ref 5.15 & 5.9).

- Inception
- Feasibility
- Outline proposals
- Scheme design
- Detail design
- Production information (working drawings)
- Bill of quantities
- Tender action
- Project planning
- Operation on site
- Completion
- Feedback

The RIBA plan of work implies that the different stages are discrete. In a poor communication environment, changes at any stage may not be accounted for in another. For example, if the design is modified after the project planning stage, activities logics, durations and materials requirements tend to be affected to a large extent. As a result, the whole planning process will be disturbed. In an integrated environment, such changes will be transferred directly as the information flow is continuously consistent. In addition, the involvement of the bill of quantities type of contract can be regarded as inefficient as the construction planner is brought into the process once the design is substantially complete. In such an environment, the construction planner is provided with drawings and documents to work with rather than an access to the CAD model which can facilitate the planning task.

With regards to current computer malpractices, it appears that present computerised planning applications are little more than manual formulation of the construction plan. In such systems, data are fed into the computer program and computations are performed using either Critical Path Method (CPM) or Programme Evaluation and Review Technique (PERT) concepts. However, data related to activity lists, resource requirements and durations are not automatically generated within the system (Ref 5.3). In addition, most of these systems can not directly accept the data related to the network.
diagrams which are produced on a sheet of paper rather than in an electronic format, thus data doublehandling is unavoidable in such systems. In addition, computer models such as expert systems, and simulation techniques developed in the past to automate the construction planning process were found not to be extensively used by the construction industry as they require large amounts of data input and lack the flexibility needed by the construction planner to account for the unique nature of construction projects.

The need, therefore, for a more advanced and flexible planning system which can automate the generation of network diagrams is imminent. The integrated system introduced in the next section has been designed to rectify many of these specified malpractices. A full explanation of this system can be found in later chapters.

5.3 INTRODUCING THE INTEGRATED SYSTEM

5.3.1 BACKGROUND

Howard defines integration as the linking of computer programs to run different applications from the same database (Ref 5.6). From a review of current literature it appears that there is a recent trend towards the use of this type of databases, but such databases are usually only available on mainframes and minicomputers. However, the manufacturing industry has gone a long way in assessing the feasibility and practicality of developing integrated applications using the concept of an engineering database (i.e. a database which can support both graphical and non-graphical information) (Ref 5.16). The construction industry lags behind in this major area of information development and management partly because of the huge investment required to support and maintain the engineering databases. As a solution, a new concept has been adopted which involves the integration and coupling of micro-based low cost and powerful software packages, thus ensuring that such an approach is within the reach of most construction companies. However, such a concept is not problem free. These problems which can be faced when developing integrated applications are discussed in Chapter Eight.

As mentioned earlier, the manufacturing industry has gone a long way in establishing fully integrated systems. The question is whether the construction industry will follow the manufacturing industry and adopt these new techniques or remain in its backward status. Previous experiences with the use of critical path method and work study techniques which were developed outside the construction industry and later adopted by this industry give researchers and practitioners some encouragement in assessing the
practicality and usefulness of the integrated system approach. The next sections and chapters six, seven and eight will explore the possibilities of developing and implementing integrated systems within the framework of construction planning.

These findings coupled with those of Chapters Two, Three and Four suggest that a CAD-system would involve the coupling of micro-based CAD project management and relational database systems and integrating the functions shown in Figure 5.1. In such an environment, the project information can be handled properly. In addition, the time and cost analyses of the project under consideration can be undertaken more easily and efficiently. Figure 5.1 shows an overall view of the CAD-based planning model which will be described in great details in the coming sections and chapters.

![Diagram of CAD-based integrated planning model](image)

**Figure 5.1** An overall view of the CAD-based integrated planning model
The integrated system approach to construction planning is proposed by the author to rectify problems encountered in the traditional working environment. In this system, designers and contractors alike would have access to information available on CAD systems and relevant to their planning processes. For instance, the planning department of the design office can produce the master schedule from the CAD model according to their requirements. Simultaneously, construction planners can use the same CAD model to generate a more detailed construction programme.

The main advantage of the integrated system is that, quantities associated with specific objects or design elements can be quickly produced. The traditional method, however, does not support such facility, and when calculations are done manually it is very likely to be error prone.

5.3.2 THE SYSTEM METHODOLOGY

As the major objective of this research is to develop a computer-based integrated system for construction planning, a methodology which consists of the following sequence of activities was adopted (Ref 5.16).

- analysis
- design
- implementation (including development)
- maintenance and review.

This sequence of activities should be of iterative nature depending on the outputs of each phase. The analysis phase should result in a system proposal and functional requirements which include the input data, the processing needs and the output generated from the system. The expected benefits from the software should exceed the involved costs in order to proceed to the next phase.

The design phase is defined by Tah (Ref 5.16) as a conscious process of translating the requirements of the user into a specification of the facilities and interfaces. This includes the design of the man-computer interface and all the computing requirements.

The third phase, system implementation, is a mere translation of the design into a working software. The flowchart shown in Figure 5.1 illustrates the layout of this phase. The following features involved at this stage included:
- prototypical programming;
- testing;
- full programming;
- documentation; and
- installation.

Finally, the last phase which is the system maintenance and review involves the removal of remaining bugs and undetected errors after the software has been released. This phase can last for the lifetime of the software.

![Diagram of the implementation phase](image)

**Figure 5.2 The layout of the implementation phase**

### 5.3.3 THE FUNCTIONAL SPECIFICATIONS OF THE SYSTEM

Traditionally, construction planners produce their network diagrams on sheets of papers which are then analysed either manually or using computers. The system suggested by the author tries to imitate this traditional approach, but the network diagram is now in its electronic format. In addition, the system offers more facilities in terms of visualisation.
and data processing. The functional specifications of the suggested integrated system are summarised as below:

- modeling;
- drafting;
- quantities and materials scheduling;
- time analysis;
- cost analysis; and
- reporting.

Each of these headings will be considered in more details in the coming sections.

5.3.3.1 THE MODELING REQUIREMENTS

The modeling phase is aimed at modeling in-situ concrete components and their associated construction activities. The following requirements should be met:

1- 2 1/2D modeling facilities to allow for better visualisation of the building model, site arrangements and equipment locations;
2- the system should allow for automatic switching between the different layers to keep various design elements, text and dimensions on different levels;
3- the system should be capable of storing pre-drawn components, as well as components of variable nature. In addition, the system should allow for textual attributes to be attached to these symbols;
4- the user (planner) should be allowed to view the design elements from any direction or orientation; and
5- the system should allow for the modeling requirements to be incorporated within the menu facilities. In addition, the system should be user friendly.

5.3.3.2 THE DRAFTING REQUIREMENTS

The drafting requirements should include:

1- the system should be capable of producing drawings from the 2 1/2D CAD building model;
2- the user should be able to import different textual information to drawings from other applications to enhance their quality; and
3- the system should allow for drawings to be produced on screens, printers and plotters.

5.3.3.3 THE QUANTITIES AND MATERIALS SCHEDULING REQUIREMENTS

One of the main tasks of the integrated system is to generate quantities and schedules based on design information stored within the CAD model. Its requirements should involve the following:

1- the user should be able to associate any set of design elements with network activities. The quantities related to these design elements should be generated within the system. Areas, volumes, weights of reinforcement bars, and durations are examples of such produced quantities;
2- the system should allow different data-related activities to be kept in different files for further processing;
3- the system should allow for data compatibilities between the various required applications;
4- the system should have the capabilities to update the network diagram automatically once design elements are modified; and
5- bills of materials facilities should be incorporated within the system.

5.3.3.4 THE TIME ANALYSIS REQUIREMENTS

The time analysis phase of the integrated system is mainly concerned with the determination of the total project duration. Its requirements should involve the following:

1- the system should be capable of processing on the arrow format of network diagrams;
2- the critical path method (CPM) calculations should be carried out within the system. Total and independent floats should also be included;
3- the user should be able to undertake resource analysis in order to establish resources loadings and requirements;
4- the system should be capable of supporting a customised version of the time analysis requirement;
5- the system should allow for automatic translation of the network diagram into planning activities;
6- the outputs of the time analysis phase should be displayed on the monitor, printed, plotted or stored on a disk for later retrieval;
7- the system should be flexible in the sense that different gang sizes and construction methods can be tried to achieve an optimal total project duration; and
8- the system should have a friendly user interface.

5.3.3.5 THE COST ANALYSIS REQUIREMENTS

Besides time analysis, the system undertakes cost analysis of the project under consideration. The following facilities should be supported:

1- the system should be capable of performing cost analysis of the concreting, steel fixing and formwork erection activities associated with in-situ concrete design elements;
2- the cost should be based on labourers and materials requirements;
3- the system should allow for a close association between time and cost in order to establish an optimised working plan; and
4- the cost analysis phase should be fully customised and should have a user friendly interface.

5.3.3.6 THE REPORTING REQUIREMENTS

The reporting phase of the integrated system is aimed at producing the various reports, graphs and charts required to facilitate the planning of the construction of in-situ concrete structures. The following facilities should be supported:

1- the system should be capable of producing a detailed network diagram for office and site uses with all the descriptive information necessary to facilitate the job of construction personnel. Colour coding should also be included on plotted and displayed charts and diagrams;
2- barcharts which are the main means of communications between management and site personnel should also be supported by the system;
3- the system should be capable of producing diagrams such as histograms to illustrate resource leveling, loading and aggregation; and
4- tabular reports should also be incorporated within the system to show activities status, costs and times.
5.3.4 STAGES OF THE INTEGRATED SYSTEMS

The proposed integrated system consists of three individual stages:

- the modeling phase;
- the data transfer phase; and
- the planning phase.

Figure 5.3 shows a simplified layout of the integrated model.

The modeling phase is implemented within the AutoCAD software package. The main task of this phase is to model the concrete elements, formwork components and reinforcement bars of in-situ concrete structures in the computer aided design system the way they are going to be built on site. A full description of the modeling phase and the AutoCAD package is given in the next chapter.

The data transfer phase is aimed at passing data extracted from the design and the network diagram model to the planning package for further processing. This phase of data transfer will be covered as well in the next chapter.

The last phase of the integrated system is the planning module which is implemented within the Artemis planning package. The main task of this phase is to analyse the data.
extracted from the CAD model in order to establish the project total duration and cost, besides producing the required charts such as barcharts and histograms. Chapter Seven is dedicated to the planning phase and the Artemis complete information management system.

5.3.5 THE SYSTEM REQUIREMENTS

The suggested integrated system was implemented on an IBM microcomputer machine. As integrated applications involve the coupling of many software packages, the requirements in terms of power, memory and financial aspects should not be underestimated. For the integrated construction planning application developed by the author, it has been found that a combination of the following hardware and software requirements has to be met in order to run the program efficiently. The cost and training aspects of the integrated system are covered separately in Chapter Eight.

5.3.5.1 HARDWARE REQUIREMENTS

The major hardware platforms which are required to run the micro-based integrated planning model have been compiled as below.

- IBM PS/2 MODEL 70
- COLOUR MONITOR
- 30 MB HARD DISK
- 4 MB RAM
- 80386 PROCESSOR
- 80387 MATH CO-PROCESSOR
- A3 HP 7475 SIX PEN PLOTTER
- IBM DOT MATRIX PRINTER
- IBM BUS MOUSE.

5.3.5.2 SOFTWARE REQUIREMENTS

With regards to software requirements, the following packages are involved.

- DOS 3.3
- AUTOCAD RELEASE 10
- ARTEMIS 2000 VERSION 2.30
5.3.6 BENEFITS OF THE INTEGRATED SYSTEM

The integrated construction application developed by the author of this thesis has proven that computer aided design systems can be used to manage construction projects. In the traditional environment, the gap between the design/engineering and the project management phases can lead to project failure and company bankruptcy. In such an environment, controls over drawings issuing, documentation, and design changes are not accounted for. In addition, most of the data used by managers and planners are originated from conventional drawings and documents which are not revised regularly and properly. Any changes, if not recorded, will lead to disturbances of resources, materials and scheduled activities. Consequently, the need for integrated applications can not be ignored any longer if construction projects information are to be managed efficiently.

The main benefits an integrated system can offer over a traditional one are that:

- planners are given a great deal of flexibility in selecting any set of design elements to associate them with construction activities;
- planners can visualise the building model to account for site restrictions and equipment and trade interactions;
- components or design elements are placed on the computer screen the way they are going to be built on site;
- project management information can have its origin in the electronic design model;
- quantities are automatically generated for any set of design elements. This would be error prone if implemented traditionally; and
- as in the manufacturing industry, drawings could be sent to the materials department for scheduling and ordering purposes.

To summarise, the traditional working practices of current design and contracting offices would just make the integrated system a theoretical concept rather than a reality. Current tendering/contracting procedures imply that construction planners can only use tendering drawings and documents to devise the construction master plan. This can be detrimental because of information losses and data inconsistencies and doublehandling. The integrated planning application can be looked at as a remedy to such problems. The
planning methodology would remain the same whether the system is traditional or integrated, it is the concept behind planning which should be changed if construction projects are to meet their objectives. The system implementation, problems and limitations are discussed in the following chapters.

5.4 SUMMARY

The main observations of this chapter are summarised below:

1- The traditional planning process is no more than re-initialisation of information captured within conventional drawings and documents.

2- The RIBA plan of work which is widely known in the UK implies that the different stages of the construction project are discrete. In a poor communication environment, changes at any stage may not be accounted for in another. In addition, the bill of quantity type of contract which is a norm in the UK can also be regarded as inefficient as the construction planner is brought into the process once the design is substantially complete.

3- The major steps which can be involved when creating the master plan include: programme definition, work breakdown structure, conceptual design/planning, the budget estimate, the network development phase, resource allocation, and finally the master schedule.

4- Planning at the construction phase can involve: pre-tender planning, post-tender planning and short term planning. In the traditional environment, construction planners extract most of the data relevant to their planning processes from the available documents and drawings of any of these stages. Such approach has been highlighted as inefficient and old fashioned.

5- The integrated system proposed by the author to rectify some of the problems encountered in the traditional environment has been introduced in this chapter. In this system, designers and contractors alike would have access to information available on CAD systems and relevant to their planning processes.

6- The system methodology has been stated as a sequence of the following activities: analysis, design, implementation, and maintenance and review.
7- The functional specifications of the suggested integrated system include: modeling, drafting, quantities and materials scheduling, time and cost analyses, and reporting.

8- The proposed integrated system consists of three major sub-systems namely: modeling, data transfer and planning. These sub-systems have been integrated using the AutoCAD 10 and Artemis 2000 packages with the help of a repository system (dBase IV). The developed package can be run on an IBM model 70 machine.

9- The main benefits the integrated system can offer over a traditional one include: flexibility in selecting any set of design elements by construction planners, visualisation, data consistency, automatic quantities generation and time and cost analyses.
CHAPTER SIX

THE MODELING AND DATA TRANSFER SUB-SYSTEMS OF THE INTEGRATED APPLICATION

6.1 INTRODUCTION
6.2 THE AUTOCAD DRAWING DATABASE AND AUTOLISP
6.3 THE MODELING SUB-SYSTEM
6.4 THE DATA TRANSFER SUB-SYSTEM
6.5 THE AUTOCAD PACKAGE AND THE AUTOLISP INTERPRETER
6.6 SUMMARY
6.1 INTRODUCTION

The previous chapter introduced the general architecture of the integrated construction planning system developed by the author and its major components. In this chapter, the overall system is presented in greater detail (Figure 6.1) in order to illustrate the different sub-systems used to design the integrated model. The modeling and data transfer sub-systems are also fully discussed. The different pull down menus developed to assist the user at the modeling stage are also described. In addition, a thorough explanation of the major AutoCAD commands and Autolisp functions are included. The planning phase is covered in a separate chapter.

This chapter demonstrates that computer aided design (CAD) systems are not the preserve of designers, but they can also be used by construction planners who are keen on facilitating and modernising the construction planning process by using computer graphics. The AutoCAD package was chosen to achieve this task as it is widely known and considered as the industry standard on microcomputers. In addition, this package has met most of the selection criteria specified in Chapter Three under the micro-CAD evaluation section. The Autolisp interpreter incorporated within the AutoCAD package was particularly useful when developing the prototypical software to aid the planning of the concreting, steel fixing and formwork activities associated with in-situ concrete design elements (see Figure 6.2).
Figure 6.1 The CAD-based integrated planning model.
6.2 THE AUTOCAD DRAWING DATABASE AND AUTOLISP

Jones et al define a drawing database file as a set of records of alphanumeric description called drawing primitives (Ref 6.9). The ability to look at this drawing database is a major feature in assessing the suitability of a particular CAD program as data can only be extracted if an access to such database is provided within the system. AutoCAD supports such facility and further data manipulation can be achieved. Autolisp takes each AutoCAD drawing database record and formats it into an association list. This association list is not the actual AutoCAD drawing database which is stored in binary format and proprietary (Ref 6.3 & 6.9). However, the actual database is structured similarly to those file formats. Some figures are cited in Table 6.1 below, on the coding of the major AutoCAD drawing primitives found in association lists.

<table>
<thead>
<tr>
<th>CODE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Entity type</td>
</tr>
<tr>
<td>-1</td>
<td>Entity name (unique index)</td>
</tr>
<tr>
<td>1</td>
<td>Primary text value</td>
</tr>
<tr>
<td>2</td>
<td>Name: shape, block, tag</td>
</tr>
<tr>
<td>8</td>
<td>Layer name</td>
</tr>
<tr>
<td>10</td>
<td>Start of insertion point</td>
</tr>
<tr>
<td>11</td>
<td>End of insertion point</td>
</tr>
<tr>
<td>66</td>
<td>Entities follow flag (attributes)</td>
</tr>
</tbody>
</table>

Table 6.1 A sample of codes used within AutoCAD association lists
An example of an association list is shown below (extracted from one of the program listing) to illustrate the structure of the drawing data stored within the AutoCAD drawing database:

```
(-1 . <Entity name: 60000048>) ;Unique ID number
(0 . "INSERT") ;Entity type
(8 . "0") ;Layer name
(66 . 1) ;Attributes follow flag
(2 . "grec") ;Name of block
(----) (----) ;Additional lists
)

(-1 . <Entity name: 60000060>)
(0 . "ATTRIB")
(8 . "0")
(10 . coordinates) ;Insertion point for text
(40 . 400) ;Text height
(1 . "5") ;Attribute value
(2 . "LENGTH") ;Attribute tag
(----) (----) ;Additional lists
```

These association lists can be addressed by Autolisp routines. For instance, a symbol with specific attributes can be inserted into a drawing, these data can then be extracted from the database for further processing using an Autolisp program. Such a strategy has been adopted in order to develop the integrated construction planning application. In the above example, the geometrical attribute "LENGTH" can be extracted in order to establish quantities such as volumes, areas, etc.

6.3 THE MODELING SUB-SYSTEM

This sub-system models the different reinforced concrete elements such as beams, columns, foundations, slabs and walls found in a typical modular building. These elements are presented as symbols coupled with attributes relevant to the planning process. These elements are used to generate concreting, steel fixing and formwork activities based on realistic data stored within the CAD model. This sub-system is described in great in the next section.
6.3.1 STAGES OF THE MODELING SUB-SYSTEM

As the main task of the modeling phase is to simulate the construction sequence of in-situ concrete elements on the computer screen and associate them with construction activities, the following tasks are required.

1- The on screen modeling task.
2- The global input module(files, gang sizes).
3- The selection set (grouping of design elements).
4- The duration estimation module.
5- The network diagram modeling.
6- The outputs of the modeling sub-system.

These various tasks are now described:

6.3.1.1 THE ON SCREEN MODELING TASK

This facility was designed to enable the construction planner to place his/her design components on the computer screen the way they are intended to be built on site. A new pull down menu with the heading MODEL is assigned to give the user greater flexibility in assembling the components of an in-situ concrete structure. A help facility is also provided to explain this task in greater detail. The layering option found in the same pull down menu can also be used to place different design elements on various levels or layers. Such an approach gives the construction planner more power in classifying these design elements and relating them to a recognised layering standard. The BS 1192 part 5 is now available and gives some guidelines on the use of layers within the construction industry to facilitate the data transfer between the different disciplines involved in the construction process (Ref 6.6). However, the prototypical package does not follow any standard and the user can decide on how to manage his/her information accordingly. As an example, the following steps can be followed if applicable to the project in hand:

1- Establish grid lines on a layer say "Grid".
2- Insert foundation layouts on layer say "Found".
3- Insert foundation formwork components if any on layer say "Found_form".
4- Insert foundation reinforcements on layer say "Found_reinf".
5- Insert additional information (text, dimensions, specifications, rules) on layer say "Found_add".
6- Repeat sequence.

It is worth mentioning at this stage that some CAD systems do not allow text coding to be associated with layer names, and others have limitations on the number of layers which can be defined (Ref 6.10). These systems should be avoided if a comprehensive layering system is to be established. In the integrated application, a facility was provided for automatic switching between the different layers. The user is prompted to select any layer while running the application. Such an approach is considered as time saving as there is no need to flip between the various drawings and documents.

As the main aim of this modeling task is to produce electronic models of the structure and its construction activities, a library of symbols was produced in order to simplify such task. However, as the developed application is highly experimental, there was no intention at any level to create a complete library of symbols to model in-situ concrete elements. For instance, only rectangular and square shapes, straight bars and stirrups were used to experiment with the model. The concept has proven to be working, but further enhancements are needed to make the package commercially viable.

**The MODEL pull down menu**

The first pull down menu on the far right of the AutoCAD screen has been used to incorporate the different facilities required to implement the modeling phase. Figure 6.3 shows the architecture of the MODEL pull down menu and its associated sub-menus. The different options available within these menus are described.
The HELP option

In order to make the software user friendly, help facilities are provided to facilitate the interaction between the user and the machine. Under this option, a full explanation of the modeling phase can be found. In addition, the various concreting, steel fixing and formwork methods supported by the package are listed. The switching facility between text and graphics screens incorporated within the AutoCAD package has been exploited to include textual information which can simplify the complex task of developing a CAD model.

The LAYER option

This facility was incorporated within the package to give the user the power to define any number of layers which can be used to keep various design elements at different levels. Also, additional layers can be defined by the construction planner to keep track of the locations of the equipment, material, and any other resources found on a construction site. In addition, specific layers can be frozen to allow for better visualisation and for plotting purposes.
The REINFORCEMENT option

This option is used to facilitate the placement of either reinforcement bars or stirrups within concrete boundaries. Figure 6.4 shows an example of the different attributes associated with these symbols (Ref 6.1 & 6.5):

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>SOFTWARE PROMPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>What is the member id?</td>
</tr>
<tr>
<td>LENGTH</td>
<td>What is the bar length in m?</td>
</tr>
<tr>
<td>DIAMETER</td>
<td>What is the bar diameter in mm?</td>
</tr>
<tr>
<td>MARK</td>
<td>What is the bar mark?</td>
</tr>
<tr>
<td>NUMBER(BARS)</td>
<td>What is the number of bars?</td>
</tr>
<tr>
<td>TYPE</td>
<td>What is the bar type (T,R)?</td>
</tr>
<tr>
<td>COVER</td>
<td>What is the concrete cover in mm?</td>
</tr>
</tbody>
</table>

Figure 6.4 The reinforcement attributes

The CONCRETE LAYOUT option

Under this option, the construction planner is given the power to model the concrete layouts of the various design elements of the project on the computer screen. However, only rectangular or square shapes are supported at present, but the same strategy can be adopted in producing circular or any other shapes of sections. The major attributes associated with these elements are presented in Figure 6.5. These attributes are important to the planning of the construction of in-situ concrete structures. For instance, the geometrical properties can be used to generate quantities such as volumes, areas, and when associated with output rates durations can also be calculated.
Figure 6.5 The concrete layout attributes

The identification of the design elements can be defined according to the type of section (c for columns, b for beams, s for slabs, w for walls, and f for foundations), the grid position and the vertical location of the element. For example, a column along the two grid lines B and 1 and in the first floor would be C1B1 (Figure 6.6).

Figure 6.6 The identification of design elements

Such an approach to identify design elements has been adopted in order to limit the number of attributes associated with these graphical elements and thus the processing power and speed was improved. A better strategy would have been to define classes, locations, etc, but this would have slowed down the system operations.
The NETWORK option

This option allows the user (construction planner) to place construction activities in the network diagram kept on a defined layer. Such a facility is mainly used to place activities such as ordering steel, curing concrete, clearing, etc, which are not specifically associated with design elements. In the developed package, most activities are modeled internally within the program. The user is prompted to place concreting, steel fixing or formwork activities related to a certain set of design elements. The following attributes (Figure 6.7) have been assigned to the network activity symbol. These attributes are explained in the next chapter covering the planning sub-system.

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>SOFTWARE PROMPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preceding event</td>
<td>What is the preceding event?</td>
</tr>
<tr>
<td>Succeeding event</td>
<td>What is the succeeding event?</td>
</tr>
<tr>
<td>Activity duration</td>
<td>What duration in days?</td>
</tr>
<tr>
<td>Gang size</td>
<td>what is the gang size?</td>
</tr>
<tr>
<td>Activity description</td>
<td>Describe your activity?</td>
</tr>
<tr>
<td>Activity code</td>
<td>Code your activity according to design element</td>
</tr>
<tr>
<td>Activity type</td>
<td>What type of activity (start, finish, )?</td>
</tr>
<tr>
<td>Activity lead</td>
<td>What lead in days?</td>
</tr>
<tr>
<td>Activity lag</td>
<td>What lag in days?</td>
</tr>
<tr>
<td>Work pattern</td>
<td>What work pattern?</td>
</tr>
</tbody>
</table>

Figure 6.7 The network attributes

The dummy, event, arrow, and drawing aid symbols have also been incorporated under this option in order to define the network logic and to facilitate the task of generating the complete network diagram.

6.3.1.2 THE GLOBAL INPUT MODULE

Once the design elements of the various layers have been defined, the user can now interact with the electronic model using the COMPUTE pull down menu. At this stage, he/she can decide on global factors such as file names, time estimating databases, gang sizes, pay per hours, etc using the COMPUTE/GLOBAL (menu/sub-menu) option. Most of the data inputs of this module are provided with default values to ensure a user...
friendly interface. In addition, errors are traced and detected automatically within the program. For instance, an input of 4.5 for a gang size will be rejected as an integer is required. Figure 6.8 shows the input prompts of the global module.

![Image](image.png)

**Figure 6.8 The input prompt of the global module**

### 6.3.1.3 THE SELECTION SET (GROUPING OF DESIGN ELEMENTS)

A selection set is defined in this research as a highlighted group of graphical objects (known as design elements), very often with the help of an electronic device (digitizer). In real life projects, design elements can belong to any combination of objects. In the integrated model, users have been given access to the CAD model which allow them greater flexibility in selecting any group of design elements. Quantities associated with the design elements are automatically generated within the system. The user can highlight the option Select Option of the COMPUTE pull down menu to select the required elements.

When compared with the traditional methods of planning, the new approach should be more reliable, less error prone and more efficient as access to the design model is provided within the system. The concept of selecting design sets can change the course of construction planning practices as for the first time accurate quantities can be associated with construction activities related to design elements. This can not be achieved in traditional approaches as quantities are associated with classes of work.
rather than real project activities. Furthermore, construction planners would be given a powerful tool to optimise the generation of network diagrams because of the greater flexibility they have in selecting any set of design elements, besides the ability to adjust any parameter associated with these elements. For instance, the user can change the geometrical attributes, gang sizes, pour type, etc to see how certain decisions influence the completion time of the project. Figure 6.9 shows two examples of selection sets (windowing and individual highlighting).

![Figure 6.9 The highlighting of design elements](image)

### 6.3.1.4 THE DURATION ESTIMATION MODULE

Once a set of design elements has been highlighted by the construction planner, the next task is to work out the durations of the various activities associated with these design elements according to the user requirements (concreting, steel fixing or formwork activities). Chapter two indicated that most UK and US top contractors rely on their experience to estimate output rates for different construction operations. This can be implicitly incorporated within the package as the user is given access to the electronic network model whereby the durations attribute can be modified based on the planner judgement. However, in this research, it was thought that the incorporation of two more sources of data for output rates would give the construction planner more opportunities to arrive at realistic figures. The first source is based on a work study database developed at Loughborough University by Price et al (Ref 6.11 - 6.14). Figure 6.10 shows a sample of the different basic times and site factors required for concreting and formwork activities of in-situ concrete elements stored within the
Autolisp program as mathematical equations developed from tabular data using the Cricket Graph package.

<table>
<thead>
<tr>
<th>Basic operation times for concreting slabs using pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT = (60.7 + 7.36V + 4.57A) x 1.0775</td>
</tr>
<tr>
<td>BT = Basic time in minutes; V = volume in m; A = area in m²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Basic operation times for large wall shutters with no stop ends</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT = (9.7A + 4.83H + 13.1L) x 1.31</td>
</tr>
<tr>
<td>BT = Basic time in minutes; H = height in m²; L = length in m³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site factor = FT = 0.863 + 7.88/P²</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = level of pay (£/hour);</td>
</tr>
<tr>
<td>(P depends upon base year)</td>
</tr>
</tbody>
</table>

**Figure 6.10 A sample of basic time calculations**

This work study database was tested statistically and was proven to be sound and reliable. A good correlation was obtained between the predicted and the actual rates. Another major feature of this database is the development of site factors to account for any lost time on construction sites. These site factors were found to be a function of pay per hour (Ref 6.11). In the developed package, these site factors have also been associated with basic times to arrive at more reliable planning times (See Figure 6.11). A detailed picture of the different design elements, types of pour, formwork, and reinforcement supported by the work study database is shown in Figure 6.12.
Figure 6.11 Duration calculations using the work study database

The second source of data to estimate output rates for concreting, steel fixing and formwork activities of the different concrete elements found in an in-situ structure (foundations, slabs, beams, columns, walls) was a company database extracted from the Wessex and Spon price books (Ref 6.7 & 6.15). An Autolisp program was specifically written to store these data in text files which can be read according to the user requirements. For instance, slabs are indexed in the concreting file by their depths, whereas columns are indexed by cross sectional area. A facility is also provided within this module to allow the user to store values which do not exist in a specific file.
<table>
<thead>
<tr>
<th>DESIGN ELEMENT</th>
<th>CONCRETING METHOD</th>
<th>STEELFIXING METHOD</th>
<th>FORMWORK METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAB</td>
<td>METHOD 1 USING SKIP AND CRANE</td>
<td>METHOD 1 IN-SITU</td>
<td>METHOD 1 FLOOR SLAB WITH KICKER</td>
</tr>
<tr>
<td></td>
<td>METHOD 2 USING PUMP</td>
<td>METHOD 2 PREFABRICATED</td>
<td>METHOD 2 TRADITIONAL DESIGN SYSTEM</td>
</tr>
<tr>
<td></td>
<td>METHOD 3 USING DIRECT POUR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEAM</td>
<td>METHOD 1 USING SKIP AND CRANE</td>
<td>METHOD 1 IN-SITU</td>
<td>METHOD 1 INTERNAL BEAM SHUTTERS</td>
</tr>
<tr>
<td></td>
<td>METHOD 2 USING PUMP</td>
<td>METHOD 2 PREFABRICATED</td>
<td>METHOD 2 EXTERNAL BEAM SHUTTERS</td>
</tr>
<tr>
<td></td>
<td>METHOD 3 USING DIRECT POUR</td>
<td></td>
<td>METHOD 3 STEEL PANEL SHUTTERS TO GROUND BEAMS</td>
</tr>
<tr>
<td>COLUMN</td>
<td>METHOD 1 USING SKIP AND CRANE</td>
<td>METHOD 1 IN-SITU</td>
<td>METHOD 1 COLUMNS WITH EXTERNAL CLAMPS</td>
</tr>
<tr>
<td></td>
<td>METHOD 2 USING PUMP</td>
<td>METHOD 2 PREFABRICATED</td>
<td>METHOD 2 COLUMNS WITH STEEL STRONGBACK SOLDIERS</td>
</tr>
<tr>
<td></td>
<td>METHOD 3 USING DIRECT POUR</td>
<td></td>
<td>METHOD 3 LONG PLASTIC COLLAR SHUTTERS</td>
</tr>
<tr>
<td>WALL</td>
<td>METHOD 1 USING SKIP AND CRANE</td>
<td>METHOD 1 IN-SITU</td>
<td>METHOD 1 LARGE WALL SHUTTERS WITH TWO STOP ENDS</td>
</tr>
<tr>
<td></td>
<td>METHOD 2 USING PUMP</td>
<td>METHOD 2 PREFABRICATED</td>
<td>METHOD 2 LARGE WALL SHUTTERS WITH NO STOP ENDS</td>
</tr>
<tr>
<td></td>
<td>METHOD 3 USING DIRECT POUR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOUNDATION</td>
<td>METHOD 1 USING SKIP AND CRANE</td>
<td>METHOD 1 IN-SITU</td>
<td>METHOD 1 &lt; 300 MM BELOW GROUND WITH BOLTS</td>
</tr>
<tr>
<td></td>
<td>METHOD 2 USING PUMP</td>
<td>METHOD 2 PREFABRICATED</td>
<td>METHOD 2 &gt; 300 MM BELOW GROUND WITH NO BOLTS</td>
</tr>
<tr>
<td></td>
<td>METHOD 3 USING DIRECT POUR</td>
<td></td>
<td>METHOD 3 ABOVE GROUND WITH BOLTS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>METHOD 4 ABOVE GROUND WITH NO BOLTS</td>
</tr>
</tbody>
</table>

Figure 6.12 The detailed work study database
Once the output rates of the different operations has been established and the crews (gang sizes) are assigned, activities durations in days can be calculated. Figure 6.13 illustrates the different stages of this task. A detailed picture of the company database with all the supported elements is presented in Figure 6.14.

![Diagram](image)

**Figure 6.13 Duration calculations using the Company database**

### 6.3.1.5 THE NETWORK DIAGRAM MODELING

A network diagram can be regarded as a graphical representation of the different activities of a project defined and sequenced. The network diagram was considered as an essential and powerful tool with which construction planners can depend upon in order to complete projects on time, within cost and to the required quality. The tedious and time consuming task of network diagram creation was automated within the developed package using the AutoCAD’s drafting facilities. Activities, dummies, events, arrows and drawing aids were stored as graphical symbols which can be inserted by the user at a defined layer when needed. The MODEL/NETWORK (menu/sub-menu) can be used to place activities not associated with design elements.
<table>
<thead>
<tr>
<th>FOUNDATION</th>
<th>CONCRETING</th>
<th>STEELFIXING</th>
<th>FORMWORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONCFOUN.DTA</td>
<td>REINBARS.DTA</td>
<td>REINF.STR.DTA</td>
<td>FORMFOUN.DTA</td>
</tr>
<tr>
<td></td>
<td>(Bare)</td>
<td>(Stirrup)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>CONC.PLAN.DTA</th>
<th>REINBARS.DTA</th>
<th>REINF.STR.DTA</th>
<th>FORMColum.DTA</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>BEAM</th>
<th>CONC.BEAM.DTA</th>
<th>REINBARS.DTA</th>
<th>REINF.STR.DTA</th>
<th>FORM.BESO.DTA</th>
<th>FORM.BESI.DTA</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>SLAB</th>
<th>CONC.SLAB.DTA</th>
<th>REINBARS.DTA</th>
<th>FORM.SLAB.DTA</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>WALL</th>
<th>CONC.WALL.DTA</th>
<th>REINBARS.DTA</th>
<th>FORM.WALL.DTA</th>
</tr>
</thead>
</table>

Figure 6.14: The detailed company database

CONCFOUN.DTA = A data file to store planning times values for concreting foundations
In order to make this module more efficient, a facility to generate the network diagram while selecting design elements was provided. Such facility allows the modeling of the network diagram in based on the information stored in the design model. The COMPUTE pull down menu of the developed model can be used to achieve such task.

The main advantage of this technique over the traditional method is that, the network diagram generation phase is done in parallel with the simulation process of the building model. For instance, the network diagram grows in terms of activities and events each time a physical component of the design model is placed in the database. In addition, the network diagram model is now in its electronic format which can be transferred to a computerised project planning application for further processing (time analysis).

Furthermore, as construction activities are associated now with design elements and global factors such as gang sizes, any changes or updates to these elements would affect activities durations. Such changes which would go unnoticed in a traditional system are now recorded automatically within the network diagram model. For example, if at a certain stage of the project any geometrical attributes such as length, width or thickness, pour type or gang sizes are changed, then the user can use the COMPUTE/UPDATE option of the developed package in order to automatically replace the durations and gang size attributes related to these factors with new values. This automatic association between activities and design elements is a new concept and can be regarded as a major breakthrough, but this can only be achieved if the CAD system is the starting point for construction planners.

6.3.1.6 THE OUTPUTS OF THE MODELING SUB-SYSTEM

The main output files generated at the modeling phase have been compiled and presented below.

- The network diagram model (drawing file).
- The 2D- 21/2D building model (drawing file).
- The activities data file (text file).
- The concreting file (text file).
- The steel fixing file (text file).
- The formwork file (text file).

The network diagram and the building models drawing files are produced to ease the construction planner's task of controlling the project activities and to provide better
facilities in order to visualise the structure to be built which can help to eliminate most of the trade/equipment interactions.

The activities data file is a mere translation of the network diagram model into an ASCII file which can be transferred to the planning package for time analysis. The data transfer sub-system explains such process in greater details.

Finally, the concreting, steel fixing and formwork data files are produced in two data formats: comma delimited formats (CDF) files which are passed to Artemis for cost analysis, and well presented tabular data with headings for reporting purposes. Figure 6.15 shows a sample of the output of the modeling sub-system. The case study presented in Appendix C includes most of the output files of the modeling sub-system.

<table>
<thead>
<tr>
<th>Id</th>
<th>area</th>
<th>duration</th>
<th>pay-per</th>
<th>gang</th>
<th>form</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m2</td>
<td>hrs</td>
<td>hour</td>
<td>size</td>
<td>type</td>
</tr>
<tr>
<td>f2b</td>
<td>9.00</td>
<td>1.13</td>
<td>4.00</td>
<td>3</td>
<td>below_bolt</td>
</tr>
<tr>
<td>f1b</td>
<td>9.00</td>
<td>1.13</td>
<td>4.00</td>
<td>3</td>
<td>below_bolt</td>
</tr>
<tr>
<td>f2a</td>
<td>9.00</td>
<td>1.13</td>
<td>4.00</td>
<td>3</td>
<td>below_bolt</td>
</tr>
<tr>
<td>f1a</td>
<td>9.00</td>
<td>1.13</td>
<td>4.00</td>
<td>3</td>
<td>below_bolt</td>
</tr>
<tr>
<td>bgr_2</td>
<td>2.50</td>
<td>1.83</td>
<td>4.00</td>
<td>3</td>
<td>steel_ground</td>
</tr>
<tr>
<td>bgr_a</td>
<td>2.50</td>
<td>1.83</td>
<td>4.00</td>
<td>3</td>
<td>steel_ground</td>
</tr>
<tr>
<td>bgr_1</td>
<td>2.50</td>
<td>1.83</td>
<td>4.00</td>
<td>3</td>
<td>steel_ground</td>
</tr>
<tr>
<td>bgr_b</td>
<td>2.50</td>
<td>1.83</td>
<td>4.00</td>
<td>3</td>
<td>steel_ground</td>
</tr>
<tr>
<td>c2b</td>
<td>1.00</td>
<td>3.39</td>
<td>4.00</td>
<td>3</td>
<td>clamp</td>
</tr>
<tr>
<td>c2a</td>
<td>1.00</td>
<td>3.39</td>
<td>4.00</td>
<td>3</td>
<td>clamp</td>
</tr>
<tr>
<td>c1b</td>
<td>1.00</td>
<td>3.39</td>
<td>4.00</td>
<td>3</td>
<td>clamp</td>
</tr>
<tr>
<td>c1a</td>
<td>1.00</td>
<td>3.39</td>
<td>4.00</td>
<td>3</td>
<td>clamp</td>
</tr>
<tr>
<td>slab</td>
<td>100.00</td>
<td>9.41</td>
<td>4.00</td>
<td>3</td>
<td>traditional_deck</td>
</tr>
</tbody>
</table>

Figure 6.15 A sample of outputs of the modeling sub-system

6.3.2 HOW THE SYSTEM WORKS

The flow chart shown in Figure 6.16 illustrates the different operations of the modeling sub-system, these include:
- the modeling of in-situ concrete elements and their associated construction activities;

- error tracing. For instance, a value of 2.5 for a gang size will be rejected;

- checking that requirements (pour type, type of database, etc..) are properly met;

- checking that every design element is not analysed more than once. For instance, if a design element is selected for the second time, then the program will display a warning message; and

- the automatic generation of quantities, (volumes, areas, weights of reinforcement, durations of activities.)
Figure 6.16 The different operations of the modelling sub-system
6.3.3 THE MAIN ACHIEVEMENTS OF THE MODELING SUB-SYSTEM

The main achievements of the modeling sub-system are summarised and presented below.

1- The user can model design elements and their associated activities on the computer screen. Pull down menus and help facilities are provided to facilitate such task and to improve the interaction between the construction planner and the processing machine.

2- In-situ concrete elements can be modeled in 3D. In this environment, the construction planner can view the design model from any direction or orientation which would produce a clear picture of the project in hand. In addition, enlarged copies of specific design elements can be produced using the zooming facility provided within most CAD systems which can simplify the installation task of components on site.

3- Quantities such as volumes, areas, and durations are automatically generated within the system.

4- Activity durations calculated within the system are based on two sorts of databases: a work study database and a company database extracted from the Wessex and Spon price books. This gives the construction planner more choices in assessing the output rates of the different operations, in addition to past experience.

5- The network diagram is produced in its electronic format to facilitate the data transfer phase to the planning package. Such automation of network diagrams can be considered as a major breakthrough.

6- Colour coding can be used for presentation and reporting purposes. For instance, dummy activities are displayed in red in the network diagram model and ordinary activities in blue.

7- A facility is provided within this sub-system to allow for automatic switching between the various layers used to store design elements. The construction planner can also use the layering option to design additional layers to keep track of equipment found on a particular site.

8- Any change in the design model is automatically accounted for in the electronic network diagram model. For instance, activity durations are directly updated once any of the parameters associated with design elements are modified.
9- The modeled elements can be used to store data based on actual performance and compare them with estimated data.

10- Data doublehandling is kept to a minimum as planning data are generated within the CAD model.

11- Textual information can be added to any drawing at any specified location. These information might include specifications, rules, etc.

12- The design model can be assembled by the project team, simulating the sequence of construction activities as they are to be conducted on site.

6.3.4 THE MAIN LIMITATIONS OF THE MODELING SUB-SYSTEM

At present, the modeling sub-system faces the following limitations.

1- The system can currently deal with concreting, steel fixing, and formwork activities associated with in-situ concrete elements. However, future developments are required to enhance this sub-system by incorporating additional activities such as excavation, backfilling, etc. This would require future additional intelligent Autolisp programs to be written to enable the recognition of elements of work. For instance, to construct an element such as a footing, activities such as excavation, concreting, steel fixing, formwork, concrete curing and backfilling should be intelligently generated within the system, whereas if the element to be constructed is a roof slab then the program should be able to detect that excavation and backfilling activities are not needed.

2- The formwork activity has been associated with that of concreting in order to simplify the task of producing symbols. However, a better strategy would have been to store an additional library of formwork symbols which can be inserted at specifically designed layers.

3- Only rectangular/square shapes of concrete elements can be defined within the CAD model. However, the same approach could be adopted to define circular on any shaped elements.
4- Only straight bars and stirrups are recognised by the model. A complete library of reinforcement elements following BS 4466 has to be defined (Ref 6.5).

5- The construction planner has to decide on the priorities and logic of activities to be placed within the network diagram as the model is not linked to an expert system.

6.4 THE DATA TRANSFER SUB-SYSTEM

The development of an integrated system will only be successful if data can be freely passed between the involved applications being used. Unfortunately, a recognised standard format for data exchanges does not currently exist. However, the availability of good computer programs such as dBase IV which can support a large number of data formats can be regarded as a means of providing a temporary solution. In the developed package, dBase IV is used as a repository system of the comma delimited format (CDF) data generated within AutoCAD. These data are translated by this package into DIF (data interchange format) files for further uses within the Artemis package. The different tasks involved within the data transfer sub-system are shown in Figure 6.17.

A dBase IV program was written to automate the task of data transfer between AutoCAD and Artemis (Ref 6.2). The different facilities supported by this program are shown in Figure 6.18.
Figure 6.18 The different facilities supported by the data transfer menu

6.4.1 THE EXTRACTION OF DATA FROM AUTOCAD DRAWINGS

AutoCAD currently supports three methods of extracting attribute text from a drawing file and formatting it into a disk file, i.e., CDF (comma delimited format), SDF (space delimited format), or DXF (drawing exchange format). DXF is normally used to transfer drawings between the different CAD systems. The SDF and CDF are ASCII files that can be read by many standard software packages such as dBase and Lotus 123. In this research, data in its CDF format is generated within the program to facilitate its transfer into dBase. However, for text data to be extracted from a drawing file, it is required to create a template file which defines the different attributes found in a drawing and their associated widths. The process of creating a template file was found to be of great importance to the successful extraction of data. An Autolisp routine was written to automate this task. For example, the user can interact with the pull down menu Extract/Template and as a result, a template file will be generated. Figure 6.19 shows a typical template file for the activities attributes of a network diagram produced within AutoCAD.
<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Attribute Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1pe</td>
<td>C004000</td>
<td>(preceding event)</td>
</tr>
<tr>
<td>G1se</td>
<td>C004000</td>
<td>(succeeding event)</td>
</tr>
<tr>
<td>G1du</td>
<td>N003000</td>
<td>(duration)</td>
</tr>
<tr>
<td>G1le</td>
<td>N003000</td>
<td>(lead)</td>
</tr>
<tr>
<td>G1la</td>
<td>N003000</td>
<td>(lag)</td>
</tr>
<tr>
<td>G1wp</td>
<td>C003000</td>
<td>(work pattern)</td>
</tr>
<tr>
<td>G1de</td>
<td>C020000</td>
<td>(description)</td>
</tr>
<tr>
<td>G1ty</td>
<td>C008000</td>
<td>(type)</td>
</tr>
<tr>
<td>G1re</td>
<td>C004000</td>
<td>(resource)</td>
</tr>
<tr>
<td>G1co</td>
<td>C024000</td>
<td>(code)</td>
</tr>
</tbody>
</table>

**Figure 6.19 A sample of the template file**

As shown above, the left hand column defines the attribute tags, the second column the format by which the data should be extracted. The field name can be any length; the next non blank character must be "C" or "N" denoting a character or a numeric field. The next three digits are the field width in characters. The last figures are those for the number of decimals places of a numeric field (Ref 6.8 & 6.3).

Once the template file is created, the second step is to extract data from the drawing model according to the template file arrangement. This step has also been automated in the developed package through the use of the pull down menu 'Extract/Attributes Extract'. The different steps required to extract data from an AutoCAD drawing has been summarised as shown in Figure 6.20.

![Diagram showing the different steps required to extract data from AutoCAD drawings](image)

**Figure 6.20 The different steps required to extract data from AutoCAD drawings**
6.4.2 A SUMMARY OF THE DIFFERENT STEPS REQUIRED TO RUN THE DATA TRANSFER MODULE.

The data transfer phase can be easily implemented using the following steps.

1- Specify a template file to define the order of the data extraction using the option Extract/Template of the pull down menu headed with EXTRACT.
2- Extract the relevant attributes using the option Extract Attributes of the same pull down menu. The type of output file should be specified at this stage as either CDF or SDF.
3- Use the AutoCAD’s Shell command to have access to the DOS disk operating system, then copy the output file to the dBase directory.
4- Exit the AutoCAD program using the End option.
5- Run the dBase program by typing : dbase,
6- Design the structure of your database program according to the data extracted from the AutoCAD drawing file.
7- Exit to the dot prompt.
8- Run the program specifically designed to transfer data between dBase and AutoCAD by typing: do acaddb4.
9- Transfer the data from the CDF file into the database file, then format these data into DIF records.
10- Exit the dBase program.
11- Rename the DIF file produced within dBase IV into a file with an extension .ART and copy it into the Artemis directory.

The transfer of data between dBase IV and Artemis is explained in the next chapter.

6.4.3 THE MAIN ACHIEVEMENTS AND LIMITATIONS OF THE DATA TRANSFER SUB-SYSTEM.

The main achievements and limitations of the data transfer sub-system of the integrated application have been summarised and here presented:

1- Data can be freely passed between three of the most powerful micro-based packages, namely AutoCAD, dBase and Artemis. This free flow of information can be considered as a major step towards the establishment of efficient integrated systems within the microcomputer environment.
2- The generally complex phase of data transfer has been made easy through the use of pull down and pop up menus, and help facilities. The user is only required to interact with these facilities in order to achieve such task.

3- The main limitation of this phase is that dBase IV was merely used to act as a communication mean between the CAD and the planning packages. However, researchers and practitioners of this field alike can write their own programs (in Basic, Fortran, Pascal) to translate CDF or SDF files into their DIF format instead of using a repository system. Appendix C contains information on the DIF format (ASCII file).

6.5 THE AUTOCAD PACKAGE AND THE AUTOLISP INTERPRETER

The AutoCAD package is the most widely known micro-based computer aided design system, with more than 350,000 copies of this software sold worldwide. This package comes with a large number of commands and features, in addition to the Autolisp interpreter which supports hundreds of functions. This research puts great emphasis on the use of information technology, particularly that of computer aided design within the construction industry. Therefore, the major aspects of the AutoCAD package were included in this chapter rather than in one of the appendices to help future developers and newcomers to this area assess these features instead of undertaking a complete exploration of the package which could take months if not years. These major facilities which were found to be of great significance to this research have been compiled and are presented.

6.5.1 THE AUTOCAD PACKAGE

Below is a summary of the functions of the most important AutoCAD's features used during the modeling and data transfer sub-systems of the integrated application arranged in alphabetical order (Ref 6.3 - 6.4).

1- Acad.mnu: the AutoCAD menu file was used to produce the different pull down menus required to design the application's user interface. Appendix D shows a listing of one of the pull down menus incorporated within the Acad.mnu file.

2- Acad.pgp: this is an ASCII text file which can be used to describe a program that can be executed from within AutoCAD if the memory reserve is enough. This facility has been exploited to store the Wordstar word processing program which was used to write the Autolisp code instead of using the Edlin program supported by AutoCAD. Each line in Acad.pgp has five fields delimited by comma: Command name, Command file, Memory reserve, Prompt, Return code. After a long process of trial and error it was found that the
following line can be used to store the Wordstar package within AutoCAD:
ws,ws,127000,,0. During experimentation with this file, it was found that Lotus 123
could be run from within AutoCAD, but not dBase III or dBase IV programs.

3- Arc, line, pline, text, dimensions: the main drawing entities which were used to produce
the graphical features of the symbols stored within the package.

4- Attdif: this command is used to create an attribute definition for textual information to be
associated with a block definition. This command was extensively used to produce a library
of symbols containing information relevant to the planning process. An example is shown
below to illustrate how this command can be applied for an attribute called "length":

   Command: Attdif
   Attribute tag: Length
   Attribute prompt: What is the length in M?
   Attribute default: 5.

5- Attdis: this is used to set the visibility of attributes values (visible or invisible)

6- Attdifit: this command allows the user to edit attributes values

7- Attdet: this command is used to extract attributes values from a drawing

8- Block: this command allows the user to form a compound object from a group of
entities. For instance, the attributes produced by Attdif can be associated with graphical
elements (lines, rectangles, etc) and blocked as one object which can be inserted as many
times as required.

9- Elev: it is mainly used for 3D visualisation. It sets elevation and extrusion thickness to
objects.

10- End: the end command allows the user to exit and save the updated drawing.

11- Insert: this command is used to insert a block/symbol into the current drawing

12- Layer: in some CAD systems, layers are known as levels. This command is used to
issue an unlimited number of layers to keep various design elements. The user can also
freeze or thaw any specified layer.

12- Pan: this command is used to see details which are off screen.

13- Plot: this command enables the user to plot an AutoCAD drawing on either a pen plotter
or a printer with graphics capabilities.

14- Setup: This is the first command to be selected when starting a new AutoCAD drawing.
It is mainly used to define the scale and boundaries of a drawing.

15- Shell: this command gives the user access to the DOS disk operating system
commands.

16- Ucs: this command is used to define a new user coordinate system. Such facility gives
the user more flexibility in assembling components and placing symbols in any direction.

17- Units: this allows the user to select coordinate and angle formats.

18- Vpoint: this command enables the user to select the view point for 3D visualisation.
19- Zoom: this is mainly used to increase or decrease the apparent size of items the user is viewing.

6.5.2 THE AUTOLISP INTERPRETER

The incorporation of the Autolisp interpreter within the AutoCAD package has allowed thousands of software developers and programmers to write third party or add-on packages. In this research, the main programming code was written in the Autolisp language to customise AutoCAD for the benefits of construction planners. The different data types and functions supported by the Autolisp interpreter can be found in reference 6.4 and in Chapter Three of this thesis. This section only deals with some of the major Autolisp functions which proved to be of extreme significance to the programming phase of the developed application. These major functions are summarised and explained below.

1- Ssget: this function returns a selection set if called with no arguments, it generally asks the user to highlight a general entity selection.
2- Sslen: this function is used to return the number of elements in a selection set.
3- Ssname: the entity name of the indexed element of the selection set is returned using this function.
4- Entnext: this function returns the name of the first entity in the drawing database when called with no arguments. However, if called with an argument, it then returns the first entity name of the following the entity name argument.
5- Entget: this is used to retrieve the called entity name as an Autolisp association list from which the user can extract items using the Assoc function.
6- Entmod: this function updates the specified entity of the AutoCAD database.
7- Entup: this function enables the user to update a modified block on the screen. This function coupled with the previous one, has allowed the author to write an Autolisp routine which can update the network diagram every time design elements or global factors are modified.
8- Gtext: this function allows the user to write into the text portion of the AutoCAD graphics screen. This function can be used for presentation and reporting purposes.
9- Append: this function takes only lists of information as its arguments and strings the elements of these lists together.
10- Assoc: this function works on an association list to extract the information associated with a key element. The Assoc function has proved to be of extreme help in managing the AutoCAD drawing database.
11- Car: this function is used to return the first element of a list. It is generally used to extract the X coordinate of a point.
12- Cdr: this is used to return a list containing all but the first element of a list.
13- Con: this function allows the user to add a new element (atom or list) to the front of a list.
14- Last: this function is used to return the last element in a list.
15- Length: this function indicates the number of elements in a list.
16- List: the List function takes any number of elements (atoms or lists) and strings them in one list.

6.6 SUMMARY

This chapter introduced the modeling and data transfer sub-systems of the proposed integrated construction planning application. Below is a summary of the work presented in this chapter.

1- The modeling phase has been designed to model the reinforced concrete elements found in a modular building and their associated construction activities. These elements have been modeled as symbols coupled with attributes relevant to the planning process. This approach has proven that CAD systems are not the preserve of designers, but they can also be used by construction planners who are keen on facilitating the planning process using computer graphics and integrated concepts.

2- The modeling phase includes the following tasks: on the screen modeling, global input module, selection sets, duration estimation module, network diagram modeling, and the outputs formats.

3- The modeling phase has been developed to include a user friendly interface with pull down menus and help facilities.

4- The AutoCAD 10 package has been found to be a powerful micro-based computer aided design package. This software coupled with the Autolisp interpreter incorporated within this package has allowed the development of the modeling sub-system of the integrated application.

5- As the development of integrated applications depends on the free flow of information between the various systems, it was found that the availability of strong computer programs such as dBase IV which supports a large number of data formats can be regarded as a temporary solution to the problem of data exchanges as no standard exists to date. The data transfer sub-system has been implemented in the dBase IV environment.
CHAPTER SEVEN

THE PLANNING SUB-SYSTEM OF THE INTEGRATED APPLICATION

7.1 INTRODUCTION
7.2 THE CONCEPT OF THE CUSTOMIZED PLANNING APPLICATION
7.3 THE STRUCTURE OF THE CUSTOMIZED APPLICATION
7.4 THE ARCHITECTURE OF THE PLANNING SUB-SYSTEM
7.5 THE SCREEN LAYOUT OF THE CUSTOMIZED APPLICATION
7.6 SUMMARY OF THE STEPS REQUIRED TO RUN THE APPLICATION
7.7 THE MAIN ACHIEVEMENTS AND LIMITATIONS OF THE PLANNING SUB-SYSTEM
7.8 THE ARTEMIS PACKAGE
7.9 SUMMARY
7.1 INTRODUCTION

Chapters Five and Six of this thesis introduced the integrated construction planning system and discussed the modeling and data transfer sub-systems of the developed package. This chapter covers the planning sub-system which was implemented within the Artemis 2000 environment. The different menus produced to customise this planning phase are described. The various achievements and limitations of this sub-system are also highlighted. Finally, a brief description of the Artemis 2000 package and its major facilities can also be found.

This chapter shows the strength a customised project management system can offer to the overall concept of integrated applications. However, the selection of such systems should be given consideration as the requirements for an integrated environment would exceed those of ordinary packages in terms of power, facilities and financial implications. Chapter Three of this research discussed the selection criteria for a project management software suitable for integration purposes.

7.2 THE CONCEPT OF THE CUSTOMISED PLANNING SUB-SYSTEM

As mentioned earlier, this research is aimed at integrating design and construction information within a single system. In such an environment, data generated within the computer aided design model should be freely passed to the project management package for other information management requirements. The strategy adopted for this sub-system was that, only data relevant to the network generation phase such as activities relationships, durations, descriptions and types, in addition to gang sizes were stored in the objects (components) modeled within the CAD system to simulate the steps of network creation. These data were then linked into more information stored in the Artemis database through unique identifiers. The algorithms for cost analysis, critical path calculations, resource leveling and reporting were all built in the Artemis total information management system. At present, the customised package can only support the arrow network diagrams. However, the same strategy can be adopted if further enhancements are to include on the node (precedence) models.

This planning sub-system of the integrated construction planning application was mainly concerned with the customisation of the Artemis package. Such customisation capabilities have been highlighted by Mahony (Ref 7.3) and Gessesee (Ref 7.2). This
project management software package has tremendous capabilities in terms of processing power and built-in facilities. However, Chapter Two showed that only 4% of the UK and 5% of US top contractors were using this system for construction management purposes. This can be partially related to the fact that the original version of the package did not have a user-friendly interface. Therefore, and with all the customisation facilities incorporated within the system, it was thought to develop a customised version of this package which would give construction planners a powerful tool for the task of managing construction information. The customised package has been developed to include a user-friendly interface which facilitates the tasks of project scheduling and costing. Pop-up menus and help facilities have been provided at almost all levels of the planning sub-system. These facilities were produced using the Artemis high level command language. A program of 3000 lines was written to fully customise the Artemis 2000 planning package.

The customised planning package is mainly used to schedule and cost the concreting, steel fixing and formwork activities modeled within the AutoCAD package. The electronic network diagram model produced by AutoCAD is automatically transferred to the Artemis datasets to be time analysed without the need to input the activities data a second time as in current traditional practices. Calendar datasets created in Artemis, can then be associated with activities and resources in order to introduce the time element into the equation. With regards to the project costs, the output files (concreting, steel fixing, formwork CDF files) described in the previous chapter which include fields such as object identifier, quantities and durations are related to cost factors stored in the Artemis database. The link is established through unique identifiers which depend on the type of activities. Finally, the various sorts of reports, schedules and charts can be produced as the main outcomes of the planning sub-system.

7.3 THE STRUCTURE OF THE CUSTOMISED APPLICATION

The Artemis database is based on the relational model which means that data are stored in tables of rows and columns, besides the fact that every data element or field can be related or cross-referenced to every other element in a file or set of files that reside in the database if key fields are defined. In the customised application, two sorts of databases were used: one was created by the author and the second existed within the Artemis package. Figure 7.1 shows the structure of the different databases used within the customised application.
Figure 7.1 The structure of the databases used within the customised application

The planning application is structured in two sections: the datasets and the documents. The datasets are used to hold data manipulated by the different program modules written as text file documents which are compiled within the system. Appendix D shows samples of the documents and datasets produced within Artemis. These datasets and documents are now described.

7.3.1 THE DATASETS

As shown in Figure 7.1, the different datasets used in the developed application have been classified as: existing or created datasets. A thorough explanation of these datasets is included in the subsequent sections.
7.3.1.1 THE EXISTING DATASETS

The various datasets which already exist within the Artemis environment and which were found to be of relevance to the customised package, particularly for the time analysis phase, are summarised below.

1- The activities dataset

The activities dataset was used in the developed package for the mere purpose of holding details of the activities modeled within the AutoCAD package. Traditionally, construction planners use this dataset to enter data, mostly copied from a network diagram produced on a sheet of paper. In the integrated system, such approach has been considered as inefficient as data doublehandling is inevitable. Therefore, in the developed application, the re-input of data into this dataset has been avoided as the network diagram model's activities are automatically absorbed by this dataset. The major fields of the activity dataset which were used in the customised application have been compiled and presented.

1- PE (preceding event) : this field is used to define the logic needed when producing on the arrow network diagram.
2- SE (succeeding event): it is also used to define the logic mentioned before
3- Work pattern: this field of the activity dataset which is used in order to be associated with specific calendars required to introduce the time element into the equation.
4- Duration: This field is used to hold details about activities durations (days) which are worked out during the modeling phase.
5- Description: to describe activities in a comprehensive way.
6- Code: to code an activity according to design elements.
7- Lead: to hold the delay(days) before the start of an activity.
8- Lag: to hold the delay(days) on completion.
9- Gang: to define the gang size associated with an activity.
10- Type: to specify the type of activity (Start, finish, dummy or hammock).

The fields F1 and F2 provided within Artemis and which are only used for coding purposes have been exploited to store details about the Code and Gang information specified before.
2- The resources dataset

The various gang sizes for the concreting, steel fixing and formwork activities specified at the modeling phase as global factors can be considered in more detail by using the resources dataset. For instance, the concreting gang can be detailed into: concretor, helper, labourer, foreman, etc. A facility has been provided by the author to allow the user (construction planner) to look at the activities dataset while inputting data into the resources dataset. Such facility has proven to be of extreme help in facilitating the data input of this phase. The major fields of the resource dataset which are required when running the application are:

1- PE (preceding event) : to define the link to the activity dataset.
2- SE (succeeding event) : also to define the link to the activity dataset.
3- Resource code: to code a resource. as an example, LAB can be used to code labourer, etc. This field can also be found in the availability dataset.
4- Duration: to hold detail of the resource duration in days.
5- Lead time: to hold the value in days of the period required from the start of the activity until the resource is needed.
6- Quantity: to hold details of the resource quantity, such as 1 foreman, 2 helpers, etc.

3- The availability dataset

The availability dataset is used to hold details of the available resources. This dataset is compared with that of resources when the scheduling and resource aggregation tasks are performed. A record in the availability dataset holds the following fields:

1- Resource code: this is the same field as in the resource dataset. It is mainly used to define the link between the resource and availability datasets.
2- Data from: the date from which a particular resource is available.
3- Data until: the date on which a particular resource is no longer available.
4- Quantity: to hold details of the quantities of the available resources.

4- The targets dataset

The targets dataset was used in the developed application to hold details of the target dates of network activities. This dataset is permanently extended from the activities dataset. Its main fields are used to store data related to imposed dates. For instance, if
an activity is to be finished on a certain date, then the field 'compulsory finish' date can be used. These main fields are listed as below.

1- Target start early: to hold a start for an activity which should not be earlier than that date.
2- Target start late: the same as above, but the start should not be later than that date.
3- Target complete early: to specify that the finish of an activity should not be earlier than that date.
4- Target complete late: the finish of an activity should not be later than that date.
5- Compulsory start date: This fields holds the date that an activity must start.
6- Compulsory finish date: to hold the date that an activity must finish.

5- The progress dataset

This dataset holds details related to the progress of actual activities. It is also permanently extended from the activities dataset. The network updating task relies entirely on information found in the fields of this dataset. A record in the progress dataset contains the following fields:

1- Actual start: to hold the date when work on an activity actually started.
2- Actual finish: to hold the date when work on an activity actually finished.
3- Percent complete: this is a value indicating the percentage of work complete on an activity to date.
4- Remaining duration: to hold the remaining duration of an activity.

6- The calendar dataset

The calendar dataset was used in the developed application to store details about rest and holiday data associated with activities in the network. The main fields of this dataset are shown below:

1- Work pattern: this field is used to hold the identification code for a particular working period. For example, a code of '1' can be defined for a set of activities which have Sundays as rest days, and a code of '2' for activities which have any other rest days. This field can also be found in the activities dataset which is used to link these two datasets.
2- Type: to define a non working period as rest or holiday.
3- From date: the date where the rest or holiday period commences.
4- Until date: the date on which the rest or holiday period ceases.
5- Day name: to hold the name of the day designated as rest or holiday.

7- The loads dataset

This dataset is created by the system to store the results of the resource aggregation process. All the fields of this dataset are not user specified, but originated and stored within this Artemis system dataset.

7.3.1.2 THE CREATED DATASETS

These datasets were created by the author of this thesis to hold cost information associated with the graphical objects used at the modeling sub-system to produce the CAD building model. These information will frequently change depending on market fluctuation, particularly inflation. Therefore, these data were stored as Artemis databases, and a facility has been provided within the customised package to retrieve, update and manipulate these data according to the market conditions. All of these cost information were collected from the Wessex and Spon building price books (Ref 7.1 & 7.5), and they are solely concerned with the concreting, steel fixing and formwork operations. The figures are those for reinforced dense aggregate concrete grade 25 N/mm². The prices represent the net cost of materials, whereas prices associated with labour gangs are declared earlier at the modeling phase.

7.3.2 THE DOCUMENTS

The architecture of the customised planning sub-system was made modular in order to accommodate any further developments. Documents which are text files were used to store the different modules required to manipulate the various datasets in order to carry out specific tasks within the developed application. For instance, the first document of the application introduces the application and gives the user the option to proceed to the first menu. Additional documents are then used to process the different menus options accordingly. These documents are used to perform the different tasks of network creation, time (critical path calculations) and cost analyses. These documents are explained later in this chapter when introducing the different menus incorporated within the developed package. A full listing of these documents can be obtained upon request.
7.4 THE ARCHITECTURE OF THE PLANNING SUB-SYSTEM

As mentioned earlier, the main task of the planning sub-system is to undertake time and cost analyses of the project in hand. Figure 7.2 and 7.3 show the overall picture of this sub-system with respect to these two requirements.

Figure 7.2 The time analysis phase of the planning sub-system

Figure 7.3 The cost analysis phase of the planning sub-system

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The different tasks performed by the planning sub-system during the time analysis phase are shown in greater detail in Figure 7.4.

Figure 7.4 The stages of the time analysis phase
On the other hand, the cost analysis phase of the planning sub-system involves the tasks shown in Figure 7.5.

![Figure 7.5 The stages of the cost analysis phase](image)

**7.5 THE MENU LAYOUT OF THE CUSTOMISED APPLICATION**

As mentioned earlier, the high level command language incorporated within Artemis was used to write a computer program which has improved the interaction between the construction planner and the microcomputer using pop-up menus. Explanation and help facilities were also provided by selecting the Help option at any level of the planning phase. The menu layout of the customised application is shown in Figure 7.6. Facilities are provided at almost all levels to return the user to the main menu, the DOS disk operating system and the Artemis asterisk prompt. A listing of a typical module which was used to produce one of the many pop-up menus can be found in Appendix D of this thesis. A thorough explanation of these various menus will be included in the coming section.
As shown above, the major tasks of the customised planning sub-system include: time and cost analyses, data transfer between dBase and Artemis and the various reporting facilities. All these tasks have been automated within the developed package as a large number of Artemis documents have been produced to achieve this objective. For example, there are documents associated with time analysis, others with cost analysis and so on. When running the application, the user is prompted with the main menu which contains all these major options (see Figure 7.7)
The time analysis option undertakes all the critical path method (CPM) calculations which involve the determination of the early start, late start, early finish, late finish, total float, and free float of the project activities. This option should be selected first in order to create the activities datasets which are used to absorb data from the CAD model. This would involve a second phase of data transfer between dBase and Artemis. To create the activities datasets, the user can activate this option which leads to another sub-menu (see Figure 7.8) which deals with the network creation task (Figure 7.9).

Once the activities dataset is created, a new phase of data transfer can then be performed to copy data from the dBase program into this dataset. Additional datasets are also needed to absorb data from the concreting, steel fixing, and formwork files generated in AutoCAD and passed to dBase IV in the first phase of the data transfer sub-system. In the second stage of data transfer, the DIF files specified in the previous chapter are transferred into these Artemis datasets. In order to automate such task, additional text

Figure 7.8 The time analysis sub-menu

Figure 7.9 The network sub-menu
files documents were used to store modules which can facilitate the information flow between dBase and Artemis. The user can now activate the Data transfer option of the main menu which leads to another sub-menu (Figure 7.10) which contains all the facilities needed to achieve this job. However, it has been found that further editing can be needed once data are in the Artemis datasets. Such editing can be implemented using the facilities provided within the Data transfer sub-menu. The various steps of the second phase of the data transfer sub-system are illustrated in Figure 7.11.

<table>
<thead>
<tr>
<th>Data transfer sub-menu</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Format data in DIF</td>
<td>1</td>
</tr>
<tr>
<td>Edit document manually</td>
<td>2</td>
</tr>
<tr>
<td>Edit document automatically</td>
<td>3</td>
</tr>
<tr>
<td>Copy DOS document to class document</td>
<td>4</td>
</tr>
<tr>
<td>Read from document</td>
<td>5</td>
</tr>
<tr>
<td>Write to document</td>
<td>6</td>
</tr>
<tr>
<td>Exit to asterisk</td>
<td>7</td>
</tr>
<tr>
<td>Exit to system</td>
<td>8</td>
</tr>
<tr>
<td>Return to Main Menu</td>
<td>9</td>
</tr>
</tbody>
</table>

Select number □

Figure 7.10 The data transfer sub-menu
Figure 7.11 The various steps of the second phase of data transfer

Following the data transfer phase, the user can proceed with creating all required calendars and resources availability to associate them with activities in the network diagram. Once all the calendar, availability, resources and activities datasets are reviewed and checked against any error, a new stage of time analysis can take place in order to determine the project total duration, the critical activities which have to be
finished on time if the project is to be executed within the specified period. The
different options of the network analysis task of the time analysis phase can be found in
Figure 7.12.

Network analysis sub-menu

<table>
<thead>
<tr>
<th>Option</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Help</td>
<td>1</td>
</tr>
<tr>
<td>Analyse network</td>
<td>2</td>
</tr>
<tr>
<td>Schedule network (time limitation)</td>
<td>3</td>
</tr>
<tr>
<td>Schedule network (resource limitation)</td>
<td>4</td>
</tr>
<tr>
<td>Aggregate network</td>
<td>5</td>
</tr>
<tr>
<td>Unschedule network</td>
<td>6</td>
</tr>
<tr>
<td>Return to time menu</td>
<td>7</td>
</tr>
<tr>
<td>Exit to system</td>
<td>8</td>
</tr>
</tbody>
</table>

Select number [ ]

Figure 7.12 The network analysis sub-menu

The 'Analyse network' option checks the logic of the network diagram and detects any
loops or dangling activities. In addition, it carries out the forward and backward phases
which calculate the early and late dates, and the free and total floats of each activity.
Such analysis does not consider any external restraints such as time and resource
limitations. It has to be said, however, that real life construction projects very often
face the dilemma of resource and time shortages. Therefore, another step of network
scheduling (options 3 & 4 of the above menu) may be required to meet the constraining
factors of resources availability and imposed time requirements. Finally, the
'Aggregate network' option is used to summarise the resource requirements of all
activities and to compare them with the resource availability. The results of this task are
stored in the loads dataset which is used to produce the loading histograms.

Having transferred the data into the Artemis datasets and analysed the project network,
the various reports can then be produced using the 'Reports' option of the main menu
which leads to the facilities shown in Figure 7.13.
With regards to the cost analysis task, similar steps can also be followed. Firstly, data associated with cost factors kept in the Artemis database should be transferred from the dBase program. Then, the 'Cost analysis' option of the main menu can be activated which leads to two more sub-menus shown in Figures 7.14 and 7.15.
The different tasks of data transfer, time and cost analyses, and reporting will be considered in greater detail in Chapter Nine and Appendix C of this thesis which cover a typical case study of an imaginary structure to validate the system and assess the acceptability of the developed package. The different sorts of print-outs will also be included.

7.6 SUMMAR Y OF THE STEPS REQUIRED TO RUN THE APPLICATION

Here is a summary of the different steps required to perform the cost and time analysis tasks of the planning sub-system.

1 - Copy the DIF files from the dBase program into the Artemis directory and rename them as ART Files.

   copy \ dbase . name of the file . DIF \ AR name of the file . ART.

2 - Change into the Artemis directory.

3 - Start the application by typing do doc initial at the asterisk level.

4 - Select the time analysis option of the main menu to create the network and eventually all activities, resources, targets and progress datasets.

5 - Perform the data transfer option of the main menu.

6 - Create the calendar and availability datasets, then enter all your data (network module option).

7 - Review all data sets using the review options of the different sub-menus.

8 - Analyse the project network using the option "network analysis" of the network sub-menu to produce the early and late dates and to calculate the total and free floats of the different activities.

9 - Schedule the network on the basis of either time or resource limitation (the analysis sub-network).

10 - Aggregate the project resources to find out what resources are required and what are available (network analysis sub-network).

11 - Produce the various reports (barcharts, histograms) if required by selecting the option reports of the main menu.

12 - Perform a cost analysis of the project if required by selecting the cost analysis option of the main menu.

13 - Exit to system (DOS).
7.7 THE MAIN ACHIEVEMENTS AND LIMITATIONS OF THE PLANNING PHASE

The different achievements and limitations of the planning phase have been compiled and presented below.

1 - A fully customised planning package was produced within the Artemis environment to facilitate the task of construction planning and scheduling. The package is user friendly and can be run by any user following the steps on the screen.

2 - The planning package has been made as a part of the complete integrated application and thus textual data can be passed to the AutoCAD package and DIF data to the dBase program.

3 - The planning phase can perform both, time and cost analyses. The different CPM and cost calculations are presented in clear formats understandable by construction personnel, either on site or in the main office. These tasks can also be optimised as data related to these two aspects are generated within the CAD environment, and then transferred to the customised package for further processing.

4 - The main limitation is that, only on the arrow network diagrams are supported by the application. However, further enhancement of the product would allow for on the node diagrams to be processed as well.

7.8 THE ARTEMIS PACKAGE

Artemis 2000 is a complete information management system designed around a relational database which includes a sophisticated project management command language (Ref 7.4). The facilities provided by this package were tested against the selection criteria specified in Chapter Three for micro-based project management software evaluation and proved to be a powerful package suitable for integrated applications development. Such facilities are summarised below.

A - PROJECT MANAGEMENT FUNCTIONS:

The different project management capabilities supported by the system compiled as follows
1 - Activity on the arrow and activity on the node
2 - Full CPM scheduling
3 - Activity logic using FS, SS, FF, SF and lead and lag
4 - Resource leveling by TIME or resource availability
5 - Resource aggregation
6 - Multiple calendars may be defined, each with a maximum of 256 work patterns
7 - Work Breakdown Structure (WBS) can be implemented using one of the four special fields provided within the system
8 - Up to 63 resources records can be defined per activity
9 - Up to 64000 activities per network

B - APPLICATION DEVELOPMENT

Artemis provides many specialised utilities to enable application developers to build powerful, efficient and well structured applications. These utilities are now described.

1 - Access to an English like high level command language which has a hierarchical structure.
2- Program and data protection (electronic devices known as dongles and passwords facilities).
3- Access to the DOS disk operating system without leaving Artemis.
4- Ability to develop customised applications.
5- Utility to import/export data with others software systems including Metier products, Lotus 123, Timeline,..etc.
6- Local area network (LAN) support is available for 3Com and Novell.
7- High level reporting standards.
8- Access to a powerful relational database which has the following main features:

- 64,000 records per dataset
- 40-200 fields per dataset depending on field name length
- Up to 10 linked datasets at one time
- Data files of the following types are supported:
  - Integer
  - Decimal
  - Date
  - Duration
  - Text
7.9 SUMMARY

This chapter discussed the planning sub-system of the integrated application. The main findings are summarised below.

1- The development of a customised project management package as a part of a complete integrated system can strengthen the overall concept of integrated applications. In this environment, the package should accept data generated in other models and associated with elements kept in this system. For instance, in the developed package, data generated in the AutoCAD 10 package is passed into the customised Artemis system for further processing.

2- Artemis 2000 has been used to accept the electronic network diagram model generated within AutoCAD which includes concreting, steel fixing and formwork activities. The cost and time analyses algorithms performed on these activities have been built in the customised planning package in order to improve the speed and power of the CAD package.

3- The customised planning sub-system consists of documents and datasets. The datasets can be reviewed, displayed and updated by the user. The documents are mainly used to write the programming code needed to manipulate these datasets. The planning sub-system has a friendly user interface with help and pop-up menus provided at almost all levels of the planning phase.

4- As the customised planning sub-system undertakes both time and cost analyses, the outputs of this phase have been presented in clear formats to be understandable by construction personnel, either on site or in the head office. These outputs include: activities status reports, barcharts, loading histograms, and resources and costs reports.

5- The planning sub-system has been implemented in the Artemis 2000 environment. This package has proven to be a powerful tool which can be fully customised according to the user or the software developer requirements and can be made as a part of a completely integrated system.
CHAPTER EIGHT

PROBLEMS AND LIMITATIONS OF INTEGRATED APPLICATIONS

8.1 INTRODUCTION
8.2 THE CONCEPT OF INTEGRATION
8.3 PROBLEMS AND LIMITATIONS
8.4 SUGGESTIONS TO NEW APPLICATIONS DEVELOPERS
8.5 SUMMARY
8.1 INTRODUCTION

The last three chapters discussed the different stages of the integrated construction planning application and its physical implementations. This chapter summarises the various problems and limitations encountered during application development. Recommendations to new computer aided construction planning applications developers are also highlighted.

The current working practices, the different technical limitations and the financial aspects have been considered as major barriers in achieving a complete comprehensive integrated model to aid the planning of in-situ concrete structures. However, recent developments in software and hardware technologies, and the adoption of new contracting methods such as design and build and management contracting would eventually motivate researchers and practitioners to adopt new approaches to construction planning based on the concept developed and implemented by the author. For instance, the limitation of the DOS disk operating system can be overcome through the use of OS/2 and XENIX operating systems which are more powerful in terms of memory and multitasking facilities.

8.2 THE CONCEPT OF INTEGRATION

Howard defines integration as the linking of programs to run different applications from the same database (Ref 6.10). In other words, it is the free flow of information between the different parties involved to achieve a specific task. In construction, it is that information exchange between clients, designers, contractors and sub-contractors.

Current computerised construction management systems are made up of a series of separate departments communicating with each other using documents and conventional drawings. Each department performs its task independently, and even the modest amount of data integration is absent.

It was against this background that the author developed a link between two individual computer aided design and project management applications. The main finding was that, available software and hardware technologies are more than sufficient to establish the intended link to a certain extent of success. As a result, data generated by the computer aided design package can be freely passed to the computerised planning application.
As specified in Chapter Five, the manufacturing industry has gone a long way in establishing fully integrated systems. The question is whether the construction industry would adopt these new techniques or remains in its backward status. Previous experiences with the uses of critical path method and work study techniques which were developed outside the construction industry and then adopted by the latter give researchers some encouragement in assessing the practicality and usefulness of the integrated system approach. It has to be admitted, however, that such a system is not a problem free concept. The next section deals with the problems which can be faced when developing integrated applications.

8.3 PROBLEMS AND LIMITATIONS

Horrocks classifies problems facing integrated systems in the manufacturing companies as (Ref 8.9):

- technical;
- organisational; and
- financial.

During this research, it has been revealed that the construction industry could face the same problems if integrated approaches are to be adopted (refer to Chapter Two). These problems are considered in great detail in the next sections.

8.3.1 TECHNICAL PROBLEMS

As the main aim of this research is to develop a micro-based construction planning application, only technical problems associated with microcomputers have been considered. These technical problems and limitations have been compiled and include:

- disk operating system and memory management;
- absence of a product model;
- full graphical data exchange facilities;
- non-graphical data integration capabilities;
- data transfer between the application programs;
- inter-computer communications;
- lack of standards.
8.3.1.1 DISK OPERATING SYSTEMS AND MEMORY MANAGEMENT

The most rapid changing area of computing is that of operating systems. The planning application described in this thesis has been developed within the planning application in the DOS disk operating system environment. During development, it has been found that memory limitation prevented the running of the database management program, dBase IV, from within the computer aided design package, AutoCAD 10. In contrast, WORDSTAR 3.3 and the spreadsheet program, LOTUS 123, were able to be incorporated within the AutoCAD environment as their memory consumption is less than that of dBase IV.

The DOS operating system can only address 640 kilobytes of memory, besides being a single user system. The 640K barrier has made DOS unsuitable for today's ever growing computer aided design applications. The need to surpass the memory limitation of DOS has encouraged companies to develop systems which can replace the PC and MS DOS unsatisfactory operating systems. OS/2 and XENIX are seeing as alternatives to the DOS option (Ref 8.5).

XENIX is a micro-based version of the UNIX operating system produced by Santa Cruz Operation (SCO). AutoCAD can be run under the SCO XENIX 386 operating system. The primary advantage of this system is its multitasking and multiusing facilities. In addition, it is very fast as it is a full 32 bit implementation.

OS/2 which has been developed by IBM (International Business Machines) and Microsoft is considered as the rightful heir to the DOS legacy. It is a multitasking operating system which requires at least 6MB of RAM for use with the OS/2 presentation manager. This system is easier to install and adapt than UNIX-based products (Ref 8.6).

As XENIX and OS/2 are not widely available, the DOS Extender operating system which can break the 640K barrier can be seen as a temporary alternative. The AutoCAD 386 compromises a DOS Extender which allows larger Autolisp programs to fit into memory because of the 32-bit addressing capability of the 386 chip.
8.3.1.2 ABSENCE OF A PRODUCT MODEL

At present, the main tool for achieving a modest degree of integration between the different disciplines of the construction process has been overlay drafting. This technique was extensively used to develop the integrated construction planning application described in the previous chapters.

Full integration can only be achieved if a product model containing all the data describing a particular building can be established. Currently, these data are found in specifications, bills of quantities and drawings.

The most promising area to build a complete product model has been object oriented techniques (Ref 8.7 & 8.2). In such techniques, information about building components can be embedded within computer aided design objects or entities. These objects which can represent real world elements, for example, walls, columns, beams, doors, windows, sockets, etc... can all be present in the intended product model.

The RATAS and Master Architect systems can make the first steps towards the establishment of a product building model. Both systems have been developed around the object oriented concept.

The RATAS model is being developed by the Technical Research Centre in Finland since late 1986. The aim of this project is to establish the framework for the future computer integrated construction. This system uses concepts such as objects, attributes and different type of relationships between the various objects. Hannus highlights the main four groups of the RATAS project as (Ref 8.7):

- public databases;
- data transfer;
- logical data structure; and
- documentation.

Figure 8.1 and Figure 8.2 show respectively a schematic representation of the RATAS project and a tree structure of the different levels used in this system.
The author of this thesis did not come across any commercial software package which was developed around the RATAS model. In fact, the scope of the RATAS project is 10 years in which period it should be possible to produce practical results with commercial aspects.

Master Architect developed by INTERGRAPH is a rather commercial software package than a description of a product model. It is the first object oriented package that will function as a module in the integrated building information system (Ref 8.17). The different environments maintained by the Master Architect system are:

- the reference database;
- the design/engineering environment; and
- the material database.
These environments involve the whole range of activities from planning to construction and commissioning.

In this research, the work undertaken was no more than pure retrieval of the design elements data kept in the drawing database. There was no intention at any level to devise a building product model which is normally the task of various cooperative professional organisations rather than individual researchers. In addition, the AutoCAD package does not offer the facilities required to establish such model. Furthermore, the Autolisp interpreter incorporated within the AutoCAD package is not a full oriented programming language which is considered as a must in developing building product models.

8.3.1.3 FULL GRAPHICAL DATA EXCHANGE

The integration environment requires that different computer aided design systems need to communicate with each other. The most common data exchange formats which can be used to achieve such integration are presented below.

- IGES
- DXF
- VDA-FS
- SET
- PDES/STEP.

1- IGES (Initial Graphics Exchange Specification)

IGES is an American data transfer format which is widely used by the US Navy, Airforce, Automotive, Aerospace and Computer industries. Adrian Laud argues that IGES was developed when CADCAM systems were little more than electronic drawing boards (Ref 8.12). Current applications, however, involve the use of graphical and non-graphical data to represent the various requirements of real world objects. To transfer these data to other systems, Laud argues again that IGES is hardly able of supporting such concepts. He adds that IGES is mainly used on mainframes and minicomputers, and at the moment only 2D and 3D wireframes with geometric information can be efficiently exchanged. AutoCAD supports the IGES data format.
2- DXF (Drawing Exchange Format)

DXF is a vendor specific data format developed by AUTODESK, the AutoCAD developers, as part of the AutoCAD program. It has become the micro-based computer aided design industry standard for data exchange and it is used in most professionally written third party AutoCAD programs that process large amounts of drawing data. In fact, the National Economic Development Office (NEDO) has recommended DXF as the data exchange standard for the construction industry, where it is already established because of the widespread use of AutoCAD (Ref 8.13). The main limitation of the DXF data format is that it can only handle 2D drawings data and not 3D models.

3- VDA-FS (Verband Der Automobilindustre Flachen Schnittstelle)

VDA-FS is a West German data transfer format which was developed by the automobile industry to handle precise surface definitions. Such facility is not required by the construction industry. Holt believes that this system will be superseded when the PDES/STEP becomes available (Ref 8.8).

4- SET (Standard D'exchange et de Transfert)

SET is a French data format which was developed to minimise the huge storage volume required by IGES. SET can support the same entities as IGES, but it is considered as faster and more efficient.

5- PDES/STEP (Product Data Exchange Specification/Standard for the Exchange of Product Model Data)

This system is being developed by the International Standards Organisation (ISO). In the US, it is known as PDES, whereas in Europe as STEP. This system is expected to replace all existing standards as it can handle more sophisticated and complex translation tasks.

Other data exchange formats include EDIF (Electronic Design Interchange Format) and CDF (Cimio Data Format).

A survey undertaken by Wix et al of the CICA (Construction Industry Computing Association) regarding the area of data exchange between computer systems in the construction industry has revealed that only 27% of construction firms exchange CAD
data (Ref 8.20). This low percentage is attributed to the fact that most systems are structured differently, in the storage of both graphical and non-graphical information. Thus data exchange between the various systems depends on the structure of data representation and as almost every system has its own data structure, then data exchange can only be achieved through intermediate formats which should be accepted and supported by the different disciplines of the construction industry.

8.3.1.4 NON-GRAHICAL DATA INTEGRATION CAPABILITIES

Most micro-based computer aided design systems support the facility to associate non-graphical descriptive information (attributes) with graphical elements known as blocks or symbols. These information can be used to produce schedules, parts lists, bills of materials, other tabulations, and even data for other application programs (Ref 8.15). Even though, sometimes there is no limit on the number of properties which could be added to a drawing, it seems that the more the drawing becomes packed, the slower the computer operates. It is a good strategy, however, to attach essential information to drawings and link these to more detailed data kept in text files, spreadsheets or databases, if applicable. Greater speed and productivity have been achieved in adopting this strategy. In some systems, it has been found that only a single attribute can be added to a graphical component. Such systems should be avoided if integrated applications are to be developed.

The necessity to associate external programs with CAD systems would involve more effort in terms of software functioning and programming. Therefore, micro-based CAD system developers should consider this area with more attention in order to device systems which can support some of the facilities found in relational database management systems.

8.3.1.5 DATA TRANSFER BETWEEN THE APPLICATION PROGRAMS

During this research, it has been found that there is no single database or spreadsheet program which can directly read a drawing file (.DWG). It has been revealed, as well, that the data formats required to transfer information between the different applications are incompatible. For example, the AutoCAD 10 does not support the DIF (data interchange format) format which is backed by Artemis 2000. This lack of standard storage format would inevitably involve the use of repository systems which act as communications means between the various applications. This can only be avoided if
standards can be established. Therefore, software developers should allow for greater
data storage capabilities in order to facilitate the development of micro-based integrated
applications.

The DIF format may have a promising future as a standard for data exchange as it is not
dependent on the features of any particular computer. In addition, it is supported by the
most powerful micro-based application programs, namely dBase, Lotus 123, Artemis
and VisiCalc (Ref 8.11).

8.3.1.6 LACK OF INTER-COMPUTER COMMUNICATIONS

In an integrated environment, diverse disciplines might need to share the same sets of
data. This would necessitate the use of an inter-processor communications means when
using different machines. Local Area Networks (LAN) which are examples of such
inter-processor communications are just emerging (Ref 8.19). However, not all
hardware platforms can fully support these facilities, especially the PC's (personal
computers). The disk operating system DOS is another major problem in networking
microcomputers. For example, to have a network co-exist with the AutoCAD program
in the 640K space can be very difficult and involves compromises. Furthermore, the
Autolisp interpreter can become disabled with some network configurations and thus
disabling any add-on package which requires Autolisp to work with AutoCAD (Ref
8.3). As networking involves some sharing of data and peripherals (printers, plotters),
then the management of drawings and files becomes of paramount importance to make
sure that the exact data or drawing is edited by the right person. This would require
more effort than needed on a single machine.

To summarise, networking offers great benefits in terms of data and resource sharing,
system performance and data security, but extra memory and data management can be
involved. Wenig lists Novell, 3COM, NFS and TOPS as the most popular PC's
computer networks (Ref 8.19).

8.3.1.7 LACK OF STANDARDS IN THE UK CONSTRUCTION INDUSTRY

In any construction project, whether building or civil engineering, up to 12 different
parties can often get involved (Ref 8.13). The huge number of the various disciplines
required at the diverse stages of the project makes the implementation of standard
computer aided design practices in the construction industry very difficult. However,
in the UK great effort has been devoted to establishing such standards. The BS 1195
part 5 (construction drawing practice, part 5: guide for graphic representation by computers) is available now in its final format (Ref 8.1). The publication of this standard has been seen as a first step towards standardisation. The draft gives guidelines for layering of drawings and use of attributes and blocks for standard symbols.

The main criticism of BS 1192 Part 5, as appears in reference 8.13, is that it only allows for numbering coding. Such criticism was found not to be realistic as the final draft is now available and it specifies that building models should be allocated layers based upon classification systems such as CI/SfB and common arrangement. It is the credibility of these classification systems which should be assessed before criticising this system. Table 8.1 shows the coding of some construction drawing elements (Ref 8.1).

<table>
<thead>
<tr>
<th>LAYER NAME</th>
<th>TYPE OF INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Drawing sheet</td>
</tr>
<tr>
<td>02</td>
<td>Frame, title block</td>
</tr>
<tr>
<td>03</td>
<td>Building plan grids</td>
</tr>
<tr>
<td>04</td>
<td>Hatching patterns</td>
</tr>
<tr>
<td>05</td>
<td>Free annotation</td>
</tr>
<tr>
<td>06</td>
<td>Details to be plotted at larger scales</td>
</tr>
<tr>
<td>07</td>
<td>Dimension lines</td>
</tr>
<tr>
<td>08</td>
<td>Origins</td>
</tr>
<tr>
<td>09</td>
<td>Vacant</td>
</tr>
</tbody>
</table>

**TABLE 8.1 The coding of a sample of elements found in BS 1192 Part 5**

The restriction imposed by BS 1195 for a simple numbering system has been criticised by many people in the construction industry. Some have argued that BS 1192 Part 5 is just an attempt to give commercial access to crude CAD programs which only allow for layer numbering and as another attempt to encourage big machines CAD systems (Ref 8.13). The final format of BS 1192, however, was found not to specify for just a numbering system. Therefore, such criticism could have been originated when BS 1192 part 5 was in its first draft format.

There is a need a comprehensive and flexible system to be devised. If such a system could allow for both numbering and texting of the layering environment, this would be
more advantageous to the construction industry as more accurate information could flow between the various departments.

The AutoCAD package which is widely accepted by the construction industry has a layering system which can accept both numbers and characters when identifying the various layers required to model the different components of the building product, including dimensions and descriptive specifications. This beneficial facility, coupled with the large number of AutoCAD users has encouraged Autodesk, the AutoCAD developer, to press to establish a more comprehensive British Standard to replace BS 1192 Part 5. Such system, once available, might have a great influence on the construction process. Previous experience with the wide acceptability of the AutoCAD product and its DXF translator as being standards would give more encouragement to producing a new standard. McCarthy believes that even if such system does not become a full British Standard, the new proposal will probably become the defacto standard for the construction industry (Ref 8.13).

McCarthy believes that the construction industry will lack a fully recognised standard, at least in the foreseeable future because (Ref 8.13):

- there is no clear market leader in the CAD industry;
- there is no dominant pressure group in the UK construction industry;
- the European factor (1992) could revolutionise all the available standards in order to establish more interaction between the parties involved in the new market; and
- the incompatibility between the CI/SFB and common arrangement classification system would make electronic data exchange between the various disciplines difficult.

However, Chapter Two of this thesis indicated the strength of AutoCAD amongst UK and US contractors. This could lead to the formation of pressure groups which promote this product in the view of establishing standards for the construction industry.

To summarise, the need for a layering standard is urgent in order to facilitate communications between the different parties of the construction industry. The standard should be flexible, comprehensive and expandable to accommodate future changes in Europe (1992) which could influence the structure of the UK building and civil engineering industries.
8.3.2 ORGANISATIONAL PROBLEMS

8.3.2.1 BACKGROUND

The construction industry operates sequentially and involves professionals from many different trades. Current working practices allow for little communications between the various parties of the construction process. Barriers between the professions involved are present and even the modest amount of integration is disregarded. Consequently, a commitment to an integrated construction planning application should impose the removal of such barriers.

Walker believes that project organisation in the UK and most parts of the world has a conventional approach whereby the architect is often still the dominant figure as a team leader, responsible for both design and management of the project, with the contractor undertaking the construction work based on a competitive tender (Ref 8.18). Such an approach limits the development of integrated applications as the design and construction teams perform their tasks separately.

8.3.2.2 INTEGRATION OF THE CONSTRUCTION TEAM

In Chapter Two, it has been revealed that most of the top 100 contractors in the UK and 400 contractors in the USA believe that the tendering arrangement in both the UK and US construction industries is the main obstacle in achieving a complete integrated system. In this sort of arrangement, the contractor is brought into the project once the design has been substantially completed. This method offers the least opportunity for integration. However, recent developments in construction circles is towards design and build, and management contracting allows contractors to be better integrated into the design team. The design and build approach is more adopted adopted in the US construction industry. This technique which known also as a package deal or turnkey contract does not separate design and construction between firms. Thus, the organisational problem encountered during the traditional competitive tendering process can be overcome by using such approach. However, in the UK, the design and build system is not commonly used and in the majority of firms, this type of service is available besides competitive contracting (Ref 8.18).

Management contracting is another technique which is used to incorporate the contractor’s expertise into the design process. A management contractor is appointed on an equivalent basis to all other consultants to manage the construction stage. It is a
fee-based contract rather than contracts awarded through the tendering process (Ref 8.18). This integration of the contractor's expertise into the design team improves communication means between the different parties of the construction process and helps avoid some of the main constructibility problems.

To summarise, the design and construction of buildings should be considered as complementary processes rather than discrete functions. Changes to the traditional contracting/tendering and working approach are essential if the management and planning of construction projects is to be improved. Design and build and management contracting have great potentials in implementing fully integrated systems to replace the current competitive tendering approach which tries to separate design and construction as two different independent activities communicating through drawings, documents and specifications.

8.3.3 FINANCIAL PROBLEMS

The commitment to an integrated system is very often associated with financial implications. Even though systems implemented on microcomputers are considered as relatively cheap, an investment in the region of tens of thousands of pounds may be involved. Primrose has identified two sorts of costs for a CADCAM (computer aided design computer aided manufacturing) environment: initial and running costs (Ref 8.16). These costs can also be involved in implementing an integrated construction planning system. The initial costs can include those of:

- hardware;
- software;
- installation;
- new locations; and
- staff training

The running costs may well involve the following:

- consultation;
- maintenance;
- insurance;
- software upgrading;
- staff updating; and
- others such as power cables, electricity, disks, books, magazines, etc.
These costs should be carefully assessed in order to select a viable and economic system. Primrose has suggested that an investment appraisal should be an integral part of purchasing a CAD CAM system. Such techniques can also be followed in assessing the profitability of an integrated construction planning application (Ref 8.16).

The system developed by the author involves an initial cost (hardware & software) of up to £15,000. Table 8.2 illustrates the costs of the different required elements.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>COST (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware (IBM 70)</td>
<td>4,500</td>
</tr>
<tr>
<td>Plotter</td>
<td>1,750</td>
</tr>
<tr>
<td>Printer</td>
<td>350</td>
</tr>
<tr>
<td>Artemis 2000</td>
<td>4,250</td>
</tr>
<tr>
<td>AutoCAD 10</td>
<td>2,500</td>
</tr>
<tr>
<td>dBase IV</td>
<td>800</td>
</tr>
<tr>
<td>WS</td>
<td>200</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>14,400</strong></td>
</tr>
</tbody>
</table>

**TABLE 8.2** The cost of the integrated system

The above table shows that a sophisticated software program such as Artemis 2000 could cost the same amount as a powerful IBM micro-machine. The software selection process has thus become an important issue in assessing the suitability of an integrated system (refer to Chapter Three).

As mentioned earlier, besides the initial costs involved, additional requirements such as training and consultation should not be underestimated. For instance, Metier (The Artemis developers) staff run different Artemis courses, the costs of which are given (Table 8.3). These figures are extracted from the Metier education and training guide (January to June 90) (Ref 8.14). With regards to AutoCAD training costs, Table 8.4 illustrates some of the figures supplied by Datech (a major AutoCAD supplier) for some of their courses (Ref 8.4).
<table>
<thead>
<tr>
<th>COURSE</th>
<th>DURATION(DAY)</th>
<th>FEE (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to CPM(critical path method)</td>
<td>2</td>
<td>350</td>
</tr>
<tr>
<td>Project management workshop</td>
<td>3</td>
<td>600</td>
</tr>
<tr>
<td>Artemis 2000 general uses</td>
<td>4</td>
<td>800</td>
</tr>
<tr>
<td>Artemis 2000 application writing</td>
<td>5</td>
<td>900</td>
</tr>
<tr>
<td>Network processing (precedence)</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>Network processing (arrow)</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>System design workshop</td>
<td>5</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Table 8.3 Micro-based project management training cost**

<table>
<thead>
<tr>
<th>COURSE</th>
<th>DURATION(DAY)</th>
<th>FEE (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOS a user's guide</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>Introduction to PC's and AutoCAD</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>Basic AutoCAD</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>Intermediate AutoCAD</td>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>Advanced AutoCAD</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>AutoCAD programming using Autolisp</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>AutoCAD applications shop</td>
<td>By arrangement</td>
<td>400</td>
</tr>
</tbody>
</table>

**Table 8.4 The AutoCAD training costs**

A survey undertaken by Datech into the UK training market shows that the Datech's average course/day rate of £150 per delegate was in some instances £100 cheaper than offered by other training companies. As a result, the overall training costs needed to run software programs required to develop integrated applications should be given due consideration. Figures in four digits are sometimes expected because of the lengthy learning period required to become familiar with the application programs involved.
8.4 SUGGESTIONS TO NEW APPLICATION DEVELOPERS

The main observations of the author throughout the implementation of the modelling, data transfer and planning sub-systems of the integrated applications are summarised below.

1- A good and sound understanding of the Disk Operating System is a must in order to develop successful applications.

2- A thorough investigation of the hardware and software requirements should be performed before proceeding with any application development. For instance, memory limitation may only be realised at a later stage of any development application.

3- Subsets of the whole system should be designed, implemented and tested before writing the complete code.

4- The learning period of computer languages and software applications should not be underestimated.

8.5 SUMMARY

The main findings of this chapter are summarised below.

1- The current working practices, the different technical limitations, and the financial aspects can be considered as major barriers in achieving a complete comprehensive integrated model which can aid the planning of in-situ concrete structures.

2- The technical limitations include: disk operating system and memory management, absence of a product model, full graphical data exchange facilities, non graphical data integration capabilities, data transfer between the applications programs, inter-computer communications, and lack of standards.

3- Current working practices in the construction industry imply that organisational problems are to be encountered when implementing integrated systems as the industry operates sequentially and involves professions from different trades. However, the adoption of new approaches such as 'design and build' and 'management contracting' can solve many of these problems.
4- The commitment to an integrated system is very often associated with financial implications as this requires the coupling of different software packages and hardware platforms implying that more staff training can be required. These financial implications include: initial and running costs. Initial costs involve those of hardware, software, installation and staff training, whereas running costs include those of: consultation, maintenance, software upgrading and staff updating.
CHAPTER NINE

THE MODEL VALIDATION AND VERIFICATION

9.1 INTRODUCTION
9.2 TESTING THE INTEGRATED MODEL
9.3 THE TESTS RESULTS
9.4 VALIDATION THROUGH A CASE STUDY
9.1 INTRODUCTION

Chapters Five, Six, Seven and Eight have introduced and explained the different subsystems of the integrated construction planning model and the problems and limitations associated with this system. This chapter describes the different tests and verification procedures performed to validate and assess the credibility and acceptability of the model. These tests include: modular testing, integration testing, and acceptance testing. The results of these tests are discussed under the headings: manual verification of the model, user interface error detection, compliance with the model specifications, and finally the model acceptability. In addition, a theoretical case study of a typical in-situ concrete structure is included to demonstrate the system in operation. This case study could facilitate the learning processes of the model by its intended users.

9.2 TESTING OF THE INTEGRATED MODEL

As specified in Chapter Five, testing has always been considered as a major and vital part of software development and implementation. The purpose of testing the integrated model is to ensure that the software is error and bug free; to verify that the system complies with the requirements and functional specifications specified and discussed in Chapter Five; and to determine whether the system is acceptable within the framework of construction planning. The software capabilities, performance, and its user interface have been considered as major criterion in assessing the suitability of the developed integrated construction planning system. The literature search revealed that three major types of tests can be performed during software development (Ref 9.1). These major tests are widely known as:

1- Modular testing;
2- Integration testing; and
3- Acceptance testing.

The first two tests can be considered as normal procedures for debugging computer programs. Such tests are usually undertaken by the software developers. Acceptance testing is normally based on the personal judgement of experts and knowledgeable people in the subject matter. The software supported facilities, processing speed and performance, and the user interface are the main areas of concern to be considered by experts when testing the acceptability of any computer package.
Tah has validated and verified his formwork integrated computer aided design model using these tests (Ref 9.1). As this work is of similar nature, except that the subject area is different, the integrated construction planning model could undergo such testing. In addition to this, a theoretical case study of a typical in-situ concrete structure was included in order to demonstrate the software to its intended users, and to prove that the package complies with its functional specifications. The different testing procedures are now discussed, and the case study example is examined later in this chapter and in Appendix C of this thesis.

9.2.2 Modular testing

The modular testing was the first test to be undertaken on the model in order to ensure that each module of the computer program was working properly. The main concerns at this stage were to ensure that there were no mistakes in the programming code, either in its logic or processing. Consequently, each module underwent the following tests:

a- checking the typed formulae, particularly those of the work study database;

b- testing the logic of the results. For example, figures taken from the model were checked against normally expected values; and

c- Performing manual calculations by running the model with a certain set of given input variables, and comparing the model output with results based on manual solutions. This proved that the model was working properly as no difference between the two sets of results were observed.

Each module of the computer program was provided with several debugging and error tracing tools wherever possible. Most of the input parameters were supplied with default values, and were designed only to accept a certain format of data types. For example, the program would only accept an integer number for a gang size value, rejecting any mistyped data of decimal format. These major debugging and error tracing facilities were mainly incorporated within the Autolisp routines as most of the data input of the integrated construction planning model would normally take place at the modelling phase implemented within the AutoCAD environment. The modular approach adopted during the development of the integrated model ensured that each individual module was tested successfully before proceeding to the next step of integration testing.
9.2.2 Integration testing

Once the modular testing procedure was successfully completed for the modules involved, a new step of integration testing was undertaken to prove that the coupling of two or more modules of the computer program would give the correct results. Once again, checking the logic of the results, and performing manual calculations were part of this integration testing.

9.2.3 Acceptance testing

The main aim of acceptance testing was to prove that the system was working as required and was acceptable to its end users. Acceptance testing involves using the software in real or simulated situations in order to verify that the system meets its requirements in terms of functionality and performance (Ref 9.1). The case study illustrated later in this chapter and in Appendix C was included to demonstrate the different functions supported by the integrated model.

The three above mentioned tests were undertaken on the construction planning model to assess its validity and acceptability. The results of these tests have shown that the model was error and bug free, can give accurate results, and it is acceptable to its intended users. A discussion of the tests results will be included in the next section.

9.3 THE TESTS RESULTS

The results of the tests performed on the construction planning model are discussed under the following headings:

1- manual verification of the model;
2- user interface error detection;
3- compliance with the model functional specifications; and
4- acceptability of the model.

The first three headings are related to both modular and integration testing, whereas the last one is discussed in relation to acceptance testing.
9.3.1 Manual verification of the model

To verify that the model produces correct results, the software was run for a certain set of input variables, and the output was recorded. A manual solution was then undertaken for the same set of input parameters and the results were compared. The results of this test have shown that the model was working as required, except that rounded figures were sometimes needed to ease the calculation process. For example, a 20m x 20m x 0.2m deep slab to be concreted using a pump was considered. The model was run and the activity duration was recorded. A manual verification considering the same design element and using the same dimensions and attributes has proved that the model was accurate by producing the same answer. The manual verification of the model was used for both modular and integration testing.

One of the main observations of this manual verification procedure is that, the integrated model has a tremendous processing speed when compared with a manual operation. In addition, once the system is successfully tested, it is more reliable as quantities associated with design elements are automatically generated from the CAD model.

9.3.2 User interface error detection

As the main aim behind developing the integrated model was to aid the planning of in-situ concrete structures, it was essential to incorporate facilities which can trace errors, particularly at the input stage as the validity of such data is a fundamental requirement of software design. Therefore, most of the Autolisp routines were designed to incorporate error checks wherever possible. For instance, an input of a decimal value for a gang size would be rejected in favour of an integer one. Also, additional Autolisp routines have been written to enrich the system with facilities which can keep track of the elements selected within the CAD model. In such an environment, if a particular design element, say slab1, was previously analysed and was chosen again by the user, the system would prompt that such item had already been considered during the running process. Such an approach is more advantageous over the traditional system as the model is enhanced with facilities which can handle errors and keep track of the different elements found in a CAD model which is a simulated picture of the structure in hand.
9.3.3 Compliance with the model specifications

The reliability of the integrated model was tested against the following functional specifications specified in chapter five.

1- The modeling requirements
2- The drafting requirements
3- The quantities and materials scheduling requirements
4- The time analysis requirements
5- The cost analysis requirements
6- The reporting requirements.

It was found that the model conforms with the overall specification satisfactorily. The detailed case study also proves that the model meets most of its functional specifications and requirements.

9.3.4 The model acceptability

The integrated construction planning model has been demonstrated to experienced construction planners from the construction industry and to interested researchers and members of staff in the Civil Engineering Department at Loughborough University. The feedback from these demonstrations has been summarised below.

1. The developed software is user friendly and easy to be run.

2. The integrated model handles data efficiently as a CAD system has been made an integral part of such model. The presence of a CAD system would allow greater access to data in its electronic format.

3. The system allows for the modelling and planning of concrete elements. As a result, all requirements in terms of quantities generation, drafting, visualisation time and cost analyses of projects are covered with the developed model.

4. The main criticism of the model was that users of such system should be trained properly in three main areas of information technology namely CAD, databases and project management system. Such task of training and educating construction planners is expected to be difficult and time consuming, but the benefits to be obtained from the integrated model would exceed the training costs involved.
5. The integrated model can only be applied if current working practices are modified. The communication between the different parties can be considered as a major area to be improved if integrated applications are to be applied.

9.4 VALIDATION THROUGH A CASE STUDY

A case study example of an imaginary structure (see Figure 9.1, Figure 9.2 and Figure 9.3) was shown to experienced construction planners and interested researchers in order to illustrate the developed CAD-based integrated planning model in operation. The structure comprised the following elements:

4 concrete footings 3m x 3m x 1m deep
Formwork type: Below ground level with bolts
Pour type: Pump

4 concrete ground beams 0.5m x 0.5m x 5m deep
Formwork type: Steel
Pour type: Direct pour

4 concrete columns 1m x 1m x 5m high
Formwork type: External clamps
Pour type: Skip

Concrete roof 10m x 10m x 0.3m deep
Formwork: traditional deck
Pour type: Skip

Reinforcement bars were also added to these design elements.

This example was designed to combine as many aspects as possible (different types of design elements, different pouring and formwork methods, etc).
Figure 9.1 The imaginary structure in 3D (case study)
Figure 9.2: A plan view of the imaginary structure (case study).
This case study will be considered in greater detail in Appendix C. Below is a brief description of the steps required to run the case study example.

1- Model reinforced concrete elements using the "MODEL" pull down menu. To facilitate such task, try to place different design elements on various layers. As an example, place the concrete layouts of the footings on a specific layer.

2- Use the copy facility to place similar elements.

3- Use the edit facility to change the attributes of a particular component.

4- To place reinforcement bars in the longitudinal and transverse directions, the UCS option should be used. For instance to place bars in the longitudinal direction, the following steps are required.

a- Use the UCS option to move the world coordinate of the AutoCAD package to a new location. Following this step, rotate the UCS around the X axis for either + or - 90 degrees as required.

b- Select the plan option and proceed as with placing concrete layouts and formwork components. This facility was extensively used in the case study to generate the 3D design model.

5- Once the CAD building model has been completed, the "COMPUTE" pull down menu was used to generate the CAD network diagram model (see Figure 9.4) based on information found in the building model. First, select the "GLOBAL" option to define all the required files, gang sizes, pay per hour, and other global data; second choose either concreting, formwork or steel fixing activities as required to be associated with any set of design elements.

6- Having produced the CAD network model, a new step of data extraction was required and the "EXTRACT" pull down menu was used to achieve such task. The attributes extracted from the network model was then passed to Artemis 2000 via dBase IV. Figure 9.5 shows a barchart of the activities involved after being time analysed in the Artemis system. Also, Figure 9.6 includes a list of the project activity status.
Figure 9.4 The network plan of the imaginary structure produced by AutoCAD
<table>
<thead>
<tr>
<th>ACTIVITY NAME</th>
<th>ACTIVITY DESCRIPTION</th>
<th>ACTIVITY DURATION</th>
<th>REMAINING DURATION</th>
<th>EARLY START</th>
<th>EARLY FINISH</th>
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<td>reinf_footing</td>
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<tr>
<td>a8-a10</td>
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**Figure 9.6 Activity status list**
### Concreting Cost Report

**Date:** 03-Jan-90  
**Report Date:** 19-Jun-91

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<tr>
<th>Element Code</th>
<th>Concrete qt (m³)</th>
<th>Labour Gang</th>
<th>Labour Cost (£/hr)</th>
<th>Material Cost (£/m³)</th>
<th>Total Cost (£)</th>
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<td>4</td>
<td>4</td>
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<td>290.05</td>
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</table>

**Grand total cost:** 3106.95£
This case study demonstrates that the development of a CAD-based integrated model to aid the planning of the construction of in-situ concrete structures can be achieved on an IBM-PC machine. The benefits of such a system was also appreciated by many of the UK and US contractors. However, the practicality of these techniques has to be assessed on real life projects which should be the subject of a further research.
CHAPTER TEN

CONCLUSIONS

10.1 CONCLUSIONS
10.2 CONTRIBUTION OF THE RESEARCH
10.3 RECOMMENDATIONS
10.4 FURTHER RESEARCH
10.1 CONCLUSIONS

This research has sought to prove that current traditional construction planning processes are not efficient and that the use of a CAD system by construction planners could improve such processes by the proper management of information generated within these systems. One of the main findings was that CAD systems can make an integral part of a totally automated construction planning application. However, this approach would entail the proper use of information technology features, namely project management, databases and CAD systems. The integrated construction planning application developed by the author has proved that available hardware and software technologies are more than sufficient to develop integrated applications within the framework of construction planning automation. The main conclusions which to be drawn from this research have been classified into the following four groups.

1- The current practices of planning techniques and the use of information technology in the UK and USA construction industries.

2- The traditional planning method.

3- Available construction planning models.

4- The developed integrated construction planning model.

10.1.1 THE CURRENT PRACTICES OF PLANNING TECHNIQUES AND INFORMATION TECHNOLOGY

Chapter Two of this research covered the results drawn from a questionnaire survey undertaken amongst the top UK and US contractors on the current status of planning and information technology within their industries. One of the main findings was that most UK and US respondents of the questionnaire agreed with the fact that new planning models are needed to take advantages of the recent developments in computer hardware and software technologies, such a reality has long been recognised by other industries such as manufacturing. Most respondents have also supported the view that a CAD system could make a good starting point for their construction planning processes. It was revealed as well that most top UK and US contractors use project management systems and that CPM/PERT techniques are still the most dominant for planning, scheduling and controlling construction projects. With regards to the use of CAD systems, it was found that a great deal of the surveyed companies have started to realise the importance of investing and acquiring such systems which indicates that the development of a total integrated construction system could soon become a reality.
However, it has to be said that organisational, technical and financial problems need to be overcome in order to pave the way to such systems. Such problems could be overcome by adopting new approaches such as design and build, and management contracting. Furthermore, the availability of a relatively cheap and powerful hardware and software packages can give some hope that automation within the construction industry can be achieved near future.

Further research into the role of information technology in the construction industry based on literature review has revealed that most British companies were developing their systems in isolation, particularly in the area of computer aided design. This potential problem has been highlighted by a working party of the National Economic Development Office (NEDO) which recommended that the UK construction industry should avoid computerising current applications without looking to eliminate inefficiency, inaccuracy and bad practices. It was also found that the software selection criteria for project management, databases and computer aided design systems suitable for integrated applications were not specified in any of the references used during the literature search. This led the author to consider some selection criteria for these computer packages. One of the major findings in this respect was that the market is almost saturated by these systems, but the big dilemma is which software is to be selected when faced with an array of different packages. After investigation it was found that the major features which are to be looked at can be summarised as: user interface, documentation, vendor support, cost, basic facilities supported by the system, customisation capabilities, incorporation of programming languages, communications and finally whether interfaces to external programs are provided.

10.1.2 THE TRADITIONAL CONSTRUCTION PLANNING PROCEDURE

The literature review on the current approach of planning construction projects indicated that this system was inefficient and can be error prone as most data have to be re-extracted from conventional drawings and documents which can be subject to a great misinterpretation by construction planners when establishing the master plan. One of the main findings was that, the RIBA plan of work which is widely known in the UK implies that the different stages of the construction project are discrete. Therefore, in a poor communication environment, changes at any stage may not be accounted for in another. In addition, the bill of quantities type of contract which is common in the UK can also be regarded as inefficient as the construction planner is brought into the process once the design is substantially completed.
With regards to the use of computers for planning purposes, it appeared that most computerised planning applications are little more than manual formulation of the construction plan. In such systems, data are fed into the computer program and computations are performed using either Critical Path Method (CPM) or Programme Evaluation and Review Technique (PERT) concepts. However, data related to activity lists, resource requirements and durations are not automatically generated within the system. Furthermore, as construction activities can be associated with any combination of design elements, a new phase of quantities generation would be imminent. Such an approach has been highlighted as error prone and time consuming.

10.1.3 AVAILABLE CONSTRUCTION PLANNING MODELS

The various construction planning models developed previous to this work have been classified in Chapter Four as procedural or computer models. The procedural models encompass techniques like barcharts, linked barcharts, line of balance and network analysis, even though these can also be computerised. One of the main findings was that barcharts and network techniques are widely used by construction planners as planning, scheduling and controlling tools. The strength of the CPM method has been enforced by the thorough explanation of a typical example included in Chapter Four. With regards to the use of computer models within the construction planning framework, it appeared that expert systems, simulation techniques and graphic models have been developed by fellow researchers in order to automate the construction planning process. These models were found not to be extensively used by the construction industry as they require huge amounts of data input and lack the flexibility needed by construction planners to account for the unique nature of construction projects.

10.1.4 THE DEVELOPED INTEGRATED CONSTRUCTION PLANNING MODEL

The integrated construction planning model was proposed by the author to rectify some of the problems encountered in traditional systems. The main achievement has been the development and validation of a comprehensive CAD-based integrated system for the planning of the construction of in-situ concrete structures based on integrated approaches. The functions integrated include the modelling, drafting, materials and quantities scheduling, time and cost analyses of these concrete elements (see Figure 6.2). The key to this development was the coupling of powerful micro-based computer aided design, databases and project management systems.
The integrated model consists of the following sub-systems: modelling, data transfer and planning. The different conclusions which can be drawn at the different stages of the model development are summarised below.

A THE ESTABLISHMENT OF THE SYSTEM STRATEGY

The integrated model was proposed to handle the textual and graphical data found in a building project with a single system. Such a model has proven to be feasible as data can now be managed properly in order to avoid inconsistency and double handling. This approach was adopted to establish the integrated program network strategy for construction planning shown in Figure 6.2. The selection of the different involved software packages, namely dBase IV, Artemis and AutoCAD has taken place after a thorough evaluation. The main finding was that, available software and hardware technologies allow the establishment of an integrated construction planning system within the microcomputer environment. Such system can emulate the concept of expensive engineering databases by interfacing computer aided design which can handle graphical data and databases which can look after the textual aspect of the project information.

B THE DEVELOPMENT OF THE INTEGRATED MODEL

As mentioned earlier, and illustrated in Figure 6.1, the integrated model involved the incorporation of three sub-systems: modelling, data transfer and planning. The modelling phase necessitated the use of a CAD system to model in-situ concrete components and their associated construction activities on the computer screen. The micro-based AutoCAD package has proven its power for the implementation of this phase. One of the main findings was that, what can only be done some years ago on a mini-computer / mainframe system is now achievable within the environment of a low cost microcomputer machine. The modelling sub-system gives the construction planner the power to simulate the construction sequence on the screen, besides the capability to undertake a what-if scenarios to arrive at an appropriate project completion time. For instance, once the network diagram has been developed and presented within its electronic format, the construction planner can change one of the parameters affecting activities durations such as type of pour, gang sizes, etc and then new durations will be calculated within the system and they will automatically replace the old ones. In addition the layering system supported by most micro-based CAD systems can be used to keep different design elements on different layers. Such approach would give the
construction planner more flexibility and freedom in classifying the design components. Also, it was concluded that the use of a CAD system would give the user more capabilities in terms of visualisation of the construction plant, site, etc to account for any restrictions and trade / equipment interactions.

With regards to the data transfer sub-system, it was revealed that a recognised standard format for data exchange between the various computer programs has no existence. However, the presence of strong application programs such as dBase IV which supports a large number of data formats has facilitated the design of this sub-system. dBase has been used for the transfer of data between the two incompatible systems: AutoCAD and Artemis 2000. The main task of the data transfer sub-system was to extract attributes from the electronic model of the network diagram, and to pass these data coupled with those generated during the modelling phase (concreting, steel fixing and formwork files) to the planning package for the purposes of time and cost analyses.

The last sub-system of the integrated model is the planning phase. This sub-system was implemented within the Artemis 2000 project management software. The main finding was that the presence of a project management system within an integrated model can strengthen such approach as planning, controlling, materials ordering and purchasing can all be implemented within this system provided that an access to a relational database facility, high level command language and interfaces to external programs are incorporated within the package. The Artemis 2000 package was customised to allow for a better user interface and to incorporate all the modules required to implement this phase. One of the main tasks of this sub-system is to undertake the Critical Path Method (CPM) in order to arrive at the project completion time and to highlight critical activities which are to be finished on time if the project is to be completed within the available period. In addition, this phase performs the cost calculations related to the concreting, formwork and steel fixing activities associated with design elements. The outputs of this sub-system can be summarised as: activities status reports, activities with float, barcharts, histograms and cost reports.

The integration of the modelling, data transfer and planning sub-systems have proven that the design and management of construction project information can be implemented within a single system. Such approach would reduce if not eliminate data redundancy and double handling. In addition, the project can be simulated on the screen from start to finish, thus an optimised version can eventually be arrived at.
The integrated model validity and acceptability has been assessed through various tests and verification procedures. The tests performed on the system have proven that the developed integrated model is generally error and bug free. The model acceptability, credibility and reliability have been approved by experienced construction planners and other interested parties. It is their view that the integrated model is useful and has considerable potential. In fact, many construction companies have started to appreciate the importance of information technology, particularly in the areas of computer aided design and integrated applications.

Finally, it has to be said that the development of integrated models within the construction industry still faces organisational, technical and financial problems. The organisational problem is related to the structure of the construction industry which needs to be modified. The technical difficulties are associated with those of computer power and memory limitations. Lastly, the financial implications are those associated with the initial purchase of the system and staff training.

10.2 THE CONTRIBUTION OF THE RESEARCH

This research has contributed to both construction planning practices and research in the sense that a new approach to the management of construction projects has been devised based on recent developments in information technology. This research has addressed the importance of information technology which would eventually lead to changes in current working practices. The integrated construction planning model has proven that new strategies should be adopted if construction projects are to be managed and planned effectively. Such strategies are based on the coupling of powerful and low cost software packages which are now within the reach of many construction companies. The contribution of the research to the area of computer aided construction planning is summarised below.

1- A new approach to computerised construction planning has been developed based on recent technical developments in the information technology industry.

2- A strategy based on the concept of integrating low cost and powerful packages has been adopted. Such a strategy has been successfully used in the past, and its usefulness has been realised once again during this research.
3- An integrated construction planning model has been developed and implemented on an IBM PS2 model 70 machine. The system is user friendly and can support facilities for: modeling, drafting, quantities generating, time and cost analyses, and reporting.

4- In the light of developing the integrated system, a questionnaire survey was undertaken amongst the top UK and US contractors. The results of this questionnaire (Chapter Two) can be looked at as a major contribution of the research as they can be used as check-lists against which construction planners choose appropriate planning models and information technology features.

10.3 RECOMMENDATIONS

The importance of information has only recently being realised by construction planners and managers. However, it has to be said that information technology aspects, particularly those of computer aided design and integrated models would demand a total rethinking of existing working practices within the framework of construction planning. Therefore, it is highly recommended that the construction industry should consider functional and organisational changes in order to apply new computer-based solutions which could improve the management and planning of construction projects through the proper management of information which would enable projects to be finished on time, within cost and to the required quality standard.

The need for integrated and automated construction planning systems has only just been realised and highlighted by the interested parties. Such integration and automation can be achieved to a certain degree of success within available software and hardware technologies. These systems would handle data in its electronic format, automate the creation of network diagrams and even optimise it as they are flexible enough to accommodate any changes in the data input.

Other industries, such as manufacturing, have successfully adopted CAD and integrated-based models for their production tasks. It is probably time for the UK construction industry to re-consider its position in the light of recent information technology advancements and developments and adopt such approaches, otherwise it would lag behind clearing the way for more competition from European companies, particularly in 1992.

The comparison made in Chapter Five between traditional and integrated systems highlighted the need and importance of the latter. The developed integrated construction
planning model has proven that integration can be achieved on powerful and low cost microcomputers which can now be affordable by many construction companies.

10.4 FURTHER RESEARCH

Several suggestions and recommendations for further research and development have been made in chapters Six and Seven of this thesis. These have been summarised as below:

1- As the developed integrated construction planning model is highly experimental, only concreting, steel fixing and formwork activities have been associated with in-situ concrete elements. Further research should, however, consider additional important activities such as excavation, backfilling, painting, plastering, sanitary work, etc. The same strategy used to develop the concept of the integrated model could be used to incorporate these activities.

2- The integrated model lacks the intelligence needed to recognise elements of work. The model was only experimented with using elements of pre-defined activities. Further research should consider the recognition of construction elements within the model itself. For instance, excavation and backfilling activities should be associated with foundations elements, etc; whereas for a slab floor such activities should be ignored.

3- In the integrated model, the user has to decide on the priorities and logics of activities to be placed in the network diagram as the model is not linked to any expert system. It is, therefore, suggested that further research should be undertaken to investigate and assess the necessity for an expert system to achieve complete automation within integrated applications. The developed integrated model can be regarded as partially automated as the construction planner has been given enough flexibility to account for the unique nature of construction projects.

4- This research has proved that the application of a CAD-based integrated planning system could soon become a reality as many information technology aspects are well within the reach of most construction firms. However, the practicality of these techniques has to be assessed on real life projects which could be the subject of a further research.
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CHAPTER EIGHT


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CHAPTER NINE

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APPENDIX B - A LIST OF JOURNALS AND MAGAZINES RELEVANT TO THE SELECTION OF MICRO-BASED PROJECT MANAGEMENT AND COMPUTER AIDED DESIGN PACKAGES.

APPENDIX C - THE CASE STUDY IN DETAIL.

APPENDIX D - SAMPLES OF PRINT-OUTS.
APPENDIX A - THE QUESTIONNAIRE SURVEY

A.1 INTRODUCTION.
A.2 THE APPROACHING LETTER.
A.3 A COPY OF THE QUESTIONNAIRE.
APPENDIX A - THE QUESTIONNAIRE SURVEY

A.1 INTRODUCTION

As the main aim of this research was to develop a CAD-based integrated model which will aid the planning of concrete structures, it was necessary to establish the current status of information technology and planning aspects among the main UK and US contractors. Consequently, a questionnaire survey had to be undertaken among these contractors. A full analysis of this survey can be found in Chapter Two of this thesis.

A.2 THE APPROACHING LETTER

The planning engineers of the top 100 contractors in the UK and of the top 400 contractors in the USA were approached to take part in this questionnaire survey. Thirty three and forty two replies were received from these UK and US planning engineers respectively. A copy of the approaching letter is included below.

Dear Sir, Madam

I am a research student at Loughborough University of Tecnology. The main aim of my research is to develop a package which will aid in the planning of in-situ concrete structures using an integrated system approach. The package will be highly experimental and it will be based on the idea of integrating the AutoCAD 10 and Artemis 2000 packages. The enclosed questionnaire is designed to seek the UK and USA construction industry response to the integrated system approach. In such a system, the construction planner would have access to the CAD system and could model his or her components in the same way they are going to be built on site. Simultaneously, he or she would generate the network diagram. The plan is then automatically transferred to the planning package for time and cost analyses.

I would be extremely grateful if you could spare me a few minutes to answer my questionnaire. Answers will be treated in absolute confidence. I look forward to hearing from you.

Yours Sincerely,

Ghassan Aouad
A.3 A COPY OF THE QUESTIONNAIRE

The questionnaire was structured in four parts covering the following major areas:

* planning in general (Part A);
* computer aided design systems (Part B);
* project management systems (Part C); and
* integrated applications (Part D).

Current practices of these major areas were all covered in the survey. A copy of the questionnaire is included below.

PART A (PLANNING IN GENERAL)

1- What kind of work does your company generally undertake? (tick both if necessary).
   a) Building work
   b) Civil Engineering work

2- What planning techniques are used in your company?
   a) Critical Path Method (CPM)
   b) Programme Evaluation and Review Technique (PERT)
   c) Graphical Evaluation and Review Technique (GERT)
   d) Bar charts
   e) Line of Balance
   f) Heuristics Methods
   g) Others

3- What sort of network diagrams do you prefer if used?
   i-
   a) On the arrow
   b) On the node
   ii- Can you give me reasons please?

iii- Some people argue that CPM and PERT were originated outside the construction industry and their algorithms are not suitable for our requirements. Do you support
these views and why?.................................................................
.............................................................................................
.............................................................................................

iv- How important is the use of CPM in the success of your company?
    a) Very important
    b) Important
    c) Unimportant
    d) I do not know

v- Do you find CPM calculations difficult?

4- Do you think that computer models such as expert systems and simulation techniques could be applied for construction planning and why?........................................
......................................................................................
......................................................................................

5- What sources of data do you use to estimate output rates?
    a) Experience
    b) Historical records
    c) Wessex
    d) Work study database
    e) Others

6- Do you think the generation of network plans from conventional drawings and documents is error prone and why?
......................................................................................
......................................................................................
......................................................................................

PART B (PROJECT MANAGEMENT SOFTWARE INFORMATION IF AVAILABLE)

1- What is the name of the package you are using?
......................................................................................
......................................................................................

2- When was it acquired?
......................................................................................
3- Is it available on
   a) Mainframe
   b) Minicomputer
   c) Microcomputer

4- What are the hardware requirements?

5- What is the cost of the package (software)?

6- How was the package acquired:
   a) After evaluation
   b) Recommendations from others
   c) Others

7- Does your package support the following:

   a) Activity on the arrow
   b) Activity on the node
   c) Relational database
   d) Good documentation (manuals and tutorials)
   e) Good vendor support
   f) Interfaces to external programs
   g) Customisation facilities
   h) High level command language
   i) Report generator
   j) Graph generator
   k) Access to data files by password
   l) Network plot
   m) Multinetworks
   n) Links to CAD systems

8- What is the maximum size of network the software can analyse?

9- How much training is needed for someone who is familiar with manual CPM calculations?
PART C (CAD PACKAGE INFORMATION IF AVAILABLE FOR PLANNER USE)

1- What is the name of the package?

2- Is it available on
   a) Mainframe 
   b) Minicomputer 
   c) Microcomputer 

3- Is the CAD package available on the same computer as the project management software?

4- Under what operating system is the package run?

5- What is the cost of the software?

6- What are the hardware requirements?

Does the package support the following:

   YES  NO

 a) 2D drafting 
 b) 2 1/2 D modeling 
 c) 3D solid modeling 
 d) Possibility to attach attributes to symbols 
 e) Interfaces to external programs 
 f) Ability to look at the drawing database 
 g) Good documentation (manuals and tutorials) 
 h) Good vendor support 
 i) Link to a planning system 
 j) Bill of materials facility 
 k) Intercomputer communications (network) 
 l) Full graphical data exchange (DXF, IGES,..)

8- What is the learning period to use the system?
PART D (THE INTEGRATED SYSTEM: GENERAL QUESTIONS)

1- Do you foresee any possibility for a CAD system to make a starting point for construction planners and why? ..................................................................................

2- Is it possible to establish a version of CIM (Computer Integrated Manufacturing) for the building industry and why? ............................................................................

3- Do you accept the fact that most construction management data is initialised at the construction stage rather than at the early development of the project? ..................

4- For an integrated system to be achieved, designers and contractors should change their way of thinking. Is that correct and why? ..........................................................

5- If yes, would that be possible in the near future? ..........................................................

6- Do you believe that construction planners have to re-extract most information from conventional drawings and documents to devise the master plan? ..................

7- Would you consider the above as data doublehandling? ........................................

8- Is it helpful in the sense that a CAD system would allow construction planners to place their components the way they would be built on site? ............................

9- Is it extremely important for construction planners to visualise the building model to account for site restrictions, and equipment and trade interactions? ..................

..........................................................
10- What difficulties would the construction industry face when implementing an integrated system approach?

Thank you for your kind cooperation.
APPENDIX B

A LIST OF JOURNALS AND MAGAZINES RELEVANT TO THE SELECTION OF PROJECT MANAGEMENT AND COMPUTER AIDED DESIGN PACKAGES.

B.1 INTRODUCTION

B.2 LIST OF JOURNALS AND MAGAZINES
APPENDIX B - A LIST OF JOURNALS AND MAGAZINES RELEVANT TO THE SELECTION OF PROJECT MANAGEMENT AND COMPUTER AIDED DESIGN PACKAGES.

B.1 INTRODUCTION

The evaluation of computer aided design and project management packages is a major concern, as the development of a CAD-based integrated planning system relies heavily on the careful examination of these packages, particularly those of project management and computer aided design. Also, it was found that the market is almost saturated with these packages, which makes the selection process of these computer systems even more difficult. However, many magazines and journals have dedicated some of their sections to the evaluation of these programs. A list of these journals and magazines can be found in the next section.

B.2 A LIST OF JOURNALS AND MAGAZINES

Novice and professional users can refer to the following list of magazines and journals relevant to the selection of computer aided design (CAD) and project management systems (PM).

1- Computer Aided Design (CAD)
2- Computer Aided Engineering (CAD)
3- CADUser (CAD)
4- Computer Aided Design and Drafting (CAD)
5- Project Management Today (PM)
6- Project Management Journal (PM)
7- Construction Computing (CAD and PM)
8- Software Review (CAD and PM)
9- Byte (CAD and PM)
10- Building (CAD and PM) and
11- Practical Computing (CAD and PM).
APPENDIX C - THE CASE STUDY IN DETAIL

C.1 INTRODUCTION
C.2 THE CASE STUDY
C.3 USER MANUAL
APPENDIX C - THE CASE STUDY IN DETAILS

C.1 INTRODUCTION

This appendix considers the case study discussed in Chapter Nine in more detail. In addition, it includes a user manual of the developed package which facilitates the interaction between the model and the user. Also, screen snapshots are shown in order to illustrate the system in operation.

C.2 THE CASE STUDY

The imaginary structure (see Figure C.1, Figure C.2 and Figure C.3) used in Chapter Nine to run the case study consisted of:

- 4 footings 3m x 3m x 1m
  Formwork type: below ground with bolts
  Pour type: pump (see Figure C.4)

- 4 ground beams 0.5m x 0.5m x 5m
  Formwork type: steel
  Pour type: direct pour (see Figure C.5)

- 4 columns 1m x 1m x 5m
  Formwork type: external clamps
  Pour type: skip (see Figure C.6)

- Roof 10m x 10m x 0.3m
  Formwork type traditional deck
  Pour type: skip (see Figure 6.7)

- Reinforcement bars were also added to these design elements. (see Figure 6.8)

This case study is now described step by step. The following procedure can be followed:

1- Establish grid lines on layer 0.
2- Use the layer option of the Model pull down menu and set a new layer; call it layer 1.

3- Place the footings concrete layouts on layer 1 (use the Model pull down menu) and give them an id starting with f for footings and followed by the grid lines (as an example, f1a), and add attributes as required.

4- Copy the first placed symbol as required using the Edit side menu.

5- Define a new layer and place reinforcement bars within the boundaries of the concrete layouts.

6- Use the same procedure to model the whole structure.

7- Once the imaginary structure is modeled, use the Compute pull down menu to generate the network plan associated with this structure (see Figure C.9 and Figure C.10). First, define global values (refer to Figure 6.8), then start selecting design elements using the digitizer (mouse). Specific routines have been stored within the developed package to work out the durations of activities associated with these design elements. The factors which affect the activity duration include: the type of database, type of design element, and finally the formwork and pouring methods. As an example, to pour concrete into a column using a pump the following procedure can be used:

a- design elements are first selected;
b- quantities associated with these design elements (volumes, areas, etc) are generated automatically within the system;
c- the basic time of this activity is then calculated using the following equation:
\[ BT = (67 + 10.04V + 3.57A) \times 1.0775 \] (in minutes) \( V \) = volume; \( A \) = area.
d- the site factor is also calculated:
\[ \text{Site factor} = 0.863 + 7.88/p^2 \] \( p \) = pay per hour £/hour.
e- the activity duration is then worked out within the program according to the gang size and the site factor values (refer to Chapter Six). Figure C.11, Figure C.12 and Figure C.13 show the outputs of the modeling phase (reports).

It is worth mentioning that when a design element is selected for the second time, the system will detect and warn the user that an activity has been associated with this design element.

8- Following this stage of activity duration calculation, the user is prompted whether to insert an activity, event, etc (see Figure C.14 and Figure C.15) into the network model (the steps can be followed on the screen) (see Figure C.16).

9- Once the network plan is generated during the modeling phase, a new stage of data transfer is then required. The user can now use the Extract pull down
menu to achieve this task. First, he/she has to define a template file (see Figure C.17) which shows the order and the format in which the attributes are to be extracted from the network model. The extracted values can be in either CDF or SDF formats. (see Figure C.18). These values are then transferred to the Artemis 2000 package via dBase IV.

10- Define a database template file (within dBase IV) for the file to be extracted from AutoCAD 10 (see Figure C.19 and Figure C.20).

11- The same procedure could be followed to define templates to transfer the files required to undertake cost analysis (see Figure C.21 and Figure C.22).

12- Run the data transfer utility incorporated within dBase IV by typing do acaddb4 at the dot prompt to produce DIF files of the network and costing files generated within AutoCAD (see Figure C.23). At this stage, the network DIF file should look as follows:

TABLE
0,1
"
TUPLES
0,21
"
VECTORS
0,10
"
DATA
0,0
"
-1,0
BOT
1,0
"PHPE"
1,0
"PHSE"
1,0
"PHDU"
1,0
"PHLE"
1,0
"PHLA"

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This DIF file is then transferred to the Artemis package for the time analysis task.

Run the customised planning system at the Artemis asterisk level by typing do doc initial.
13- Transfer the dBase IV DIF file into Artemis 2000 using the data transfer option of the first pop-up menu (see Figure C.24).
14- Undertake the time and cost analyses tasks following the steps on the screen. (see Figure C.25 and Figure C.26).
Figure C.1 The imaginary structure in 3D (case study)

Figure C.2 A plan view of the imaginary structure
Figure C.3 A detailed reinforced concrete footing

Figure C.4 The foundation attributes
Figure C.5 The ground beam attributes

Figure C.6 The column attributes
Figure C.7 The roof slab attributes

Figure C.8 The reinforcement attributes
Figure C.9 The network and the design models

Figure C.10 The network model after zooming
Figure C.11 The concreting file (report)

Figure C.12 The formwork file (report)
Figure C.13 The reinforcement file (report)

Figure C.14 The activity attributes
Figure C.15 The event attributes

Figure C.16 The detailed network model
Figure C.17 An AutoCAD template file

Figure C.18 An SDF file of the attributes extracted from the network model
Figure C.19 A dBase IV template file

Figure C.20 A dBase file containing values extracted from AutoCAD
Figure C.21 The CDF concreting file

Figure C.22 The CDF formwork file
Figure C.23 The data transfer utility

Figure C.24 The main menu of the planning sub-system
Figure C.25 A barchart of the project activities

Figure C.26 Activity Status list
C.3 USER MANUAL

This user manual is included in order to facilitate the interaction between the user and the developed model. The following steps are required to run the application.

1- Place dongles (electronic device) in the appropriate socket at the back of the microcomputer
2- Switch on the microcomputer; you will see c:\>
3- Type cd\ga and hit enter; you will see c:\>ga
4- Type extlisp and hit enter; you will get the message "Release 10 extended"
5- Type acad and hit enter (twice); you will get the main AutoCAD menu

Main Menu

0 Exit AutoCAD
1 Begin a new drawing
2 Edit an existing drawing
3 Plot a drawing
4 Printer plot a drawing
5 Configure AutoCAD
6 File utilities
7 Compile shape/font description file
8 Convert old drawing file
Enter selection

6- If you want to start a new drawing, select option 1; if you want to edit an existing drawing, choose option 2
7- Type name of a drawing and hit enter; you will see the message "loading acad.lsp (it will take about a minute)
8- Select setup from the AutoCAD side menu
9- Select Unit type decimal
10- Select Millimtr
11- Select 1/100 as a scale
12- Select 279x210 for sheet size
13- Select settings
14- Select Grid
15- Type 1000
16- Select Snap
17- Type 1000
18- Select draw from the side menu and place grid lines on layer 0
19- Select the Model pull down menu and choose concrete layout/rectangular
20- Insert point using the digitizer
21- Select X scale factor
22- Select Y scale factor
23- Select rotation angle
24- Add attributes
25- Edit attributes if required.
26- Select Dtext to insert text into a drawing
27- Undertake the steps explained in the previous section using Model, Compute and Extract pull down menus
28- Type end to save your drawing and exit AutoCAD
29- Type cd\dbase and hit enter
30- Type dbase and hit enter
31- Use the different menus provided within dBase and design a template database file (see Figure)
32- At the dot prompt, type do acaddb4 and hit enter to run the data transfer utility
33- Format data into DIF using the data transfer utility provided
34- Quit dBase using the exit to DOS option
35- Type cd\ar and hit enter
36- Type artemis and hit enter
37- Type 1 and hit enter (three times)
38- At the asterisk level, type do doc initial and hit enter
39- Select the appropriate option from the main menu (see Figure)
40- Quit Artemis by selecting exit to the disk operating system.
APPENDIX D - SAMPLES OF PRINT OUTS

D.1 INTRODUCTION
D.2 A SAMPLE OF AN AUTOCAD PULL DOWN MENU MODULE
D.3 A SAMPLE OF AN AUTOLISP MODULE
D.4 A SAMPLE OF A DBASE IV MODULE
D.5 A SAMPLE OF AN ARTEMIS 2000 MODULE
APPENDIX D - SAMPLES OF PRINT-OUTS

INTRODUCTION

This appendix contains samples of the program modules written in the Autolisp, dBase IV and Artemis languages and integrated within the developed CAD-based planning application. A full listing of these programs can, however, be obtained from the Department of Civil Engineering at Loughborough University.

D.1 A SAMPLE OF AN AUTOCAD PULL DOWN MENU MODULE

The ACAD.MNU incorporated within the AutoCAD 10 package has been used to design the different pull down menus required to develop the integrated model. A listing of some of the modules written and incorporated within the ACAD.MNU file to produce additional pull down menus within the AutoCAD 10 package (pull down menus 7, 8, 9) is shown below.

```plaintext
***pop 7
[Extract]
[Help]rchelp1
[Template file]ctemplate
[Attribute extract]catttext
[Text to drawing]ctextimp
***pop 8
**p8a
[Compute]
[Help]rchelp2
[Select option] $p8=p8b $p8=* 
[Update] $p8=p8c $p8=* 
**p8b
[Select option]
[Global]ccolumn1
[Concreting&formwork]c(option)
[Steel fixing]c(opt)
[Exit] $p8=p8a
**p8c
[Update]
```

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D.2 A SAMPLE OF AN AUTOLISP MODULE

The Autolisp interpreter incorporated within the AutoCAD package was mainly used in the developed model to write the different routines required to automate the generation
of network diagrams and their associated materials and quantities. Below is a listing of some Autolisp modules.

(defun c:columnl()
   (setq fuel "concdura"); a file to store the values of concreting durations
   (princ "\nenter file name for concreting durations <")
   (princ file)
   (setq file (getstring">:\")); to provide default values
   (cond ((equal file "") (setq file "concdura")
         )
   )
)

(defun net(layernme la/ act x y or q qy qyn)
   (command "layer" "thaw" layernme "); to thaw a layer
   (command "layer" "M" layernme "); to make a layer
   (command "layer" "freeze" la "); to freeze a layer
   (setvar "attdia" 0); to set attribute dialogue to 0 (no dialogue window)
   (command "plan" "")
   (setq act "event")
   (princ "\nenter /event/dummy/arrow/aid/form_task/conc_task/steel_task <") ; to model network
   (princ act); to provide default values
   (setq act (getstring ">:"))
   (cond ((equal act "") (setq act "event")
         )
   )
   (initget 1); to initialise input
   (setq in (getpoint "\nenter insertion point : ")
   (setq x 1)
   (princ "\nenter x factor <")
   (princ x)
   (setq x (getreal ">:"))
   (cond ((equal x nil) (setq x 1)
         )
   )
   (setq y (getreal "\nenter y factor"))
   (setq or (getreal "\nenter rotation angle"))
)
(setq or (rtos or)); real to string
(cond ((equal act "event")
  (setq edi (getstring "\ncode your event"))
  (command "insert" act in x y or edi); to insert event
)
((equal act "dummy")
 (setq pdi (getstring "\nwhat preceding event"))
 (setq sdi (getstring "\nwhat succeeding event"))
 (setq xdi (getstring "\nwhat work pattern"))
 (setq lei "0" lai "0" dti "dummy")
 (setq ddi "it_is_a_dummy" dci "no_code_for_dummy" gdi "0" dui "0")
 (command "insert" "g1dum" in x y or pdi sdi dui lei xdi ddi dti dci)
)
);

; the same procedure to insert other symbols
; to make this routine of recursive nature (to call itself) the following is required
(setq q nil)
(setq qyn '(0 13 32 78 89 110 121)); keyboard codes
(setq qy '(0 13 32 89 121))
(prompt "do you wish to select another event or activity <Y>: ")
(while (equal member q qyn) nil)
 (setq q (last (grread)))
)
(if (member q qy)
  (net); to call itself
)
)

A full listing of the Autolisp program can be obtained from the department upon request.

D.3 A SAMPLE OF A DBASE IV MODULE

The dBase IV program incorporated within the developed CAD-based integrated planning model was mainly used to transfer data from the AutoCAD package into the Artemis 2000 software. A program was written in the dBase language in order to automate this data transfer phase. The following is a sample program written in dBase IV.
set talk off
@ 0,0 clear
store 'y' to run
@ 5,12 say "file transfer utility"
@ 7,12 say 'by G.Aouad and A.Price'
@ 9,12 say 'of Loughborough University'
@ 13,12 say 'a utility to format data as required'
@ 20,12 say 'do you want to continue';
    get run picture '!' read
    if run = 'y'
        @ 0,0 clear
    else
        clear
        cancel
    endif
do while .t.
    @ 0,0 clear
    choice = " "
    @ 3,24 say "MAIN MENU"
    @ 5,24 say "(0) transport AutoCAD CDF file"
    @ 7,24 say "(1) format file into DIF for Artemis uses"
    @ 9,24 say "(2) Transport AutoCAD SDF file"
    @ 11,24 say "(3) exit to operating system"
    @ 13,24 say "(4) exit to dot prompt"
    @ 18,24 say "enter option" get choice
read
do case
case choice = '0'
    @ 0,0 clear
    store .t. to a
    do while a
        store ' ' to sdfile
        @ 5,15 say 'what AutoCAD CDF file do you want to transport?';
        get sdfile picture '!!!!!!!!!!!!!!'
        read
            if sdfile = ' '
D.4 A SAMPLE OF AN ARTEMIS 2000 MODULE

The planning sub-system of the CAD-based integrated planning model was implemented within the Artemis 2000 environment. This package was fully customised using the high level command language provided within the system. Such customisation has allowed the development of an easy to use and friendly planning sub-system. A routine sample written in the Artemis 2000 language is shown below.

; doc main
create process gmains ; the main options of the planning sub-system
local; local variable
  a type text
end
do
$clear
use
  type terminal
  window vec(0,0,8,40,12,2,0,0,0,3,0,80,3) ; to produce a window
$window_title(2,'Main Menu')
$form_init()
$form_text (3,6, 'Help 1')
$form_text (4,6, 'Data Transfer 2')
$form_text (5,6, 'Time Analysis 3')
$form_text (6,6, 'Cost Analysis 4')
$form_text (7,6, 'Reports 5')
$form_text (8,6, 'Exit to asterisk 6')
$form_text (9,6, 'Exit to system 7')
$form_text (11,9, 'Select Number')
$form_field(11,30,4,0,0,6)
$form_input(a,1)
if $form_get(1)=1
    exe doc help
end
if $form_get(1)=2
    exe doc option
end
if $form_get(1)=3
    exe doc time
end
if $form_get(1)=4
    exe doc cost
end
if $form_get(1)=5
    exe doc report
end
if $form_get(1)=6
    quit
end
if $form_get(1)=7
    bye
end
if $form_get(1) <> 6 and $form_get(1) <> 7
    do process gmains()
end
end
end
end
end
do process gmains()
end