THE DEVELOPMENT AND APPLICATION OF
COMPUTER-AIDED MONO-PHOTOGRAMMETRY
FOR RECORDING ARCHITECTURAL FACADES

(VOLUME ONE)

DAVID STUART WATT

A thesis submitted in partial fulfilment of the
requirements of the Council for National Academic Awards
for the degree of Doctor of Philosophy

July 1990

Leicester Polytechnic
ERRATA

THE DEVELOPMENT AND APPLICATION OF
COMPUTER-AIDED MONO-PHOTOGRAMMETRY
FOR RECORDING ARCHITECTURAL FAÇADES

DAVID STuart WATT

LEICESTER POLYTECHNIC - JULY 1990

Volume I

At the following locations, the word 'specialist' should read 'specialised':

Page 68, Para. 4, Ln. 5.
Page 83, Para. 1, Ln. 9.
Page 87, Para. 2, Ln. 6.
Page 95, Para. 5, Ln. 2.
Page 123, Para. 1, Ln. 2.
Page 125, Para. 1, Ln. 1.
Page 152, Para. 2, Ln. 2.

At the following locations, the word 'historic' should read 'historical':

Page 74, Para. 4, Ln. 7.
Page 78, Para. 4, Ln. 6.
Page 160, Para. 5, Ln. 3.
Page 57, Para. 2, Ln. 7: 'Niepce' should read 'Niépce'.
Page 73, Para. 1, Ln. 2: 'by' should read 'be'.
Page 78, Para. 4, Ln. 2: 'fashions' should read 'fashion'.
Page 82, Fig. 4.2: '1.2mm' should read '1.5mm'.
Page 94, Para. 4, Ln. 4: 'property' should read 'properly'.
Page 100, Ln. 3: 'draws' should read 'draw'.
Page 105, Para. 4, Ln. 3: 'fail' should read 'fails'.
Page 107, Para. 3, Ln. 2: 'adapting' should read 'adopting'.
Page 125, Para. 2, Ln. 4: 'make' should be 'makes'.

Page 125, Para. 3, Ln. 6: 'applications' should read 'application'.

Page 147, Para. 2, Ln. 7: 'has' should read 'had'.

Page 155, Para. 4, Ln. 4: 'media' should read 'medium'.

Page 164, Para. 2, Ln. 4: 'by' should read 'be'.

Page 172, Para. 1, Ln. 6: 'have' should read 'has'.


---oOo---

Volume II

Page 31, Para. 4, Ln. 3: 'were' should read 'was'.

Page 36, Para. 5, Ln. 1: 'were' should read 'was'.

Page 42, Para. 1, Ln. 1: 'possessed' should read 'possesses'.

Page 43, Para. 4, Ln. 1: 'were' should read 'was'.

Page 43, Para. 4, Ln. 3: 'were' should read 'was'.

Page 106, Para. 1, Ln. 2: 'have' should read 'had'.

Page 126, Para. 1, Ln. 2: 'a' should read 'the'.

1
ABSTRACT

THE DEVELOPMENT AND APPLICATION OF COMPUTER-AIDED MONO-PHOTOGRAMMETRY FOR RECORDING ARCHITECTURAL FAÇADES

DAVID STUART WATT

LEICESTER POLYTECHNIC - JULY 1990

This project has been undertaken to investigate the potential for extracting measurements from photographs, and restituting the information using computerised draughting facilities. Techniques of recording dimensional information from photographs do exist in the forms of stereo-photogrammetry and orthophotography, but the present work seeks to provide an economic and flexible alternative for recording the façades of buildings, monuments and other structures. The mechanics of the method developed in this work are based on the existing technologies of 35mm single-lens reflex photography and computer-aided draughting (CAD). The architectural, or standing archaeological, subject is recorded by normal-case photography using non-metric equipment, and standard surveying instrumentation provides the necessary dimensional control. The required information is entered into the CAD system by manual digitisation and restituted electronically. Analytical rectification of oblique data has also been investigated. The link between photographic surveying and CAD restitution is one fostered in the original work of the candidate, with the resulting theoretical technique having been progressed sufficiently to enable practical surveys to be undertaken using a varied sample of façades. In this respect, dimensional accuracies of ±10-20mm at a plotting scale of 1:50 have been achieved, providing suitable graphical documentation for application in architectural building conservation, including repair, consolidation and visual impact analysis. It has also been demonstrated that information may be recovered from archive data sources to provide graphical and visual information for interpretative studies and architectural analysis.
ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Professor Peter Swallow, Director of Studies, and Mr. Rob Ashton, Director of the Leicester CAD Centre, for their advice and guidance during this work.

I would also like to thank the following for their support and assistance:

Miss Iona Cruickshank and the staff of the Photography Centre, Media Services, Leicester Polytechnic, with particular thanks to Mr. Andy Jablonski.

Mr. Ross Dallas, Chief Surveyor at the English Heritage Photogrammetric Survey Unit, Institute of Advanced Architectural Studies, University of York.

Mr. John Haigh, Departments of Mathematics and Archaeological Sciences, University of Bradford.

Ms. Anne Hilton, Academic Librarian, Kimberlin Library, Leicester Polytechnic.

Mrs Mandy Nelson, Secretary to the Leicester CAD Centre.

Mr. Chris Watts, Director of the Resources Centre, School of the Built Environment, Leicester Polytechnic.

Thanks also to those who provided the opportunity for recording those buildings, monuments and structures that have been used as case studies in this work. Consultancy clients have been credited below.

Finally, special thanks to my wife, Julie, for her support over the past three years.

D.S.W.
LIST OF CONTENTS

VOLUME ONE

LIST OF FIGURES vi
LIST OF APPENDICES vii
PREFACE x

1.0 INTRODUCTION
  1.1 Background to investigation 1
  1.2 Aims and objectives 7
  1.3 Research methodology 8
    1.3.1 Management of investigation 8
    1.3.2 Data gathering and analysis 10
    1.3.3 Selection of sample façades 12
  1.4 Thesis organisation 16

2.0 THE PURPOSE OF SURVEYING
  2.1 The need for surveys 18
    2.1.1 What is a survey? 18
    2.1.2 Aspects of surveying 20
  2.2 Surveying practice 21
    2.2.1 Survey applications 21
    2.2.2 Generators of surveys 24
  2.3 Building surveys 31
    2.3.1 Condition surveys 32
    2.3.2 Measured surveys 35

3.0 HISTORICAL DEVELOPMENTS IN RECORDING METHODOLOGY
  3.1 Introduction 38
  3.2 The development of surveying methods 41
  3.3 The recording of buildings 48
    3.3.1 Treatises, paintings and prints 48
    3.3.2 Architectural drawings 51
    3.3.3 Architectural photography 55

4.0 PRACTICAL SURVEYING AND RECORDING
  4.1 Direct surveying 63
    4.1.1 Building measurement 63
    4.1.2 Building interpretation 67
  4.2 Indirect surveying 75
    4.2.1 Photographic surveying 78
    4.2.2 Rectified photography 87
    4.2.3 Close-range stereo-photogrammetry 91
  4.2.4 Other techniques 105
  4.3 Synopsis of recording practice 107
### 5.0 COMPUTER-AIDED MONO-PHOTOGRAMMETRY

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Introduction</td>
<td>110</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Justification for investigation</td>
<td>110</td>
</tr>
<tr>
<td>5.1.2</td>
<td>Development of methodology</td>
<td>113</td>
</tr>
<tr>
<td>5.1.3</td>
<td>Programme of application</td>
<td>117</td>
</tr>
<tr>
<td>5.2</td>
<td>Mechanics of computer-aided mono-photogrammetry</td>
<td>119</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Photography</td>
<td>120</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Dimensional control</td>
<td>135</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Image restitution</td>
<td>141</td>
</tr>
<tr>
<td>5.3</td>
<td>Analysis of project data</td>
<td>149</td>
</tr>
</tbody>
</table>

### 6.0 SUMMARY AND CONCLUSIONS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Rationale for investigation</td>
<td>160</td>
</tr>
<tr>
<td>6.2</td>
<td>A solution to a recognised problem</td>
<td>162</td>
</tr>
<tr>
<td>6.3</td>
<td>Aspects concerning practical application</td>
<td>166</td>
</tr>
<tr>
<td>6.4</td>
<td>A contribution to the developing practice of recording architectural façades</td>
<td>169</td>
</tr>
</tbody>
</table>

### REFERENCES

BIBLIOGRAPHIC AND UNPUBLISHED SOURCES | 174

---oOo---

### VOLUME TWO

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPENDIX A</td>
<td>Case studies</td>
<td>1</td>
</tr>
<tr>
<td>APPENDIX B</td>
<td>Measured and photographic surveys</td>
<td>156</td>
</tr>
<tr>
<td>APPENDIX C</td>
<td>Specification and references for equipment</td>
<td>159</td>
</tr>
<tr>
<td>APPENDIX D</td>
<td>Published and presented material</td>
<td>175</td>
</tr>
</tbody>
</table>

---oOo---
LIST OF FIGURES

Figure 1.1  Categorisation of survey problems  14
Figure 2.1  Activities that generate change  23
Figure 2.2  Standards of dimensional survey  28
Figure 2.3  Building survey plotting scales  30
Figure 4.1  Criteria for a photographic survey  80
Figure 4.2  Limitations of central-projection photography  82
Figure 4.3  The Scheimpflüg Principle  86
Figure 4.4  Scope for photogrammetry  91
Figure 4.5  Practicalities of non-metric photography  97
Figure 5.1  Electromagnetic spectrum  123
Figure 5.2  Film speed ratings  124
Figure 5.3  Summary of lens aberrations  128
Figure 5.4  Distortion tests  130
Figure 5.5  Calculation of magnification factors  139
Figure 5.6  Elements of digitised elevation  143
Figure 5.7  Digitised construction of arch  145
Figure 6.1  Computer-aided mono-photogrammetry in use  164
Figure 6.2  Summary of survey criteria  165
## LIST OF APPENDICES

### VOLUME II

### APPENDIX A: CASE STUDIES

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Hawthorn Building, The Newarke, Leicester</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td>Scraptoft Hall, Scraptoft, Leicestershire</td>
<td>9</td>
</tr>
<tr>
<td>III</td>
<td>Jewry Wall, St Nicholas Circle, Leicester</td>
<td>14</td>
</tr>
<tr>
<td>IV</td>
<td>The Church of St Mary and St Laurence, Bolsover, Derbyshire</td>
<td>21</td>
</tr>
<tr>
<td>V</td>
<td>King’s Mill Viaduct, Mansfield, Nottinghamshire</td>
<td>30</td>
</tr>
<tr>
<td>VI</td>
<td>Lacock Abbey, Lacock, Wiltshire</td>
<td>36</td>
</tr>
<tr>
<td>VII</td>
<td>The Church of St John the Baptist, Ault Hucknall, Derbyshire and Tickhill Castle, Tickhill, South Yorkshire</td>
<td>42</td>
</tr>
<tr>
<td>VIII</td>
<td>Bagshaw Hall, Bakewell, Derbyshire</td>
<td>50</td>
</tr>
<tr>
<td>IX</td>
<td>Kirby and West Building, Western Boulevard, Leicester</td>
<td>56</td>
</tr>
<tr>
<td>X</td>
<td>The Gazebo, Kelham Hall, Kelham, Nottinghamshire</td>
<td>62</td>
</tr>
<tr>
<td>XI</td>
<td>Eyre Chapel, Newbold, Chesterfield, Derbyshire</td>
<td>69</td>
</tr>
<tr>
<td>XII</td>
<td>Flacketts, Flacketts Lane, Sudbury, Derbyshire</td>
<td>79</td>
</tr>
<tr>
<td>XIII</td>
<td>The Market Place, Aylsham, Norfolk</td>
<td>84</td>
</tr>
<tr>
<td>XIV</td>
<td>Norman cellar, Guildhall Lane, Leicester</td>
<td>91</td>
</tr>
<tr>
<td>XV</td>
<td>Terracotta balustrade, Castle Ashby House, Castle Ashby, Northamptonshire</td>
<td>99</td>
</tr>
<tr>
<td>XVI</td>
<td>Grammar School, Hales Street, Coventry</td>
<td>106</td>
</tr>
</tbody>
</table>
Case Study XVII South-west transept, Ely Cathedral, Cambridgeshire 118
Case Study XVIII The Church of St Mary de Castro, Castle Street, Leicester 126
Case Study XIX Burleigh Cottage, Loughborough University, Leicestershire 131
Case Study XX Leicester Road Cemetery, Loughborough, Leicestershire 141
Case Study XXI Field Cottage, 28/30 Main Street, Ratcliffe-on-the-Wreake, Leicestershire 147

APPENDIX B: MEASURED AND PHOTOGRAPHIC SURVEYS

I. Measured surveys 156
II. Photographic surveys 157

APPENDIX C: SPECIFICATION AND REFERENCES FOR EQUIPMENT

I. GABLE CAD System 159
II. Photographic System 166
III. Surveying System 174

APPENDIX D: PUBLISHED AND PRESENTED MATERIAL


PREFACE

BACKGROUND

During the year 1986/7, following graduation in building surveying, the author was awarded the Hunter + Partners Educational Trust Award to investigate and report on the potential for converting and reusing redundant railway buildings (Watt, 1987). This work led to a number of conclusions, with recognition of the fact that, at the time, as now, many projects involving both static and dynamic intervention are ill-prepared, both in the skills required to undertake the work, and in the documentation used to communicate the intentions of the architect or surveyor.

In order to gain an increased knowledge and awareness of historic buildings and architectural conservation, the author undertook a period of post-graduate training at Leicester Polytechnic leading to the conferrment of a Post-Graduate Diploma in Architectural Building Conservation in 1988. This assisted in responding to the technical and philosophical issues raised by schemes studied for the above report, and developed an awareness within the author for the need to accurately interpret and record all aspects of historic buildings and monuments, whether great or small.

At that time the School of Land and Building Studies (now a department in the School of the Built Environment) established the Leicester CAD Centre to provide a teaching resource, giving building surveying students hands-on experience using computer-aided design/draughting (CAD) facilities. In order to fund initial capital outlay and regular upkeep, it was necessary to undertake consultancy work, primarily in producing three-dimensional visualisations of proposed developments.

This work had progressed sufficiently by 1987, through developing an approach to recording existing buildings using three-dimensional graphics, to consider expanding and investigating the use of CAD for other aspects of building surveying. It was at that time that the author joined the Centre principally to consider the use of photography
and CAD for recording the external faces of buildings.

This initial interest developed into a proposal for combining the two advancing fields of photographic surveying and CAD to formulate a method whereby accurate elevational records could be produced of existing buildings, monuments and other structures, for use in projects involving conservation or preservation.

Early studies were undertaken using buildings chosen for specific reasons, in order to develop a methodology suitable for practical application. Once this had been satisfied, it was found that a demand existed for such a technique, and consultancy work was undertaken, providing further survey problems for which practical solutions were required. The funds generated by this work, together with other contracts, allowed additional equipment to be purchased for the CAD Centre, and led to other research proposals being considered.

The author was able, at this time, to establish links with a local architectural practice, which included an historic buildings team dealing predominantly with the repair and adaptive reuse of historic buildings and ancient monuments. This relationship has benefited both parties, by providing a continual dialogue relating to survey problems and the adoption of practical solutions.

Involvement in professional practice has allowed this work to progress at a level of practical credibility, with the opportunity to learn from previous experiences. This knowledge is being passed on to others involved with existing buildings and monuments through the training offered by the previously mentioned Diploma course; demonstrations for interested groups, including the Building Conservation Group of the Royal Institution of Chartered Surveyors (RICS); and published papers and articles.

Building surveying, as a profession, is concerned with 'the study and evaluation of building performance, and the application of technical, scientific and resource management practices, to create, adapt and maintain favourable built environments' (Swallow, 1990, 22).
The recent move within the property professions to consider the practice of building surveying as something more than just building technology has been stressed at conferences and seminars, and by the recent creation of the Society for the Advancement of Research in Building Surveying (SARBuS), with which the author has been involved. Post-graduate research within this relatively new surveying discipline has been limited, and it is right that early works of investigation, such as this, concentrate on practical aspects that have benefits for many.

BIBLIOGRAPHIC DATA STORAGE AND RETRIEVAL

As part of the management of this project, consideration has been given to the storage and retrieval of bibliographic data. These data form an essential tool in the classification and referencing of the text, and it is thus considered that some comment should be made regarding database structure and operation.

Raw data collected from literature searching and personal communications was required to be easily accessible and cross-referenced. In order to construct such a bibliographic database, a unique thesaurus was first created, representing the multi-disciplinary nature of the work. This was based on a conventional series of hierarchical relationships between the source data (Aitchison and Gilchrist, 1987, 39-44).

Database entries for each item were thus ordered according to the hierarchical descriptors or index terms as used in the thesaurus, so giving consistency, flexibility and ease of interrogation. An example of a bibliographic database entry is included to demonstrate the structuring of the hierarchical relationships. Each entry is classified by its relevant key terms, having broader and narrower terms defined as a means of cross-referencing and for data management purposes. Bibliographic searching operates on an elected key field basis.
AUTHOR(S): Chitty
INITIAL(S): G.
MEDIA: Paper (edited and abridged version of thesis)
BOOK/PERIODICAL: Transactions of the Association for Studies in the Conservation of Historic Buildings (ASCHB)
ARTICLE/PAPER: A Prospect of Ruins
PUBLISHER: ASCHB
PLACE OF PUBLICATION: Kilmersdon (Som.)
DATE OF PUBLICATION: 1987
VOLUME: 12
PART: -
PAGES: 43-60
EDITION: -
STORED: File copy (C)
KEY TERMS: Ancient Monuments; Ruins;
BROADER TERMS: Terminology;
NARROWER TERMS: Conservation; Preservation;
COMMENTS: Definition of 'preservation' cited from Sir Frank Baines, 1923, 104; Appendix charting attitudes and philosophies to care of ancient monuments.

For the citation and structuring of bibliographic references within this thesis, the Harvard system has been adopted throughout, giving the name of the author or editor, year of publication and relevant page number(s). Unpublished sources are cited in a similar manner, although given distinction by the inclusion of the abbreviation 'Unpub.' in the text entry, and appear with the bibliographic references at the end of this volume.

SMART DATA BASE MANAGER, SMART WORD PROCESSOR AND SMART SPREADSHEET (Innovative Software Inc.) have been used for the management and presentation of this thesis, mounted on AMSTRAD PC1512 and OLIVETTI M24 personal computers.
ATTENDANCE AT CONFERENCES AND SEMINARS

Education and Training Seminar, Royal Institution of Chartered Surveyors (Building Surveyors Division), London, 9 April 1987.

Effective Computer Solutions, Royal Institution of Chartered Surveyors (Building Surveyors Division), University of Manchester, 23 September 1987.

Quarrying and Stone Supply, University of Leicester, Department of Adult Education (Continuing Education Unit), Loughborough, 8-10 January 1988.


Repair and Restoration of Listed Buildings, Refurbishment Register, Nottingham, 13 December 1988.

Equipping the Profession for the 1990s, Royal Institution of Chartered Surveyors (Building Surveyors Division), London, 27 April 1989.


Planning the Future of Archaeology in the Peak, The University of Sheffield (Division of Continuing Education), Sheffield, 10 February 1990.

The Geology of the British Isles, The University of Sheffield (Division of Continuing Education), Sheffield, 10 March 1990.
CONSULTANCY CLIENTS

Brayshaw Harrison Partnership, Architects, Chesterfield, Derbys.
Compton Estates Management Services, Castle Ashby, Northants.
Derek Latham and Company, Architects, Derby.
Gibson Hamilton Partnership, Architects, Loughborough, Leics.
Leicestershire Museums, Arts and Records Service, Leicester.
Newark and Sherwood District Council, Kelham, Notts.
Oulsnam Bradbury Design Partnership, Architects, Bakewell, Derbys.
Purcell Miller Tritton and Partners, Architects, Norwich.
S.A. Wright, Architect, Coventry.
T. and J. Design Services, Surveyors, Wanlip, Leics.
1.0 INTRODUCTION

1.1 BACKGROUND TO INVESTIGATION

'We mean to build,
    We first survey the plot, then draw the model;
And when we see the figure of the house,
Then we must rate the cost of the erection;
Which if we find outweighs ability,
What do we then, but draw anew the model
In fewer offices, or at least desist
To build at all?'

This passage, taken from Shakespeare's Henry IV: Part II (Act 1, sc. 3, l. 41 [Bardolph]), introduces two important concepts: that surveying is fundamental to the successful provision of buildings, and that the practices of surveying and design are interrelated.

The processes of measuring and recording the physical enclosure and spatial arrangements that make up a building are crucial to the many activities that seek to alter or adapt its form and function. Demand for these measured surveys varies widely, extending from the production of plans for basic identification purposes through to accurate records of buildings of special architectural or historic interest.

As there can be no form of record that is appropriate in all circumstances, each class of survey represents a different level of information based on a related set of data. The intention of a measured survey is thus to match this level of information with the particular proposal that is being considered.

The various operations that make up such a survey have largely been considered by academics and practitioners alike as a series of practical routines. The result of this is a 'closed' attitude to dimensional surveying, whereby reliance is placed on standard solutions for what are often highly individual survey problems. Measured surveys carried out by the author involving large, complex and often ornate
buildings have resulted in a reappraisal of how, and more importantly, why, survey routines are, in fact, implemented. This intellectual consideration of what is, historically, a practical activity, results from a need to redefine survey problems to generate a set of principles on which new solutions might be based.

The techniques of measurement, recording and interpretation commonly used in the production of a measured drawing have, until recently, remained essentially the same for about four hundred years. Thus, the tape and rod, long-standing symbols of the surveying profession, remain much in use, and represent a direct link back to the Ancient World. Recent refinement of these practices has brought advanced data capture and computer-generated drawing to the forefront of practical surveying.

This introduction of technical solutions to the age-old problem of surveying buildings has, to a large extent, made use of technologies from related disciplines. As a case in point, there can be no doubt that stereo-photogrammetry, originally used for topographic surveying based on aerial photography, has become an established technique for providing accurate architectural and archaeological records. It is clear, however, that an understanding of the parent science, and of the principles on which present methods succeed or fail, is needed in developing an alternative strategy and fostering a mechanistic for successful surveying.

In proposing a solution to a particular problem, it is essential to first recognise the nature and range of the issue. An understanding of what is offered as the preferred response, in the circumstances, provides a model for subsequent appraisal and investigation, leading to the construction of a framework for practical advancement. If the goal is a 'better technique' in that particular application, then 'better' needs to be carefully defined, as often it is interwoven with other related aspects.

Previous research concerning techniques of surveying and recording the façades of existing buildings has concentrated, to a large extent, on the benefits to be derived from increased computer-processing power.
available within current photogrammetric procedures. Where, for instance, in the early 1980s, the bulk of architectural photogrammetry was undertaken using analogue plotters, it is now considerably more common to produce drawings using analytical recording methods.

There is presently, however, no fundamental research being undertaken within the traditional centres of surveying in this country that is directly related to architectural stereo-photogrammetry. This has been offset, in part, however, by an increase in the application of existing practices and equipment to the problems of architectural, and increasingly archaeological, recording.

The work currently being undertaken within the Civil Engineering Department of City University using INTERGRAPH Intermap Analytic, including work on the Mansion House (Coutts, 1988, 2-3) and the Trocadero, Piccadilly (Evans, 1988, 11), demonstrates the manner in which such work is proceeding.

Commercial activity has resulted in a number of alternative photogrammetric products, including the LEITZ Elcovision 10 non-contact measuring system, the SFS-3 full analytical system developed by Ross Instruments Limited, the ROLLEIMETRIC MR Image Analysis System, the ADAM TECHNOLOGY MPS 2 Micro Photogrammetric System, the PENTAX Photogrammetric Analytical Measurement System (PAMS), and the ZEISS G3 Stereocord stereoplotter. These, however, remain outside the budget of most general surveying offices.

Validation of the ROLLEIMETRIC system is currently being undertaken at the Technical University of Braunschweig (Federal Republic of Germany) under Professor W. Wester-Ebbinghaus, using the cathedral and churches of Siena as a model for this work. Science and Engineering Research Council (SERC)-sponsored research at the University of Leeds (Department of Civil Engineering) is currently investigating the use of the ADAM TECHNOLOGY MPS 2 system for the production of improved architectural drawings and monitoring of crack propagation (Van Emden, 1989; Uren, 1990, Unpub.).
Recently, the release of the FOTOMASS photogrammetric system (CAD Solutions Limited) allows the creation of three-dimensional model drawings of existing buildings and objects from standard camera and/or video images, with calculation of the co-ordinate spatial form undertaken using existing CAD facilities. This system is presently being considered by those working at the fire-damaged National Trust property at Uppark (W. Suss.) for generating information for works of restoration from extant photographs.

One might ask whether further pure research is, in fact, needed. It is conceivable that any advances are more likely to stem from increased empiricism, rather than theoretical research. There are, in this respect, a small, but growing, number of persons and organisations actively investigating alternative recording methodologies.

Of these, the work of N. Fradgley, Royal Commission on the Historical Monuments of England, on the use of a total-station theodolite and data logger for recording plan and elevational data; J.G.B. Haigh, University of Bradford (Departments of Mathematics and Archaeological Sciences), with the analytical rectification of aerial photographs for archaeological information recovery; R. McClaren, Turnbull Jeffrey Partnership, Edinburgh, on the use of rectified photography and computer graphics for visual impact analysis; K. Mooney, Trinity College, Dublin (Department of Engineering), with the digital recording of building façades; J. Uren, University of Leeds (Department of Civil Engineering), as detailed above; and Leicester CAD Centre, with the measurement and three-dimensional modelling of buildings and sites, is important in developing complementary techniques for surveying and recording façades.

In 1983, Mr. R. Dallas, discussing the application of alternative recording methodologies, raised the point that research was needed on the whole topic of applying modern instrumentation, and land surveying philosophies, to the measurement of buildings. This was further examined by Dallas (1989a) in considering the contribution of the land surveyor to the surveying and recording of historic buildings, monuments and sites.
This has not, however, been taken up to any great extent, and currently there remains a situation of many methods, with no unity of purpose or conformity to an accepted standard. Isolated practical solutions, such as the use of a Telemeter by Durrant (Dallas, 1983, 23), do not, in themselves, represent viable alternatives, unless developed in a manner that allows their usefulness to be assessed and the results evaluated.

An investigation of these particular issues forms an important part of the on-going research programme at Leicester. This has centred on the critical evaluation of recognised forms of direct and indirect measurement, leading to the development of optical survey procedures for establishing dimensional control, in conjunction with three-dimensional digital modelling of existing buildings and sites.

One particular aspect of building recording that was identified at Leicester as offering potential for further study was in the production of scale drawings of building façades, which placed limited reliance on the input of costly specialised techniques, and yet had tangible benefits over manual surveying. An investigation was therefore initiated, leading to the development and application of computer-aided mono-photogrammetry, as presented in this thesis.

During this inquiry it has become evident that a great deal of the work involved in measuring a building façade could be dispensed with by relying on simple photographic data capture. Little attention has been paid to the potential that exists for using photographic techniques to record building fabric in a manner that allows dimensional analysis to be undertaken. Close-range stereo-photogrammetry performs this function, but is reliant on metric photography and analogue or analytical plotting, and the often-quoted statement that 'whatever can be photographed can also be measured' remains subject to a high level of technical input and an even higher recording budget.

Casual photography, as distinct from its technical counterpart, has become an accepted method of recording information about the condition of a building, and is also widely used as an aide mémoire for hand measurement. There are also occasions where archive photographs
provide essential information, be it in the form of evidence in the case of a dispute, or in the reconstruction of a damaged or missing feature. What is perhaps the key to the successful use of photography in surveying – photographic surveying – is the underlying philosophy that guides the processes of recording, and the subsequent use of the image.

In order to restore the latent data held on a photograph to provide useful information, techniques of image restitution have been examined that make use of existing computer-aided draughting (CAD) facilities. It has long been recognised that the ideal situation would allow scale drawings to be produced in-house, preferably by someone involved with the actual project who has the intimate knowledge of what must be recorded in order to facilitate the subsequent processes. This situation has become a more realistic proposition with the introduction of CAD systems into architectural surveying offices.

The purpose of this work is thus to test and verify the hypothesis that the façades of buildings, monuments and other structures might be indirectly measured and recorded to an acceptable standard through a process of photographic data capture and computer-aided image restitution. Within the structure of this investigation it has been the intention of the author to interpret this proposition in a sufficiently wide manner to avoid it becoming an end in itself, and, in so doing, offer it as a useful exposition in the wider field of architectural recording.

Development and verification of the proposed procedures is thus seen to provide both an intellectual and practical challenge in a previously unresearched area of building surveying. It is also one that has the potential for application in certain allied disciplines, notably in the archaeological recording of standing buildings and elements of construction.
1.2 AIMS AND OBJECTIVES

In any structured investigation there is a need to define the overall concepts, and how they are to be attained within any restraints imposed on the work. It is of the utmost importance to the profitability of the research programme that these two levels of organisation are closely defined, and their differences fully comprehended.

The direction of this investigation has been carefully ordered so as to present a logical and strategic framework within which to implement and attain the stated objectives. The aims are thus to:

(a) Address the problems posed by the desire/need to record the façades of buildings, monuments and other structures.
(b) Provide a means of indirectly recording the façades of buildings, monuments and other structures without recourse having to be made to costly and often contextually inappropriate techniques.
(c) Prove that measured elevational drawings can be produced to an acceptable level of accuracy using standard photographic and CAD facilities.

The objectives of this investigation are to:

(a) Evaluate the processes and products of current direct and indirect surveying methodologies, and compare with those based on the use of computer-aided mono-photogrammetry.
(b) Consider the adaptation of existing measuring and recording methodologies from related disciplines, and evaluate their theoretical and practical benefits.
(c) Refine experimental techniques for routine use in the surveying of built fabric.
1.3 RESEARCH METHODOLOGY

1.3.1 Management of investigation

At the foundation of this work lies the belief that the application of existing science can, through re-interpretation and utilisation, satisfy certain present-day needs. This work is therefore concerned, not with the creation of a new base of learning through pure research, but rather the exploitation of existing technologies through applied research within the discipline of practical architectural recording.

Applied research is, according to Beveridge (1957, 126), a deliberate investigation of a problem of practical importance, in contradistinction to pure research done to gain knowledge for its own sake. Where the application of existing knowledge might be limited to finding a solution to a particular problem, then by seeking to understand the underlying principles, it is intended, as with this work, to achieve a wider general application.

Research, itself, has been described as being 'fundamentally a state of mind involving continual re-examination of doctrines and axioms upon which current thought and action are based...critical of existing practices' (Smith, 1929, 742). In this respect, attention has been paid to present methods of building survey and representation.

Analysis of direct and indirect measurement methodologies, including their historical developments, has been considered necessary in order to provide a justification for elements needed in the production of a viable alternative. Once these have been evaluated, it is then possible to investigate the options available for practical experimentation.

In an initial consideration of the external appearances of a building, it is reasonable to concur that it is the apertures that bring an otherwise blank wall to life, and require the attention in both surveying and interpretation. The author thus felt justified in concentrating experimentation, in the early stages of this investigation, on the recording of door and window openings where the
plane that carried them was not of prime importance. In this manner, the main hypothesis under consideration was proven, and case studies of increasing complexity could be undertaken.

As survey skills and confidence were developed, specific problems were identified and responded to within the range of the criteria laid out in Section 1.3.3 below. It became evident as more surveys were undertaken, however, that there were certain issues that needed to be addressed in order to provide a wholly efficient means of elevational recording.

The use of oblique photographs was seen as an important area for study, enhancing the capabilities of the basic output, and providing an important vehicle for the use of archive material. In addition, the recording of multi-plane and curved façades represented, in themselves, complex problems that would require the application of stereo-imaging technologies in the first instance, and extend the defined aims beyond the scope of this present project.

In this respect, a conscious decision was taken to produce a broad-based research thesis that would offer guidance to future researchers, and could be used as a manual for practitioners involved in producing measured drawings up to a point where it becomes prudent to involve established specialised methodologies. When this becomes so, and how it is acted upon, can only be determined by reference to the individual circumstances of the surveying office concerned.

The purpose of this work should be to derive the maximum possible amount of information given the constraints imposed by the structure of the project in hand. However, this should not preclude research into all forms of survey and measurement technique, as low-cost alternatives may be found. Examination of all the possibilities will lead to a better understanding of the nature of building recording, both for survey fieldwork and the interpretation of dimensional data.

Once the details of the technique had been established, consideration was given to the categories of survey that might be undertaken. During
the course of fieldwork, the author came into contact with others interested in recording and evaluating buildings and structures, and it became obvious that there was a potential within other disciplines, notably archaeology, for an alternative recording methodology.

As Brooke (1987a, 21) points out, the framework of current archaeological administration and funding is such that recording is often undertaken within a tightly-constrained budget. It has thus been the intention of the author to demonstrate the practical applications of computer-aided mono-photogrammetry in other fields of surveying and recording (Watt, 1990a).

Throughout the text of this thesis, a clear distinction has been made between what constitutes a façade and an elevation of a building. It is necessary to define these, given the confusion and misuse that is prevalent in current writing. A façade is taken to be the face of a building, especially its principal front, that looks towards a street or open space; an elevation is a drawing made of a façade, which may be presented at a scale.

1.3.2 Data gathering and analysis

Data generated by this work falls into one of three categories: primary, secondary and anecdotal. Primary data refers to observations derived from planned experimentation on selected façades and analysed by reference to defined criteria; secondary data comes from facts and observations collected by others and published in books, journals and technical publications; and anecdotal data is derived from structured conversations with architectural and archaeological surveyors concerning particular aspects of recording methodology and practice.

The range of data gathered for this project reflects the nature of the investigation (Section 1.1), and, as such, refers little to previous empiric work. There is, instead, greater reliance placed on structured and anecdotal data produced, organised and recorded by the author.
The role of analysis is, according to Howard and Sharp (1983, 120), 'to supply evidence which justifies claims that the research changes belief or knowledge and is of sufficient value'. In order for this to be convincing, the analysis must be based on reliable data and satisfy the principles of logical inference.

With any new technique or methodology, its verification must be beyond reproach by those wishing to test it in a variety of circumstances under differing conditions. Observation and experimentation must, therefore, lead to the possibility of falsification (Chalmers, 1982, 39). It is in this respect that use may be made of a model, by which to evaluate any results.

A model is a complex analogy, and one that is chosen specifically to describe the structure of something. The adequacy of such a model may be questioned by checking that it is actually describes all the variables, including both easy and hard to represent, and that all the variables built into it are relevant, rather than just being readily accessible (Broadbent, 1973, 89).

It has not been possible in this work to provide a wholly representative model since, what has been produced by computer-aided mono-photogrammetry cannot, in some cases, be produced manually, and may not realistically be compared with other current methods of indirect surveying. The variables that have a bearing on the relationships of the model cannot thus be specified, and so prevent a robust theoretical representation from being formed.

Although such a model cannot be considered strictly valid, as each technique presents differing factors into the equation, its value lies in allowing such differences of output to be considered in the process of evaluation.

In order to assess the theoretical and practical worth of computer-aided mono-photogrammetry, as developed in this work, comparisons have been drawn, wherever possible, with established survey methodologies. Whilst it has not been practicable to manually survey
and produce measured elevations of the sample façades, nor provide rectified photographic or photogrammetric records, comparisons based on the author's experience in surveying buildings has allowed subjective commentary to be made.

In addition, it is the opinion of the author that a further, more powerful and realistic, basis on which to evaluate the results of this work lies in determining whether what is produced has a practical application in an actual surveying situation. Where work has been undertaken for a specific application, comments from those who have seen and used the completed record have provided important evidence.

The analysis of the data generated during this investigation has therefore been designed to communicate the value of the findings in a manner that reflects the practical aims of the work. The products of the twenty-one case studies undertaken are a form of information, and, as such, may be assessed according to established criteria. Analysis of this data, with commentary on the practical applications of the technique, are presented in Section 5.3, and evaluation of the evidence in respect of the model of current recording practice given in Chapter 6.0.

1.3.3 Selection of sample façades

In order to pursue the aims and objectives of this work to a satisfactory conclusion, consideration has been given to the benefits of undertaking experimentation on sampled building façades.

As it would be both inappropriate and unnecessary in the context of this inquiry for an unlimited number of façades to be recorded, the selection of a sample allows greater benefit to be gained from the time and resources available. As Redman (1975, 148) states, 'Initial work can help direct subsequent research more efficiently and detailed results of later intensive work can refine inferences based on the more general earlier stages'.

-12-
In drawing maximum conclusive information from a sampled population, it is important that every aspect of the parent population should have an equal chance of being included in the sample. In this respect, random selection should produce an ideal representative sample within acceptable limits of statistical probability.

Where there are more potential observations than are possible to study, or where it is reasonable to think that all possible observations need not be made in order to obtain convincing data, it is important to consider how the selection of a sample might be undertaken. A lack of any indication between necessary and unnecessary observation also demands a strategy for deciding on a particular course of action. Cowgill (1975, 261) considers that in the selection of samplers (sic), interest is less in the intrinsic properties of the sample than in what inference it permits about the entire population.

Unbiased random sampling of façades was considered impractical for this investigation, however, due to the nature of the specific objectives established. Survey problems are the product of specific sets of conditions, and it is impracticable for these to be reproduced within an investigation of this scale. The function of the sample is thus to present a series of unknown problems for experimentation and observation.

What practical benefits were to arise from this work were felt to come from exposure to differing categories of survey problem, identified by the author from experience, as lying within one of four categories or strata (Figure 1.1).

Although stratified random sampling is an accepted technique in the collection of data, the selection of façades within each strata was not deemed to be wholly random as each was chosen on subjective grounds. Non-statistical judgement sampling, on the other hand, provides a basis for the inclusion or exclusion of certain data based on judgement and experience (Edelman, 1986, 144). The provision of qualitative, rather than quantitative, information, in this respect, negates the use of statistical methods for testing sample relationships.
FIGURE 1.1 CATEGORIES OF SURVEY PROBLEMS

Building Type - This provides an important test for establishing the practical application of this work over the diverse nature of buildings, both in terms of size and complexity.

Building Construction - The manner in which a building is constructed, and its façades presented as a series of detailed planes, requires a technique that is capable of making a complete and accurate representational record, often without direct physical intervention.

Building Condition - The presence of visible defects and material decay represents a challenge to conventional recording methodologies and an opportunity for further investigation.

Building History - Where historical detailing provides important evidence on which to base decisions, its recording can be of critical importance.

In deciding on the façades that were to make up this sample, three different approaches were considered: using one specific building, one particular building type, and examples from several building types. Difficulty was anticipated in finding one building that would contain sufficient problems to test all speculative theories, and which would be representative of a realistic workload. As the intention was to rigorously and ruthlessly test proposed theories, extended experience was considered essential. The requirement for continual access to the building was also thought to be problematic.

Where a single building type was considered as the basis for the sample, the question was raised as to whether the particular type selected would contain a representative selection of problems, or whether those it contained were, in fact, inherent in that particular form of construction. In order to have been representative of a practical workload, the building type must have been one that was typically met in practice. In addition, sufficient examples must also have been available for investigation.
Thus the greatest possible coverage of problems as posed by a realistic workload, giving extended practical experience, was deemed to be found within a sample containing examples from a number of differing building types.

The study of the building types that make up our architectural heritage, as determined by authors such as Pevsner (1976, 9), provides only a checklist of broad type groupings. They do not deal with the individual variations that occur within one particular building group, and which can be of considerable importance for projects involving the alteration or adaptation of the existing fabric. It is on these variations that the character of the property relies.

Conversations with architects, surveyors and archaeologists involved in surveying and recording existing buildings have identified certain aspects inherent within particular groups, but it is beyond the scope of this present work to offer solutions to all potential survey problems.

The selection of a sample requires a compromise between what is the ideal and what is, in fact, attainable. In considering whether such a sample is sufficient for the purposes of providing conclusive data, it must be acknowledged that the selection is based on subjective grounds and might result in insufficient coverage. It has thus been the response of the author to adopt a flexible approach and dismiss a geographically-defined area for experimentation as being artificially restrictive.

The sampled building façades used in this work therefore represent an open statement as to practical building recording problems, reflecting a small part of the total spectrum of building types. It is believed, however, that those recorded illustrate some of the more familiar. Much of the initial work used to test developing theories has made use of local sites; later study has included more distant material.

In order to minimise the subjectivity of this sample, however, criteria have been adopted to assist in the selection of façades. Each has had
to offer a new challenge in respect of:

(a) The shape, size, style or condition of the building fabric, and the building type involved.
(b) Individual features or details to be recorded either separately or in the context of a whole façade.
(c) The photographic requirements specific to its recording.
(d) The provision of adequate dimensional control.

1.4 THESIS ORGANISATION

The structure of this thesis has been organised in such a way as to allow each part to be read as a separate unit, containing sufficient information for the reader to build up the necessary knowledge and background information to become fully cognizant with all that has fed into the development of computer-aided mono-photogrammetry as an alternative recording methodology.

Chapter 2.0 provides a general introduction to property surveying, with discussion of the practical requirements, and relating it to who and what is involved in the actual organisation and implementation of the service.

Chapter 3.0 considers the historical developments in recording methodology, with methods ranging from treatises, paintings and prints to architectural drawings and photography, and the creation of a distinct surveying profession.

Chapter 4.0 brings the practice of building recording up to date, with discussion on methods of direct and indirect surveying, the nature of current problems, and the generation of an alternative approach.

Chapter 5.0 provides a definition of computer-aided mono-photogrammetry, introduces the underlying philosophy to its development, considers the component parts of the technique and its practical application, and analyses the project data in relation to
criteria established for the field of study.

Chapter 6.0 forms the synopsis to this work, summarising what has been achieved, and drawing conclusions as to the contribution of the thesis in the development of architectural recording, where its limitations lie, and what new work would be appropriate.

The appendices, contained in Volume Two, provide detailed commentary on individual case studies (Appendix A); references to measured and photographic surveys undertaken by the author during the course of this work (Appendix B); a specification to, and references for, the equipment used (Appendix C); and copies of published and presented material arising from this investigation (Appendix D).

Specific terms within the text referring to CAD elements and functions have been reproduced in italics, and the reader is directed to Appendix C (I) for necessary definitions.
2.0 THE PURPOSE OF SURVEYING

2.1 THE NEED FOR SURVEYS

2.1.1 What is a survey?

Surveying, as distinct from a mere cursory view of a subject, offers a means of providing qualitative and quantitative information, gained through recognised processes of analysis, synthesis and evaluation. The survey, in its widest sense, is thus a general or comprehensive view of something for a specific purpose.

The expression 'specific purpose' might be taken as meaning that the subject could be utilised for a variety of uses. The real significance, however, is that there can be a wide variety of reasons for requiring a survey, each necessitating an individual approach, dependent upon purpose and extent.

The most common basis for a survey lies in the demand for information relating to a specified property, whether it be a parcel of land or a building. Whilst land surveying is, in itself, important to the development of the surveying profession, and today exists as a distinct discipline concerned with 'making measurements of the relative positions of natural and man-made features on the earth's surface' (Bannister and Raymond, 1984,1), this thesis is principally concerned with the recording of building façades, together with those of monuments and other structures.

An all-encompassing definition of surveying is, by the nature of the activity, difficult to determine, unless a list-approach is adopted to reflect the various branches of survey practised under the common heading. This is not just a recent problem: the General Report on the Professional Class, published in 1881, held surveying to be a 'somewhat vaguely-used term' (Thompson, 1968, 161). A clear distinction may, and should, however, be made between the actual examination or inspection and the account given of the findings, both of which are often known as the 'survey'.
In perhaps what is the most thorough non-technical exposition available, Horsley (1970, 1011) defines surveying as:

'The art of determining the value of all descriptions of landed and house property and of the various interests therein; the practice of managing and developing estates and the science of admeasuring and delineating the physical features of the earth; the valuation, management, development and survey of mineral property and the measuring and estimating of artificer's work'.

One of the most informative ways of further defining a survey is to classify it according to its purpose or use. For this, there are three broad categories of technical survey: condition, dimension and valuation. Surveys of condition are generally related to building stock, whereas dimension or measured surveys involve both land and buildings. Valuation surveys provide an assessment of financial relationships with regard to both condition and dimension.

Other classifications of survey may be made in relation to the purpose for which they are being undertaken or the technique to be employed. These include, for instance, cadastral, engineering, mining and hydrographic surveys, or chain, tacheometric, photogrammetric and plane table surveys.

The demand that operates in a property-orientated market arises from a need to understand more fully the nature and state of the commodity as derived from a survey. The opportunity thus presents itself for a service that offers information on which to base administrative, economic and managerial decisions at all levels throughout the market. In this respect, the practice of surveying might be undertaken in an architectural or archaeological context, dependent on its purpose.
2.1.2 Aspects of surveying

Whilst the emphasis so far has been on the nature of the activity, it is important to closely identify the subject to ensure an appropriate use of resources. The activities to which the label 'survey' might be applied can include the ordering of diverse data into useful or convenient categories, drawing together derived information to form principles on which to base actions and decisions, and putting a value on what has been achieved.

These three stages of analysis, synthesis and evaluation form the basis for all reasoned investigation, and are fundamental to the practice of surveying as a learned discipline. The basic skills requisite in such practice are those founded on observation, inference and communication.

Historically, surveying has been seen, both by its practitioners and the public, as a means to an end, both in terms of the service offered and the level of skills required. This attitude has, it is felt, restricted any furtherance of the profession in the academic arena to its detriment. The resulting complacency has come to be seen as an issue of some importance, warranting action by the governing bodies to prepare and present an image of modernity and prospect. The recent introduction of continuing professional development (CPD) for corporate membership, and seminars addressing the very question of education in the profession, can therefore be seen as a healthy response which should be fostered by practitioners and academics alike.

Surveying, however, is still rarely thought of as an intellectual discipline. Questions of 'how' have been addressed, and solutions posed in response to practical problems on an ad hoc basis, with typically limited dissemination of the facts. Examination of the basic philosophy underlying measured building surveying has previously been set aside in favour of the continuance of accepted practices. A move from mechanistic to strategic reasoning thus offers principles on which to formulate and evaluate policies to deal with practical issues in a fresh and more effective manner.
2.2 SURVEYING PRACTICE

2.2.1 Survey applications

Surveying plays an important, if not critical, part in the various proposals set to alter or conserve the national stock of buildings. There are, therefore, a number of reasons why a building might be surveyed, each of which presents differing sets of circumstances that demand an individual response.

Whatever the purpose of a particular survey, Rodwell (1981, 56) considers it important to 'see the end of the job before you begin', and consider the various objectives that fashion the kind of survey and its specific requirements. In dealing with an existing building, it is these considerations that should provide the criteria on which to base the selection of appropriate recording methodologies. The overall objectives might be:

(a) To record accurately the form of the building by way of measurement and interpretation, including spatial arrangements and levels of division.

(b) To understand the anatomy of the building through analysis of the plan, main elements of the external and internal fabric and the structural system.

(c) To diagnose and prognosticate defects within the fabric and structure of the building, and quantify their extent.

(d) To consider the materials and building methods, and the features, decorative elements and furnishings, as an aid to assessing the age and status of the building.

(e) To understand the manner in which a building or group of buildings performs, or might perform (if new uses are to be considered), with regard to a particular use or series of uses carried on by the occupants.

-21-
McDowall (1980, 3) has classified record surveys into four broad types—superficial, external only; superficial, external and internal; measured; and destructive. The varying products of such surveys are well illustrated in relation to the Peacock Inn in Chesterfield (Derbys.) (Ibid., 21). This late medieval timber-framed building was examined by a series of investigators with the differing aims of establishing its antiquity, preparing schemes for its rebuilding, and recording it before its intended demolition. Each produced drawings whose detail was appropriate to the purpose in hand, and which therefore provided a wide variety of styles and information.

Proposals that may affect buildings can be grouped according to criteria laid out in planning and building control legislation. For the purpose of this discussion, however, they have been divided into two main categories, static and dynamic.

The term 'static' is used to describe activities that can be thought of as engendering a resistance to change, be they maintenance, preservation or consolidation. Conservation can contain both static and dynamic elements according to its rôle and extent, and has come to be regarded as an umbrella term for various other practices. 'Dynamic' activities, by contrast, seek to enforce change, and thereby reform or reorganise the structure and/or fabric.

The distinction is thus between what may be termed 'internalising factors', such as time and physical decay, and 'externalising factors', including market forces and increased expectations. Both factors are, in effect, different forms of obsolescence and, according to Williams (1985, 134), dictate change.

The manner in which this change is implemented can be considered under various headings (Figure 2.1):
FIGURE 2.1 ACTIVITIES THAT GENERATE CHANGE

STATIC ACTIVITIES

Conservation - Work undertaken to facilitate making a building fit for 'some socially useful purpose' (Article 5, Venice Charter, 1964).
Consolidation - Work that includes weatherproofing and minimal repair, undertaken to arrest the rate of deterioration suffered by the exposed ruins of buildings and monuments.
Maintenance - Work undertaken in order to keep or restore every facility (i.e. every part of a site, building and its contents) to an acceptable standard (British Standard 3811: 1984).
Preservation - 'A method involving the retention of the building or monument in a sound static condition, without any material addition thereto or subtraction therefrom, so that it can be handed down to futurity with all the evidences of its character and age unimpaired' (Baines, 1923, 104).
Repair - Work necessary due to damage or decay that prevents further deterioration and reinstates structural integrity. The philosophy of how and when to repair has long been a subject for discussion, and is reviewed by Chitty (1987, 43-58).

DYNAMIC ACTIVITIES

Adaptation - Work that is carried out to accommodate a change in the use of a building, which can include alterations or extensions.
Alteration - Work carried out to change the structure of a building to meet new requirements.
Conversion - Work undertaken to make a building of one particular type fit for the purposes of another type of usage.
Extension - Work carried out to increase the floor area of a building, whether vertically by increasing height or horizontally by increasing plan area.
Improvement - Work that is carried out to bring a building and/or its facilities up to an acceptable standard, possibly including alterations, extensions or some degree of adaptation.
Modernisation - Work undertaken to bring a building up to a standard laid down by society and/or statutory requirements.
Refurbishment - Work necessary to totally overhaul a building and bring it up to the requirements of a client.
Rehabilitation - Work carried out, beyond the scope of normal maintenance, to extend the life of a building, which is socially desirable and economically viable. This term has, in many cases, supplanted various others due to the very generality of its definition.
Renovation - Work undertaken to restore a building to an acceptable condition, which may include works of conversion.
Restoration - Work that aims to restore the physical and/or decorative condition of a building to that appertaining at a particular date or event. Philosophical questions concerning repair versus restoration are frequently aired, the solution to the partial destruction at Uppark in August 1989 being a case in point (Venning, 1989, 10).
Revitalisation - Work intended to extend the life of a building by providing or improving facilities, which may include works of repair.
2.2.2 Generators of surveys

The demand for building surveys does not stop with those who wish to implement change. Archaeologists, architectural historians, macro-conservators, planners, researchers, amenity societies and pressure groups, private individuals, and a host of other agencies support the examination and recording of building fabric for a variety of reasons.

Lindsey (1982, 15) considers that the recording of monuments and sites should form the basis for study, conservation or restoration, and 'where dimensional integrity is significant, surveying, with its fundamental concepts, together with modern technology, has a contribution to make'. This is echoed by Charles (1982, 78), who considers that the recording of all listed buildings, not just those for which listed building consent for demolition has been received by a local planning authority, would assist in understanding problems of building history, and at the same time teach construction to those involved.

The need for surveys has already been commented on (Section 2.1), and the question of 'why survey?' addressed in part. It is, however, important to identify who is responsible for initiating the surveys, and understand their specific requirements.

Chitham (1980, 1), in his introductory comments on the role of measured drawings, identifies four key generators of such work as being measured surveys for alteration work, records of buildings before demolition, scholarly production of exemplars, and training of students.

Within these categories, each survey that is undertaken represents an individual statement about the dimensional and spatial relationships within a particular building. The mechanics of performing the survey are, to whatever specification, primarily fixed by convention and influenced by training. There is, however, inherent in any such human activity, scope for subjectivity, requiring some means by which work is regulated by the adoption of standard procedures.
There are, within such an activity, two key issues that face any person wishing to undertake a programme of building recording. The first is the awareness and familiarity with which the available techniques are considered, and secondly, the use that is made of the completed record.

It is only after the characteristics of each technique have been analysed that a balanced selection can be made, based on the specific requirements of the subject building. It is rarely appropriate to select just one technique on its obvious merits, as different parts of the building, or different requirements related to the particular stage in the project, may require the attentions of an alternative technique.

The manner in which a dimensional record is used will obviously have an important bearing on the accuracy to be sought and the amount of detail to be recorded. Both will have strong financial implications. The desired level of accuracy will be determined by the reliance to be placed on it by subsequent processes. In certain cases, the record may form the basis for assessing quantities for costing purposes or indicating the precise nature of repair or replacement.

Much of the work undertaken to initiate change within existing buildings can be considered as separate, though related, stages. Thus, a feasibility study might require information for initial presentation and outline costings, whereas programmed repairs will require accurate dimensional information on which to base decisions, indicate the scope of the work and invite tenders.

It is often the case that one particular stage will lead on to another. Once a feasibility study has been prepared, the client might decide to continue with the programme of repairs as indicated. In this case, there will be two separate levels of information founded on the same physical evidence.

The nature of the feasibility study is such that often it is abandoned soon after it has been prepared. It is therefore the case that architects and building surveyors called upon to prepare such reports require quick and inexpensive methods of survey on which to base their
recommendations. Often, reliance is placed on outline drawings and photographs. These may be ideally suited in the first instance, but where the recommendations are to be implemented, a degree of duplication in the work becomes necessary to produce suitable working drawings.

It is therefore seen to be, at least, prudent to consider the survey stage from the 'bottom up'. The ideal case would allow for outline drawings to be worked up to a detailed stage with total confidence in the accuracy of the adopted base drawings.

There is, inherent in such an approach, however, a danger that the integrity of the record may be compromised, as one set of criteria conflicts with another. This must be reconciled at the earliest stage with all parties concerned.

The benefits to be derived from this approach favour greater use of precise surveying techniques in the early stages of the project, with the inclusion of appropriate detail as and when required. CAD-based storage and retrieval of information is, in itself, ideally suited for such a proactive response to demand.

Once the drawings have been utilised in their primary rôle, further use may be made of them for wholly different purposes. Cooper (1988a, 44) points out that the surveys of an architect may often lend themselves to the purposes of the historian, to serve as the basis on which to record those features that are of concern.

It is important, if such serviceability is to be maximised, that certain facts are brought to the attention of the would-be user by notes recorded on, or filed with, the drawing. Scale and date are obvious, but how and why the survey was undertaken, and to what degree of accuracy it is true to scale, are pertinent points.

National repositories, such as the National Monuments Record, the National Monuments Record of Scotland and the National Monuments Record for Wales are maintained and expanded by the Royal Commission on the
Historical Monuments of England, and the Royal Commissions on the Ancient and Historical Monuments of Scotland and Wales respectively. Various other repositories hold material that can be freely examined, and which can provide valuable data for present-day proposals. These may include:

(a) County Record Office archives.
(b) Parish records.
(c) Local authority planning and building control departments.
(d) Architects' and surveyors' offices.
(e) Statutory undertakers.

2.2.3 Survey specification

The purpose of a survey has been shown to vary according to the needs of the client and the character of the property. Ideally these requirements should be specific in order to avoid confusion and wasted resources, although discretion plays an important part in certain circumstances.

The need for a clear understanding based on the nature and requirements of the survey directly affects how it is organised and implemented. The management of resources, both labour and equipment, plays a key role in survey organisation, and time spent at this stage will invariably pay dividends later on.

Each survey may be thought of as being the product of a series of interactions between variable factors that make up the property, be they physical, social or environmental. These parts in the survey equation take on greater importance in respect to one another as basic requirements change. Recently, for instance, increased consideration of secondary factors has brought about the term 'full analytical survey' in relation to building interpretation.

Resulting categories of survey may be defined according to standards of accuracy and content as presented typically in the form of a
specification. This will ultimately determine the techniques to be used for measurement, recording and interpretation. A summary of survey standards is provided below (Figure 2.2).

### FIGURE 2.2 STANDARDS OF DIMENSIONAL SURVEY

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Plotting scale</th>
<th>Level of detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification</td>
<td>Not to scale</td>
<td>Position of buildings relative to established landmarks and principal roads.</td>
</tr>
<tr>
<td>Block plan</td>
<td>1:500</td>
<td>Site boundaries; drainage runs; outbuildings.</td>
</tr>
<tr>
<td>Alteration and and conversion</td>
<td>1:200/1:100/</td>
<td>Floor plans, sections and elevations showing structure and main features.</td>
</tr>
<tr>
<td></td>
<td>1:50</td>
<td></td>
</tr>
<tr>
<td>Buildings of architectural or historic</td>
<td>1:100/1:50/</td>
<td>Floor plans, sections, elevations and details for documentation or repair.</td>
</tr>
<tr>
<td>importance</td>
<td>1:20/1:10/</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1:5/1:2/1:1</td>
<td></td>
</tr>
<tr>
<td>Archive record</td>
<td>Various</td>
<td>Sufficient to show important details, forms of construction, materials and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>stylistic influences.</td>
</tr>
</tbody>
</table>

Accuracy is determined directly from the end-user requirements of the survey, and, as such, justifies careful consideration. The level of accuracy adopted will influence the choice of technique(s) used, and ultimately determine the amount of detail recorded and represented. The accuracies attainable with manual techniques can vary considerably as a result of human error and the limitations inherent with the equipment employed. Common situations include:
(a) Stretched, slack or misread tapes.
(b) Wrongly booked measurements.
(c) Omission of detail and measurements from booking sheets.
(d) Inconsistent measurements (e.g. measuring to structural opening or door leaf).
(e) Problems of reach and parallax experienced with vertical measurements.
(f) The use of inexperienced assistants during manual surveying.
(g) Limitations to the amount of detail shown on one set of booking sheets.

Electronic measuring devices and recording instrumentation have gained popularity with land surveyors, and their use in building surveying is increasing. The accuracy attainable, and the amounts of dimensional data that can be recorded, require greater sophistication in interpretation, with increased use being made of computer draughting and modelling facilities (Section 4.1).

The accuracy achieved using a particular survey methodology, or in relation to a specific recording project, may be described in a number of ways. Measured surveys are traditionally plotted to conventional scales, relative to the specific subject, such that mapping surveys are usually reproduced at 1:1,250; land surveys at 1:500 and 1:200; building surveys at 1:100 and 1:50; and specific details at 1:20, 1:10; 1:5, 1:2 and 1:1. For building survey requirements, Staveley (1984, 3) recommends certain plotting scales (Figures 2.3).

When dealing with existing buildings, the availability of large-scale drawings provides an opportunity for the architect or surveyor to record in detail his specific requirements, such that the work is carried out within an overall predetermined framework. The realities of actual site work throw a heavy burden on to the drawn, rather than the written, contract documentation. The clarity of such information is thus directly and critically related to the standard of work attained.
**FIGURE 2.3 BUILDING SURVEY PLOTTING SCALES**

<table>
<thead>
<tr>
<th>Purpose of survey</th>
<th>Plotting scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alterations and extensions</td>
<td>1:100 or 1:50 depending on the size of the building and the purpose of the survey.</td>
</tr>
<tr>
<td>Installation of new services</td>
<td>1:100 or 1:50.</td>
</tr>
<tr>
<td>Installation of fittings</td>
<td>1:20 or 1:10.</td>
</tr>
<tr>
<td>Buildings of architectural or historic interest</td>
<td>1:100 or 1:50 for floor plans and elevations, depending on the size of the building, and 1:20 or 1:10 for specific features of interest.</td>
</tr>
<tr>
<td>Block plans</td>
<td>1:500 with attention given to the shape of the site.</td>
</tr>
<tr>
<td>Structural surveys</td>
<td>Usually only floor plans are required, being to a scale not greater than 1:100.</td>
</tr>
</tbody>
</table>

In the Specification for surveys of land, buildings and utility services at scales of 1:500 and larger, produced by the Royal Institution of Chartered Surveyors (1986, 8), the recommended accuracy for measured building surveys is such that 'the absolute plan position of any well defined point shall be correct to within ±0.3mm root mean square error (r.m.s.e.) at the specified plan scale, when checked from the nearest control station on that floor'. This, in effect, means that 68% of all points on a 1:100 plot should lie within ±30mm (1.18in.), and 95% within ±60mm (2.36in.), of their true positions. Alternatively, an accuracy of 1% scale error means that measurements are accurate to 10mm (0.39in.) in 1,000mm (39.37in.), although 100mm (3.93in.) in 10,000mm (32.8ft) might be considered too high.
It is evident that the standard of accuracy achieved will be affected by the size and complexity of the building, and the surveyor should state his estimate of the accuracy achieved for each project. With regard to the accuracy of two-dimensional representations of buildings and standing structures, Rodwell (1981, 85) makes the point that only in exceptional circumstances can accuracy to within less than 10mm (0.39in.) be seriously called for.

2.3 BUILDING SURVEYS

The majority of surveys undertaken on a building are related either to its condition or spatial arrangements.

Aside from surveys of condition and dimension, there are a number of property-related activities that maintain a direct input of both forms of data. Valuations undertaken for the purposes of sale, purchase, mortgage, rental, insurance, compulsory purchase and probate all rely, to some extent, on a knowledge of appearance and size (Millington, 1988, 39-41). Guidance on the measurement of buildings is given in a code of measuring practice written specifically for general-practice surveyors and valuers (Royal Institution of Chartered Surveyors/Incorporated Society of Valuers and Auctioneers, 1979, 1-11).

Surveys are also undertaken in order to increase our knowledge about a particular building or aspect of its architectural/archaeological significance. The Countryside Commission for Scotland organised a comprehensive survey of Scotland’s rural buildings during the late 1970s in an attempt to improve the design and siting of new buildings, and protect the external appearance of the existing vernacular architecture.

In order to programme such an immense undertaking, the following objectives were adopted (Fladmark, 1979, 956):

(a) To identify and describe that which constitutes traditional building character in Scotland.
(b) To select from (a) those elements of building and layout which determine regional or local characteristics within that tradition.

(c) To derive principles from (a) and (b) for application in the design, construction and siting of new buildings in the Scottish countryside.

(d) To study the problems of converting and adapting old buildings for contemporary uses.

2.3.1 Condition surveys

An inspection of a property to ascertain the condition of its structure and fabric may be required in order to quantify and undertake repairs and future maintenance, or provide a level of confidence prior to acquisition. The scope of such inspections has been documented by the Royal Institution of Chartered Surveyors for residential (1981, 12-19), and commercial and industrial (1983, 5-9), properties.

These inspections, referred to as 'structural surveys', wrongly imply an analysis of the structure using mathematical and engineering techniques to assess its strength and structural performance. Swallow (1982, 1) considers that the terms 'detailed inspection' or 'building condition survey' would, in this respect, provide a less ambiguous statement of implied scope and intent.

In addition to these full surveys or inspections, surveys may be undertaken to investigate a specific problem, such as a building defect. These may require the services of a specialist, such as a Structural, or Mechanical and Electrical (M&E), Engineer, or specific equipment, including fibre-optic probes and radon detectors. The importance of understanding the purpose and limitations of such specialised services is noted by Hollis (1986a, 45).

Particular forms of inspection have been developed in order to provide guidance in relation to specific building types and aspects of property husbandry. Under the provisions of the Inspection of Churches Measure...
1955, every church within the Church of England has to be inspected at least every five years. The so-called 'quinquennial report' is a requirement of law and can be enforced by the Archdeacon in the event of noncompliance by the parochial church council. The appointed inspecting architect has to report on the condition of the fabric, and make recommendations as to any necessary repairs, maintenance and further investigations. The detailed requirements of such inspections are covered by Walker (1985, 24-25; 34-42) and the Council for the Care of Churches (1987, 21-23).

A similar arrangement of regular inspections is operated by the Property Services Agency (DoE) for historic buildings in their care (Property Services Agency, 198?). Accommodation and Works (A&W) Circular 35/85 requires United Kingdom Territorial Organisation (UKTO) Directorates to ensure that all historic buildings, for which they have a significant maintenance responsibility, receive a detailed inspection every four years. The purpose of such 'quadrennial surveys' is to determine the condition of the buildings, establish priorities and costs of work required, and develop long-term objectives for conservation. The National Trust undertakes similar planned maintenance inspections of their properties on a five-year basis.

Further forms of inspection have been developed to provide specific information on property matters. These have been described by Seeley (1985, 1) as 'building surveys' to distinguish them from 'structural surveys'.

A schedule of condition is essentially a report on the state of a property at a given point in time. The purpose of such an inspection is, according to Seeley (Ibid., 164), to 'set out in sufficient detail the condition of the structure, finishes or fittings so that subsequent defects or missing items can be readily identified'. The exactitudes of such a schedule are relied upon in conjunction with tenancy agreements, and works of alteration or demolition, where damage may be caused to adjacent buildings.
A schedule of dilapidation, on the other hand, is required where a lease contains a covenant to repair, and where dilapidations have arisen from failure to comply with such a covenant. The schedule is either prepared as an interim schedule listing the defects that require remedial action to comply with the repairing covenants during the term of the lease, or a terminal schedule that details the necessary items of repair at the end of the lease.

Less exacting inspections include building society and bank surveys, which provide information on the condition of a property, with commentary on its value, as a condition of making a financial loan to the prospective purchaser. Current debate, however, concerning the fundamental differences between mortgage valuations and surveys has not provided a wholly adequate answer, and this will continue to rage for the foreseeable future.

The difference between full condition surveys and the less detailed forms of inspection has been bridged to a certain extent by the introduction of standardised survey procedures, including the *House Buyers' Report* and *Valuation Inspection Report* (1987a) and the *Flat Buyers' Report* (1987b), by the Royal Institution of Chartered Surveyors. Comparisons have been made between these various forms of survey by Hollis (1986b).

Where the condition of a large number of buildings has to be assessed, the criteria on which such inspections are based have to be carefully formulated in order to provide a coherent policy for the collection and processing of the survey data.

Surveys are regularly undertaken to assess the condition of large numbers of houses and flats, as part of local-authority housing programmes. In this respect, the uses for pro forma sheets, optical readers and expert systems have been identified, and, in some cases, implemented. Park (1985, 70-87), in his work on computerised equipment for architectural and interior design surveys, considers their application in both measured and condition surveys.
In a programme of condition surveys undertaken on over a thousand listed and historic buildings in the central conservation areas of Norwich between October 1986 and April 1987, the first stage comprised a rapid external assessment based on a standard survey form for computerised data storage (Smith, 1988, 1-4).

Buildings were selected for a follow-up survey for the following reasons:

(a) Further information was required about the structure and interior of buildings in a very poor condition.
(b) An additional check was required internally on a suspected structural fault.
(c) The building had not been fully inspected during the initial survey due to access difficulties.

2.3.2 Measured surveys

Measured surveys, as the name suggests, are concerned with the collection of linear and angular measurements, sufficient to define features and determine extent, whether of land or buildings. Distinction has to be made between the types of survey performed, relative to the purpose. This influences the level of accuracy and amount of detail required during both collection and processing of the data.

With regard to land surveying, Whyte and Paul (1985, 4) draw distinctions between the various classifications of surveys. Each of these surveying activities provides solutions for specific problems, and have become established disciplines in their own rights.

Measurement of built fabric, necessary to provide detailed information concerning construction and spatial arrangements, involves processes different to those used in topographic surveying, in which concern is chiefly with the position of buildings on the site.
The processes of measuring a building may be defined by the accuracy of the dimensional data collected or by the purpose for which it is to be used. Rodwell (1981, 45) draws the distinction between 'detailed' or 'intensive' surveys, and 'general' or 'non-intensive' surveys used for architectural and archaeological recording. Together with the specialist survey of condition, these three kinds of survey form the basis for all recording of buildings, and, as such, are of interest to various disciplines from architectural historians to macro-conservators. Outside of these purely utilitarian operations and investigations lie those surveys carried out on a voluntary or academic basis.

Each category of survey is distinguished by the specific requirements made in relation to the particular task in hand. These may include:

(a) The level of accuracy with which the building is measured and represented.
(b) The amount of detail recorded and subsequently presented as dimensional and contextual information.
(c) The method of presentation, which will have implications for how the data are collected and processed, the scale chosen for reproduction, and the manner in which the information is stored.

Recording large numbers of buildings requires detailed selection criteria similar to those adopted for condition surveys (Section 2.3.1). In the course of ensuring that all eventualities were covered in case of further hostilities during the 1950s, the Belgians found that the photography involved in recording their heritage buildings was so vast that they had to restrict the survey to selected buildings, and often only to selected parts (McDowall, 1972, 397).

In considering the use of stereo-photogrammetry for recording large numbers of buildings and monuments, Tait and Atkinson (1973, 825) have suggested the following four groups as being worthy of attention:
(a) Buildings on the point of collapse and for which plans are necessary for restoration work.
(b) Buildings about to be demolished for redevelopment or other reasons.
(c) Interesting buildings which are structurally sound, but whose detail would be lost in the event of disaster such as fire.
(d) Buildings in good repair which are to be extended or converted.
3.0 HISTORICAL DEVELOPMENTS IN RECORDING METHODOLOGY

3.1 INTRODUCTION

Surveying, as discussed earlier (Section 2.2.1), has applications in many varied situations. This diversity becomes all the more apparent when one follows its history through from ancient times. Whether as an art or a science, surveying, in its many guises, has been at the heart of countless decisions that have had implications well beyond the minds of those who first commissioned them.

The concept has been developed earlier that surveying is concerned primarily with condition and dimension. This broad bifurcation continues when viewed against the evidence afforded by an overview of historical advancement. There exist, however, other stimuli that have occasioned surveys, primarily into the determination of location, boundaries and ownership.

The Domesday Survey, carried out by officials of William the Conqueror soon after the Norman Conquest of England, was to provide all the necessary information for the levying of a land tax and other dues, and to ascertain the value of Crown lands. The whole undertaking was completed at speed, in less than twelve months, though the fair copying of the main volume may have taken a little longer.

The manner in which the Survey was conducted has been recorded by the Saxon Chronicle, such that in 1085:

'at Gloucester at midwinter...the King had deep speech with his counsellors...and sent men all over England to each shire...to find out...what or how much each landholder held...in land and livestock, and what it was worth.... The returns were brought to him'.

Although not the work of technically-expert surveyors, the Domesday Book of 1086 was 'the fruit of a grand overlooking of the whole realm, the product of inquiry and testimony concerning ancient and current
property usage, and of the counting of property on the hoof and in the land, a great descriptive enumeration and valuation of the property rights and obligations of the King, his tenants-in-chief, their subtenants, and peasants according to their status' (Thompson, 1968, 3).

In order to give an indication of the style and scope of survey, two entries are cited for the county of Derbyshire, as presented by Morgan (1978, 276b; 278b-c):

**LAND OF WILLIAM PEVEREL**

In BOLSOVER Leofric has 3 c. of land taxable. Land for 4 ploughs. Now in lordship 2 ploughs; 14 villagers and 3 smallholders who have 4 ploughs. Meadow, 8 acres; woodland pasture 2 leagues long and 1 wide. Value before 1066, 40s; now 60s. Robert holds it.

**LAND OF ROGER OF BULLY**

In ROWTHORN Ulf and Steinulf had 1 c. of land taxable as a manor; in BRAMLEY 2 b. of land, of Rowthorn jurisdiction. Land for 2 ploughs. 6 villagers with 1 smallholder have 1 plough. In lordship 1 plough; meadow, 2½ acres. [Value] formerly 20s; now 16s.

**Notes:**

**c. CARUCATA:** The unit of land measurement in Danish areas. It was, in effect, a unit of assessment, which took into account amenity value. A carucata is thought, in some regions, to have been approximately 120 acres (48.5ha).

**b. BOVATA:** One eighth of a carucata.

This type of survey was being continually performed by men who needed to know and record the range and condition of their estates, hence the manorial extent and survey. The Hundred Rolls of 1279 were even more detailed than Domesday (Rackham, 1986, 12), but most have subsequently been destroyed.
Written and graphical records of this sort provide useful evidence for establishing patterns of settlement and land usage. The Anglo-Saxon settlement of Laxton (Notts.), for instance, remains one of the few villages in England where open fields are still worked in strips, and provides an example of the early open-field system of agriculture (Hoskins, 1970, 48). Comparisons, in this instance, may be made between present maps of the area, and those prepared in the seventeenth century, which define individual holdings.

During the fifteenth and sixteenth centuries, the process of enclosure, begun in the fourteenth century as a means of converting common lands into private property, and the substitution of enclosed fields for the open-field system, led to serious rebellions in 1536, 1569 and 1607. The previous informal process of 'enclosure by agreement' gave way, in the eighteenth and nineteenth centuries, to renewed enclosure by individual Acts of Parliament. These became the origin for the preparation of large numbers of enclosure maps that set out, and recorded, the extent of the new estates and parks.

Military mapping presented further motivation for surveying, with a greater emphasis being placed on achieving higher standards of detail and dimensional accuracy. Following the campaigns of the 1745 Rebellion, it became obvious that accurate maps were required if the military were to operate effectively and efficiently. In 1747 work began on a project to map the Highlands, and following many delays, including the Seven Years' War and the American War of Independence, the Ordnance Survey was established in 1791. Today this national mapping agency provides surveys and maps of Great Britain for military, scientific, commercial and industrial purposes.

The essence of all these surveys is that they provided information, in one form or another, which assisted in the management of resources. Much of the work was undertaken, not by 'technically-expert surveyors', as Thompson (1968, 3) points out, but by advisers and followers, working to the best of their abilities. At some point, however, it became necessary to break this pattern and place reliance on, what might be described as, 'professional' surveyors, as distinct from
informed laymen. This, in turn, led to the emergence of a recognised surveying profession, with advances made both in the methods and instrumentation used.

3.2 THE DEVELOPMENT OF SURVEYING METHODS

It is probable that one of the first practical applications of surveying was as a means of assuring structural integrity with the levelling of the pyramid bases in Egypt during the Fourth Dynasty between about 2700 and 2500 BC. Recent work by Lehner with the Giza Plateau Mapping Project has helped to identify the use of water-filled depressions at regular locations from which taught lines were run off the tops of accurately-levelled stakes (Fagan, 1987, 14). Biblical reference to surveying practice is made by the Old Testament prophet, Ezekiel, who describes measurements taken in a city of Israel 'with a linen cord and a measuring rod' (Ezekiel 40:4).

Technical advances made by the Egyptians, Greeks and Romans in the fields of surveying and construction are evident in the extant buildings of the Ancient World. This was a time of mathematical advancement, engineering triumph and an understanding of structure and design. Such achievement was, however, doomed to end, and with the collapse of Rome, Europe entered what is justifiably described as the Dark Ages. A period of stagnation followed, during which time much of the theoretical and technical knowledge that had been previously acquired was forgotten or ignored.

At what point in time came the resurgence in technical and aesthetic inquiry is difficult to establish. It might be supposed that religion provided the force behind a new wave of building that carried with it through the Middle Ages a feeling of honest toil and craft competence. Previous works, both literary and physical, were evaluated by Christian scholars early in the twelfth century, and produced what Henderson (1967, 49) describes as the 'new disciplined coherent ecclesiastical polity'.
With this new-found order came a need for craftsmen capable of expressing such feelings in their work. The men that are presented in contemporary records as being responsible for the work appear as widely talented individuals who possessed the ability to work in various media. The sculptor Matthew Paris (d. 1259) was well acquainted with techniques of carving and casting, and André Beaunevé (1335-1403?) produced exceptional results in both sculpture and paint.

This readiness to practice many arts also saw the production of detailed instruction and guidance given in the form of sketches and notes. The handbook of the thirteenth-century master craftsman Villard de Honnecourt (c.1225-c.1250) provided instruction for apprentice cathedral builders, and has given us an appreciation of how medieval craftsmen considered their own work and their rôle in ordered society (Gimpel, 1988, 89).

The absence of evidence for surveyors in documentary records of this period has led some to infer a period of decline in surveying practice that extended up to the early sixteenth century. It is, however, more reasonable to expect that measurement was undertaken by the master craftsmen, such as de Honneecourt and others, and the sixteenth century brought with it only a reappraisal of measuring techniques that had lapsed since the third century AD.

Whether or not these Renaissance 'surveiours' revived archaic principles and practices is difficult to establish. Thompson (1968, 2) considers this not to be the case, preferring to see the emergence of newly-developed theories as a response to the demands brought about by the changing economic and social conditions of the period.

The development of such practices, leading ultimately to the creation of a specific surveying profession, needs to be considered against contemporary conventions in both architecture and building if sense is to be made of the prevailing divisions in skill and responsibility. Evidence for this comes mainly from early expositions concerned with the form and ornamentation of Graeco-Roman architecture.
The first English printed book to use the term 'surveying' was John Fitzherbert's *Book of Surveying* (1523), in which he considered a surveyor to be responsible for inspecting the condition and situation of the property, and overlooking its management. In this description lies three distinct activities common to the present-day practitioner, namely the preparation of surveys of condition, evaluating the potential of both land and buildings, and managing an estate.

It is clear from the work of John Thorpe (c.1565-c.1655), now in the John Soane Museum, which includes plans of houses designed before he was born, that he undertook surveys of existing buildings, as well as practising as a land surveyor. The Smythson collection, housed in the library of the Royal Institute of British Architects, also contains surveys as well as designs (Girouard, 1983, 11).

Although surveyors like Thorpe made 'plats' or 'plottes' and 'uprights', plans and elevations, a building was often designed as it progressed on site. The prospective aristocratic owner explained what he wanted, giving instructions to his master mason, often referring to books on Classical orders and decorative detail.

The *Firste and Chief Groundes of Architecture used in all the auncient and famous monyments: with a farther and more ample discourse uppon the same, than hath been set out by any other* (1563), published by John Shute, and *Variae Architecturae Formae* (1563) by Hans Vredeman de Vries, provided such references and may be considered as the forerunners of the Georgian and Victorian pattern books.

Surveying theory and instrumentation has evolved over many centuries, much of it developing from other practices, notably astronomy, geometry and navigation. The work of Euclid of Alexandria (fl.300 BC) on geometry and arithmetic, in particular, has been considered by Dilke (1971, 26) to have had a profound effect on the theory of Roman surveying, and later practices.
The Roman land surveyors or 'agrimensores' made use of simple pieces of equipment, such as the 'groma' for surveying straight lines and right angles, 'chorobates' or water levels, sundials, various measuring rods and chains, compasses and set-squares. Exceptional standards of precision were achieved by using a 'dioptrea' or combined theodolite and water level. These, according to Singer et al (1957, 512), represented the highest development of surveying apparatus known to have been reached in antiquity.

During the Middle Ages, surveyors continued to make only simple direct measurements using lines, rods or pacing for length; and groma, plumb-line and water-level for setting out right angles, and establishing verticals and horizontals. Indirect techniques included the use of shadow-squares, and geometric quadrants and squares, though mainly for vertical measurements. In this way distances were recorded more accurately than angular bearings.

Advances in surveying instrumentation and practice followed quickly during this period. In 1512 the 'potimetrum' was designed for taking bearings and altitudes, and also for levelling. In its construction it represented a prototype of the later theodolite. A notable technical advance was made in 1533 when Gemma Frisius (1508-55) explained the principle of triangulation, and so eliminated the need for distance measurement, other than for the setting out of base lines.

Survey by triangulation became increasingly used by surveyors following the introduction of the plane-table in 1551, and improvements were rapid. The technique became especially favoured by estate surveyors, as no mathematical knowledge was required and plans could be produced with speed.

The theodolite was first made in the early sixteenth century, its name being introduced by the English mathematician, Leonard Digges (d.1558). Later, telescopic sights, carrying cross-hairs, and finely-graduated scales increased the standards of accuracy attainable.
By the late sixteenth century the science and practice of surveying had reached the stage where all the basic items of optical equipment available to the modern surveyor were in use. Land surveying activities expanded rapidly during the sixteenth and seventeenth centuries as a result of early mapping activities, undertaken to provide estate maps for the manorial lords. Such was the position of Charles Knevet, Surveyor to the Duke of Buckingham, who, in Shakespeare's *Henry VIII*, lost his job 'on the complaint o' th' tenants' (Act i, sc. 2, l. 172 [Katharine]).

Early direct measurements were taken using a rod or line that was susceptible to variations in length during conditions of changing temperature and humidity, and local custom. With the demand for more accurate maps came the use of standard chain lengths, usually Gunter's chain of one statute rod (E. Gunter, 1581-1626), and hadometers, for linear measurement, and plane-tables, circumferentors and theodolites for angular measurement. Increased understanding of geometry and trigonometry made triangulation and other calculations established surveying practice.

As surveying theory developed into a practical occupation, treatises were produced, firstly for scientific explanation, and later as surveying manuals for the increasing numbers of apprentices in the seventeenth century.

Land surveying instrumentation and techniques were explained in Ralph Agas's *A Preparation to Plotting of Lands and Tenementes for Surveys* (1596); Aaron Rathborne's *The Surveyor in Four Bookees* (1616), in which he advocated the new decimal arithmetic and trigonometry; *Pantometria or the Whole Art of Surveying* (1650) and *The Compleat Surveyor* (1653) both by William Leybourn; George Atwell's *The Faithfull Surveyor* (1658); and Henry Wilson's *Surveying by the Chain Only* (1732). Both Leybourn's *The Compleat Surveyor* and Wilson's book, later re-styled *Surveying Improved*, remained as working guides for practising surveyors until well into the eighteenth century.
No new principles were introduced into surveying or cartography during the seventeenth or eighteenth centuries, although plane-tables, theodolites and levels were increasingly refined. In 1784 the English and French triangulation systems were linked across the Straights of Dover using a theodolite possessing a horizontal circle three feet (914mm) in diameter with readings made to single seconds.

With the development of national transport systems, demand increased for surveyors capable of mapping the land for acquisition and route planning. The later turnpike trusts and canal companies of the eighteenth, and the railway companies of the nineteenth, centuries, provided work for increasing numbers of trained surveyors, both for mapping and levelling. Land enclosures also continued to provide work, along with estate surveys required for boundary disputes, legal documentation, agricultural records and sale particulars.

Tacheometry was introduced as the basis for indirect distance measurement as early as the seventeenth century, where distances and heights were determined from instrumental readings alone. The tacheometer, essentially a combined range-finding device and level, became popular with engineers engaged in rapid surveys for canals and railways during the early nineteenth century.

For angular measurement, azimuthal observations or the measurement of horizontal angles, were made using topographic instrumentation derived from magnetic compasses up to the eighteenth century. Large circumferentors or surveying compasses were used widely in this country, although liable to errors of 2' or more. Early Ordnance surveyors detected errors of 'nearly three miles... in a distance of eighteen' in the English county maps (Skelton, 1958, 602). Considering, however, the intense surveying activities of the nineteenth century, little improvement was made in either the theodolite or level until comparatively recently (Fryer, 1958, 444).

Today, the introduction of advanced technologies, notably those of computing and optoelectronics, has changed the practice of both land and building surveying. High standards of dimensional accuracy are now
readily attainable, and of increased importance as records become used for a variety of purposes. In building recording, the possibility of cumulative errors occurring in a series of linear measurements over a long distance, and distortion in single taped measurements, is now acknowledged.

When higher accuracies are required, it becomes necessary to combine linear and angular measurements to record the relationships of one point to another. This has traditionally been performed using a theodolite for measuring horizontal and vertical angles, and a tape or chain for horizontal distances. Electromagnetic distance measurement (EDM) systems have, more recently, been used to provide indirect linear measurements with accuracies of ±5mm (±0.20in.) ±5p.p.m. Total-station theodolites — theodolites with integrated EDM facilities — have become popular during the past decade.

The amount of data generated by a typical land survey has led to the introduction of field computers and data-logging devices for storing the readings in a form suitable for later restitution. This increased use of electronic and optical instrumentation in land surveying has recently been adopted for building recording, especially as the information is increasingly used for other tasks, such as analysis and interpretation.

Typically for a building survey undertaken by the Leicester CAD Centre, a 'footprint' of the building would be prepared using a total-station theodolite linked to a data logger, with automatic CAD restitution of survey information back in the office. This would be supplemented by additional data obtained from series levelling and conventional direct measurement. Increased demand for digital, rather than drawn, records has promoted this form of surveying over the past five years.
3.3 THE RECORDING OF BUILDINGS

3.3.1 Treatises, paintings and prints

Prior to the invention of photography, the only available methods of recording were written descriptions, sketch drawings or engravings, and technical elevations and plans (Brooke, 1987a, 23). The study of architecture, and subsequent dissemination of its virtues through drawings and texts, has proved a forceful catalyst for further adaptation and expression throughout many centuries. The ten-book treatise, De Architectura, written by the Roman engineer Marcus Vitruvius Pollio (fl.46-30 BC) had a monumental effect upon the architectural theorists and practitioners of the Renaissance.

Whilst the architecture of the medieval and post-medieval periods in England was developed to an extent through passive contact with foreign influences, sustained during travel and from immigrants, the theories of Classical architecture, and later revivalist styles, were spread by the many treatises produced throughout Europe, which included drawings made either at first hand or copied from other sources. The accuracy of these records was not, however, high, and often they were only artistic representations drawn with a subjective eye.

The publication of later treatises, many arising from periods of foreign travel, including the 'Grand Tour' of the nobility, and an antiquarian interest in architectural ruins, provided detailed information for academic study and the emergence of revivalist architectural styles. At this time detail and dimensional accuracy in architectural and archaeological recording became important issues.

The Antiquities of Athens (1762) produced by James Stuart (1713-88) and Nicholas Revett (1720-1804) after a period of four years (1751-55) spent studying and drawing the principal monuments of ancient Greece, took an archaeological approach to recording, and provided a reliable source for decorative aspects during the Greek Revival of the early nineteenth century. Similarly, the classic work on Egyptian art, Voyages dans la Basse et la Haute Egypte by Baron Dominique Vivant...
Denon (1745-1825), published as three volumes in London in 1803, and subsequently Description de l'Égypte (1802), provided a more reliable record than previously available.

Academic study continued through the eighteenth and nineteenth centuries with lectures and textbooks: Sir John Soane (1753-1837), C.R. Cockerall (1788-1863) and Reginald Blomfield (1856-1942) provided important influences to future generations of architects. One of the most complete collections of measured drawings prepared at this time was A History of Architecture on the Comparative Method by Sir Banister Fletcher (1866-1953), first published in 1896 for educational purposes, and presently in its nineteenth edition (1987).

The thread of antiquarian study, with the recording of medieval and earlier monuments, resulted in the creation of itineraries, collected views and early attempts at inventory, and fed into the serious study of ancient monuments in the eighteenth century (Chitty, 1987, 46). The contribution made by the Dilettanti Society, founded in the 1730s for artistic encouragement and patronage of excavation and research into the antique Classical world, especially the source of true Classical architecture, is considered by Yarwood (1985, 164; 206) to have been substantial.

Later, with the emergence of archaeology as a separate discipline at the start of the following century, pioneering work by William Cunnington (1754-1810), Richard Colt Hoare (1758-1838) and others generated a new force in the recording and study of architectural ruins. Pressure by the Society of Antiquarians, founded in 1707 and recognised as the guardians of medieval monuments, together with other influential persons, led, in time, to parliamentary measures that today protect those structures scheduled as 'ancient monuments'.

Buildings also became the subject of artistic attentions during the seventeenth century, with many such paintings and drawings representing the wealth and standing of the patron. Landscape paintings, perhaps
showing a view of the house set in a garden laid out to the latest fashion, became popular expressions of the owner's successes and aspirations. In this respect, Robert Street, Serjeant Painter to the King, was one of the earliest to produce such works; his View of Boscobel House, known for being where Charles II hid in 1651, is one of the first paintings of a country-house and its setting (Halliday, 1967, 170).

Towards the end of the 1720s a new fashion for 'conversation pieces' became popular in England, typically a painting of an informal group of persons, family or friends in the home or garden (Waterhouse, 1978, 188).

The importance of these works as visual records is significant, representing, as they do, a link back to the lives of past generations. Views of Dunham Massey (Ches.) are among the most remarkable and comprehensive surveys of a country house ever painted (National Trust, 1981, 22). The earliest, by Adriaen Van Diest (1655-1704), shows a Tudor house in 1696; this also appearing in a painting by Leendert Knyff (1650-1722) early in the eighteenth century. Four other views were painted by John Harris (active 1722-59) in about 1750, providing a unique record of an eighteenth-century formal layout, being amongst the last 'bird's-eye views' ever painted.

Such works were, however, often commissioned as pieces of art, rather than accurate records, and much was not as it appeared. The primitive-style painting of Belton House (Lincs.) (1690), erroneously attributed to Henry Bugg (d. 1695), demonstrates a degree of artistic licence in the way the church, physically out of the composition, was moved some 500m (546yds) to the west to fit into the gap between the house and service range (Barbour, 1989, Unpub.). The aerial view of c. 1750 by Thomas Badeslade, the landscape artist who published many drawings of country-seats belonging to the English nobility and gentry in various county histories between 1718-50, clearly shows the house and park prior to later alterations (National Trust, 1985, 44).
From the eighteenth century, wider interests in antiquity and the natural world gave rise to a more scholarly approach in recording. Topographical prints, representing the features of a particular locality, became a popular means by which people could be informed about distant places. It is noted by Brooke (1987a, 23), however, that even these accurate and meticulous early records inevitably fell short of an ideal standard simply because of the limitations imposed by the techniques available. The transcription of unseen views, together with aspects of aesthetic theory and artistic composition, led also to significant inaccuracies (Russell, 1982, 18).

Important architectural studies have included the mid-eighteenth century work of Samuel and Nathaniel Buck, which resulted in over 400 plates of castles, abbeys, palaces and other old and important buildings, issued individually and subsequently published in three volumes. The Architectural Antiquities of Great Britain, The Cathedral Antiquities of England, Picturesque Views of English Cities, and Picturesque Antiquities of English Cities by John Britton during the early nineteenth century provided detailed studies of British architecture, and also a documentary of social history. As well as such general collections, certain geographic areas had their own specialists, working in a particular region or on a specific aspect, such as ports and harbours.

As steel engraving displaced copper, so lithography overtook aquatint in the 1830s, providing a rapid technique suitable for topographic work. Britannia Delineata, the Lake District views of J.B. Pyne; J.P Lawson’s Scotland Delineated; and Original Views of London As It Is (1842) by Thomas Shotter Boys, used the new printing process to good effect.

3.3.2 Architectural drawings

Architectural recording, according to Smith (1985, 143), started with the attempts of antiquaries to recover better specimens of the classical orders and as a sideline to delving in the ruins of Italy for
Roman and Greek sculptures, at a time when the aristocracy saw itself as heir to the manners of the Roman patrician class'. Often the collection of such treasures necessitated new galleries and libraries in the homes of the nobility (Yarwood, 1985, 206).

It soon became obvious that such free-handed exploitation of important international monuments needed to be checked. Academic study, based on examination and documentation, led to important publications that extended the knowledge and understanding of the Ancient World, and helped to change the attitudes of many from materialistic selfishness to learned deliberation.

The production of accurate record drawings, as opposed to free-hand sketches, began with this change during the eighteenth century, and saw the publication of measured drawings such as those by Robert Wood and Nicholas Revett during the 1750s and 1760s. It is from these times that the art of architectural drawing may be said to have begun.

Architectural drawing is, according to Earl (1982, 19), a precise and elegant way of transmitting information and ideas about architecture and buildings, to be enjoyed by all who understand simple and logical rules of representation. Its history is outlined in this section, and commentary on present practices given in Section 4.1.

Drawings are normally used to represent the designs of architects and others, and are a recognised means of translating their ideas into three-dimensional buildings. If the most efficient way of describing a building that is yet to be constructed is by means of drawings, Chitham (1980, 1) considers that drawings are also the best means of recording a building that exists. Such an attitude is by no means new: historical references clearly demonstrate the importance placed on draughtsmanship, and an understanding of archaic forms of construction and ornamentation.

Colvin (1978, 19), in tracing the development of the building trades and architectural profession with regard to their organisation and training, points out that for the builder of the eighteenth century, it
was recommended by Campbell in his *London Tradesman* (1747) that 'he must learn Designing, and to draw all the five Orders of Architecture according to their several Proportions'.

The emphasis placed on acquired knowledge and accurate reproduction of Classical architecture persisted into the following century. Peter Nicholson (1765–1844) and his son, Michael Angelo (1796–1842), writing in *The Practical Cabinet Maker, Upholsterer and Complete Decorator* (1826), stressed that the careful study of Greek architecture would encourage improvement in the art of decoration and an understanding of the geometrical principles upon which 'such precious remains of antiquity' were based (Nicholson and Nicholson, 1973, vii).

In conveying the ideas of such images, language alone was though to be inadequate, and recourse was made to 'some sensible mode of representation, by which the analogy, positions, and connexions of the separate parts of a body, may be clearly exhibited to the eye' (*Ibid.*, vii–ix). Two distinct modes of representation were cited, by which 'the forms, positions and measures of the original parts of a complex object' could be understood.

These essentially were perspective drawing and orthographic projection. With the first, the object was said to be 'exhibited to the eye in such a manner as to produce the same image, and the same effect on the imagination, as the real object itself, when viewed from a corresponding point'. By means of the second, 'although the object be not so agreeably represented to the eye, the exact measures of all its parts can be ascertained with incomparably less trouble than be perspective representations'. Although the use of plans, sections and elevations were acceptable for representing the wishes of an architect to the workmen, it was considered that, for complex designs, perspective representation offered many advantages.

As concern spread for the plight of historic buildings, individuals, such as William Morris (1834–96) and John Ruskin (1819–1900), began to
consider means of protection and study. In 1877 the Society for the Protection of Ancient Buildings (SPAB) was founded by Morris in order to '...protect our ancient buildings, and hand them down instructive and venerable to those who come after us'. Legal protection soon followed, including the Ancient Monuments Protection Act of 1882.

During the 1890s, the loss of London's architectural heritage prompted the architect, designer and writer, C.R. Ashbee (1863-1942) to set up a committee of various professionals to 'watch and register what still remains of beautiful or historic work in Greater London, and to bring such influence to bear from time to time as shall save it from destruction or lead to its utilisation for public purposes'.


In their work, the Survey of London has, over the years, developed a recognisable style of record drawing that, according to Earl (1982, 22), discovers and expresses original form and architectural intention, to a high degree of perfection. This is achieved by the use of simple line drawings, with no rendering, half-tones or colour; edges and depth being expressed purely by line weight (Clements, 1989, Unpub.).

Sanders (1989, 133) points to the fact that architectural drawings contain three kinds of graphic objects: pictorial, symbolic and annotative. Present CAD systems do not easily distinguish between these objects, and for this reason, the Survey of London makes only limited use of such facilities.

In 1908, the Royal Commission on the Historical Monuments of England (RCHME) was established to compile inventories of every historic building dating from before 1714 throughout the country. Due to the
enormity of the task, and, in part, the slow rate of progress, the National Monuments Record (NMR) was set up in 1941 in order to record post-1714 buildings and provide a data-bank of visual records concerned with old buildings (Fowler, 1981, 106 et seq.; Cooper, 1988b, 28 et seq.; Croad, 1989, 23 et seq.). The extent of the archive photographic material held by the National Monuments Record, and its relevance to present-day conservationists, has been highlighted by Noble (1982, 27-41), and an introduction to the Royal Commission and National Monuments Record provided by Cooper (1982, 11-13).

At the present time, the Architectural Heritage of Britain, founded in 1986, is concerned to 'measure, draught and produce definitive line drawings and coloured illustrations of every building of significant architectural merit in Great Britain' (Architectural Heritage of Britain, 1988, 5-8; Aldous, 1989, 46; McGhie, 1989, B11). In this immense undertaking, consideration is given only to the façades which, as determined by the organisation, are neglected in the work of the Royal Commission and the files of the National Monuments Record.

Other countries have also established agencies responsible for recording historic buildings. In the United States, the National Parks Service of the Department of the Interior use a combination of drawings, photography and written data to record buildings, with completed surveys lodged in the national archive of the Library of Congress. In Australia, the Australian Heritage Commission co-ordinates building recording undertaken within the various States. On the Continent, the recording of historic buildings and cultural sites is generally in advance of practices within the United Kingdom.

3.3.3 Architectural photography

Buildings have been an important subject for photographic experimentation and dedication since its invention in the 1830s, and, as such, might be regarded as a source of inspiration for the art of photography. There is, however, another side to this attitude. Photography itself offers potential for recording that no other basic
technique can offer. Photographic records have provided factual information to present-day audiences that would otherwise have been lost; offering, as it does, the unique characteristic of total objectivity.

The use of photography in both artistic and scientific recording is well documented. It is, however, considered appropriate, in the context of this investigation, to reflect on the development of photography in relation to architecture, and its rôle as a tool for the architectural or archaeological surveyor.

The word 'camera' is the Latin form of a Greek word and from it has derived the Italian word 'camera', the French 'chambre' and the English 'chamber'. Thus, the original use of the word meant a vaulted room forming an enclosed living space in a building (Scott, 1983, 91). From the Middle Ages a room darkened so that an image might be focused through a small hole was described by a variety of Latin terms. From these, the Camera Obscura (darkened room) has come to be accepted as the common term given to the earliest form of camera, although Camera Clausa (closed room), Conclave Obscura (darkened room) and Cubiculum Tenebriscom (darkened bedchamber) were also used. With the insertion of lenses and a gradual reduction in size down to a portable box, the Camera Obscura became commonplace as an aid to graphic reproduction and entertainment.

Knowledge of the optical principles on which the use of the Camera Obscura was based can be traced back to 350 BC, when Aristotle (384-322 BC) made reference to the process of projecting images optically. Leonardo da Vinci (1452-1519) probably worked with optical toys during his period in Rome (1513-19), as did his precursor, Leone Battista Alberti (1404-72) over eighty years earlier (Clark, 1988, 236). The woodcut entitled Demonstration of Perspective Drawings of a Lute (1525), from a book on scientific perspective by Albrecht Dürer (1471-1528), was based on the work of the Italian Piero della Francesca (c.1418-92) (Janson and Janson, 1982, 130), described as the greatest geometrician of his day (Horsley, 1970, 443). The device allowed correctly foreshortened pictures to be produced in a purely mechanical
way, later to be replaced by the Camera Obscura.

The application of image projection as an aid in drawing was pioneered by Giovanni Battista della Porta (1538-1615) and postulated in *Magiae Naturalis* (1558) (Gernsheim, 1971, 10). Work by such luminaries as Johannes Kepler (1571-1630), the celebrated astronomer and mathematician, who set up a revolving tent with a tube holding a lens, so allowing a drawing to be produced by tracing the image projected by the lens; and the light emission theory of Isaac Newton (1642-1727), further advanced the understanding of optical principles to a state where, by the seventeenth century, knowledge of light-sensitive chemicals lagged far behind that of optics. This half-knowledge was to remain as an enigma until the nineteenth century, when attentions turned to the question of creating a permanent image.

The chief concern with those experimenting in this area was to transform the visible image into a permanent record. Early attempts failed due to a lack of chemical knowledge, but in 1826, the first ever photograph was taken by the Frenchman, Joseph Nicéphore Niépce (1765-1833) (de Maré, 1961, 20). It consisted of a metal plate coated with a solution of bitumen of Judea and recorded, after an eight-hour exposure, a view of the courtyard of Niepce's home. The latent image was made visible in positive form by washing the plate with a mixture of oil of lavender and white petroleum, which dissolved away those parts of the bitumen which had not been hardened by light.

In the following years many attempted to chemically fix images on to a variety of materials. One of the most successful was that patented by Louis Jacques Mandé Daguerre (1789-1851) in 1839. Called a 'Daguerreotype', many such examples have remained, covering a variety of subjects. With the introduction of photography on to paper came an alternative to the daguerreotype. In 1835 William Henry Fox Talbot (1800-77) made a paper negative of the lattice window of his library at Lacock Abbey (Wilts.). That experiment was the basis of modern photography, as the light-sensitive paper was produced by bathing it first in a solution of common salt and then in one of silver nitrate, the two forming silver chloride. Talbot patented an improved process
in 1841, which he called a 'Calotype', later becoming known as a 'Talbotype'.

The introduction of the terms 'photography' and 'photographic' have been credited by Eder (1945, 258) to Sir John Herschel in a lecture on 14 March 1839, although Buckland (1980, 44) points to the use of the term 'photographic' in a letter from Sir Charles Wheatstone to Talbot early in February of that year.

Stereoscopic photography became established early in the history of photography, during the 1850s, especially with the production of stereo view-cards (Hannary, 1976, 30). Stereoscopic vision, the concept that two eyes see different images, on which three-dimensional photography is based, is attributed to Euclid (f.300 BC). Similar work was also undertaken by Ptolemy or Claudius Ptolemaeus in the second century AD. Detailed investigation into the phenomena by da Vinci concluded that because of the different relative positions of the eyes in respect of the subject, their views would be different.

The invention of the stereoscope by Wheatstone during the nineteenth century allowed three-dimensional images, taken by moving the camera laterally by a distance equating to the distance between the human eyes, to be viewed. Early stereo-photography was heralded by the commercial introduction of the stereo camera by Louis Jules Duboscq in 1851, providing photographs to be viewed in Sir David Brewster's (1781-1868) lenticular stereoscope.

In the context of this work, it is sufficient to have acquired a basic introduction to the history of photography in order to appreciate the application of the science to the recording of architecture. Generally, at this time, buildings became popular subjects, whether as individual studies or incidental scenery, and certain individuals produced important documentary works.
Due to their ease of access, general immobility and acknowledged artistic appeal, Rosenblum (1984, 95; 99) considers that landscape, nature and architecture provided congenial subjects for the first photographers, who were heirs to the picturesque and topographical traditions of landscape imagery. This 'ferment of experimentation', as Zwingle (1989, 530) has noted, meant that the first fifty years of photography saw the greatest evolution in both technical and artistic matters.

Within a few years, daguerreotypes were being used to record the architecture and archaeology of many countries around the world, furthering the popular interest initiated in the eighteenth century with finds at Troy, Pompeii and Herculaneum, and stimulated by academic study in the ancient cultures of Egypt, Greece and the Near East.

The work of Horace Vernet and Francis Frith in Egypt; Hamburg Carl Fernidand Stelzner in Germany; Auguste Salzmann in Jerusalem; Joseph Philibert Girault de Prangey in Italy, Greece and the Near East; and that of others, introduced to many, for the first time, the wondrous buildings of foreign lands. The work of Robert MacPherson, one of the leading architectural photographers of the nineteenth century, and, to a lesser extent, that of James Anderson, led to a greater appreciation of ancient Roman architecture and culture during the 1850s.

In Britain, David Octavius Hill (1802-70) and Robert Adamson (1821-48) were recording architectural scenes from Edinburgh and St Andrews on to paper from as early as 1843 (Langford, 1980, 21), and between 1854 and 1856 Thomas Keith (1827-95) produced many waxed-paper photographs of Edinburgh's architecture. The work of Roger Fenton (1819-69) at this time, in producing a series of photographs showing English cathedrals, was much admired.

Reaction to the fast-changing social and physical conditions of Victorian Britain led some to record everyday scenes, including Frank M. Sutcliffe (1853-1941) in Whitby and P.H. Emerson (1856-1936) in Norfolk during the 1870s and 1880s; Thomas Annan (1829-87) in Glasgow for the Glasgow City Improvement Trust during the period 1868-1877; and
Henry Dixon, and A. and J. Boole, for the Society for Photographing the Relics of Old London between 1874 and 1885.

As photographic techniques improved, large-scale government and privately sponsored commissions were awarded to produce photographic records of a specific nature or theme. The 'Missions heliographiques', established by the French Government's Commission des Monuments Historiques in 1851 to provide a pictorial census of France's architectural patrimony, was one of the earliest applications of photography in providing an extensive architectural record (Gernsheim, 1971, 92; Rosenblum, 1984, 100).

Based on the work of Gustave Le Gray, O. Mestral, Henri Le Secq, Edouard Baldus and others, the project never reached full fruition, the negatives and prints being filed away without publication. They were, however, individually used by architects and masons working under Eugène-Emmanuel Viollet-le-Duc (1814-79), the French architect whose scholarly interest in the Gothic style made him the foremost exponent of its revival in France (Lewis and Darley, 1986, 310), in matching and fabricating decorative elements during works of repair and restoration.

Later, in 1854-55, Baldus undertook a full photographic survey of the new wing of the Louvre for the French Government, amounting to some 1,500 detail photographs. Ferdinand Ongania's extensive work on the Basilica di San Marco in Venice from 1878 to 1886 recorded, on over 500 photographs, every noteworthy feature of the exterior and interior, and was, at one time, thought to be the first photographic survey ever to be made of a building.

In Britain, Philip Henry Delamotte (1820-89) took a series of photographs during 1853-54 tracing the rebuilding of the enlarged Crystal Palace at Sydenham from bare site to the opening ceremony by Queen Victoria on 10 June 1854.

The work of photographers dealing with architecture and buildings has formed a core for the National Monuments Record, operating since 1963 as part of the Royal Commission on the Historical Monuments of England.
One of the more important collections held in this manner is the photography of Harry Bedford Lemere (1864-1944), dealing with period interiors. A selection of his work, brought together under the authorship of Cooper (1976), provides a unique record of late Victorian and Edwardian taste in interior design.

It is evident from the preceding sections that buildings have been surveyed and recorded using a variety of means, for many purposes, over a considerable period of time. We have, so far, considered the nature of surveying in its broadest sense, introducing the general questions of practice and content in relation to contemporary demand. These issues, set against the historical pattern of recording, leading ultimately to the professional status of surveying, need to be examined in the context of practical surveying and recording as practised today, if sufficient credibility is to be accorded to the introduction of new philosophies and techniques.

The following chapter therefore draws on these general points, and concentrates on the practical aspects of dimensional surveying. Consideration is given to established and recent techniques, in measuring and recording built fabric, and in doing so, provides a basis for the essential purpose of this work, the proposition and development of a system of elevational surveying based on photographic data capture and computer-aided restitution.
A building, in essence a three-dimensional envelope in and around which we base our lives, can be represented in a number of ways. Considering only those methods that provide a true-to-scale representation or model, with an accuracy within known tolerances, there are three main forms of visual description: analogue, iconic and symbolic (Broadbent, 1973, 89).

Architectural drawings are essentially analogous to the composition of the building as a series of graphical elements, such as lines, planes and shapes. Real models, solid three-dimensional representations of the proposed or subject building, share many of its basic properties, including mass and volume. However accurately they represent the original, such iconic models can never share all its properties. Recently, digital models have become more widely used in the design and recording of buildings. These symbolic models have the capacity to relate one set of data with another, and have become popular with those dealing with acoustic, thermal and structural interactions.

A measured survey is essentially the product of two distinct procedures, data collection and data processing. These take the form of surveying the building, that is, measuring the structure and recording the dimensions, and subsequently translating the survey sketches and notes into finished drawings. Although this distinction may be reduced by what Chitham (1980, 20) calls 'scale plotting', that is developing a properly measured drawing on site, it is to be retained as a means of ordering the contents of this chapter.

Site surveying amounts to providing a representation of the physical structure and fabric of the building in a manner that allows the collected data to be analysed and interpreted. The various building components represent a three-dimensional space, or more correctly, a series of interrelated three-dimensional spaces, within which activity is focused. The manner in which these volumes are translated into meaningful graphic images, either as two-dimensional drawings or
three-dimensional models (real or digital), is a product of the resources, including skills and equipment, the intentions and the aspirations of those concerned.

The process of data collection can itself be considered in two parts - taking the measurement, whether linear or angular, and recording it in a way that allows the spatial relationships to be subsequently determined and reconstructed. The nature of the measurements and the way in which they are taken can be related to what is being surveyed.

The various classifications of building survey have been discussed elsewhere (Section 2.3), but within the scope of this work it is important to consider the methods that might be applicable to the recording of buildings and monuments, and their façades in particular. In this respect, Kirk (1983) and Dallas (1989b, 10 et seq.) provide useful summaries of established direct and indirect surveying techniques.

4.1 DIRECT SURVEYING

Direct surveying, in the context of this work, covers the production of measured drawings based on physical measurement and recording. This forms the basis for most contemporary building surveys, providing information by way of plans, sections, elevations and metric projections. As each phase is usually completed as a distinct operation, measurement and interpretation are considered separately.

4.1.1 Building measurement

This section is concerned with the general principles of extracting and recording the dimensional data necessary for the production of a measured drawing.

The theory and practice of general building measurement and surveying are covered by Fairweather (1978), Staveley (1984), and Whyte and Paul.

The traditional building survey commences with the preparation of free-hand sketches roughly true to shape and in proportion, but usually with no attempt made at sketching to scale. In order to avoid the fragmentation that results from recording each space separately and attempting to fit them together at a later stage, Whyte and Paul (1985, 159) suggest that lower-order work is added to an accurate framework, in accordance with the customary expression of 'working from the whole to the part'.

The graphical representation of a façade has been considered by Rodwell (1981, 82) to be effectively a plan of the wall surface in question. As such, it can be theoretically argued in favour for adjusting conventional horizontal-plane recording techniques for use with vertical planes. This has been well proven in the archaeological recording of standing edifices with the use of string grids secured to the surface for manual scaling and drawing (Sutherland and Parsons, 1984, 46-47; Williams, 1986, 3, Unpub.; Parsons, 1989, 71).

Recent technological advances have resulted in the production of electronic devices capable of single-handed linear measurement, collectively known as 'sonic tapes'. The accuracy and reliability of these aids is currently under discussion, though for certain applications, their usefulness is apparent.

The recent release of the SURVEY MASTER (Surveying Technology Limited) provides a customised data logger for undertaking measured surveys and transferring site measurements, and also data from existing drawings,
into a CAD system. It is too soon to provide commentary on its practical application, but if reliable, it offers a valuable tool for the generation of digital data and computerised survey drawings.

Sophisticated means of recording dimensional data using field computers, often linked to total-station theodolites, are becoming increasingly used for measured surveys of buildings. Particular applications in this respect have been described by Park (1985, 46-61) and Mooney (1988, 83-87).

Total-station theodolite surveying has also been applied in the context of archaeological excavation, where the site is too large to make economic use of conventional string grids and other techniques. Powesland (1988, 9, Unpub.), in his work on recording archaeological finds during excavation, notably at Heslerton (N. Yorks.), logs polar co-ordinates instead of recording the usual Cartesian or XYZ co-ordinates. A similar technique is used by Leicester CAD Centre in recording the interiors of large buildings, or those with complex geometrical forms.

Such instrumentation has also been used to obtain control for the digital 'mapping' of façades. The work of Fradgley (1988, Unpub.) at Lacock Abbey (Wilts.), in particular, shows how simple façades may be mapped using a total-station theodolite and field computer with both speed and relative accuracy. Such mapping techniques have been used by the author to provide the dimensional control for digitised photographic data. It might also be used for a similar purpose with rectified photography, in order to provide the necessary control for a photographic montage.

There are, therefore, opportunities presently available within the range of 'direct' surveying techniques for selective automation and computerisation. This also applies at the interpretative stage of a measured survey, which will be covered later (Section 4.1.2).
In preparing a topographic survey drawing, the basic survey methods used in the supply of detail, height and control information are already well documented, including texts by Bodey and Hallas (1977), Breed and Hosmer (1977), Harwood (1982), and Whyte and Paul (1982). These methods of controlling a survey have been identified by Whyte and Paul (1985, 6) as being:

(a) **Methods of Supplying Detail**
- Offset/Rectangular co-ordinates
- Polar co-ordinates/Radiation
- Intersecting arcs
- Intersection/Triangulation

(b) **Methods of Supplying Height**
- Levelling
- Trigonometric heighting
- Barometric heighting
- Hydrostatic levelling

(c) **Methods of Supplying Control**
- Use of a base or base line
- Triangulation
- Trilateration
- Traversing

Many of the principles on which these methods are based can be applied to the surveying of buildings for the preparation of plans, sections and elevations. The principle difference between topographic and building surveys is one of scale: chain surveys are typically reproduced at scales of 1:50,000 to 1:500, whereas building surveys are commonly at 1:100 or 1:50. This has an important effect on how the measurements are taken, and ultimately the level of accuracy to be adopted in relation to the purpose of the survey.
4.1.2 Building interpretation

A building is usually arranged as a series of blocks, being of varying shapes and sizes at different levels. It is, thus, important to record not only the necessary dimensions for each space, but also the horizontal and vertical relationships of one space with another. This three-dimensional information is conventionally represented in two-dimensional drawings by means of related views - plans, sections and elevations - known as an orthographic projection.

Dimensional plan information is the most common means of representing a building, demonstrating both spatial relationships and areas of accommodation. It is relatively simple to collect the data and plot to scale, and recent advances in surveying techniques have concentrated on the collection and collation of survey data by means of sonic tapes, field computers and proactive expert systems.

Sectional data allows vertical relationships to be studied, having important consequences when considering elements such as staircases and service integration. Elevations again provide this information, but also fix the position of elements, such as doors and windows, horizontally. In providing a dimensional record of a building, it is often sufficient to present plans and elevations, with vertical relationships defined by levels noted on the relevant floor plans.

Great stress has been placed by many on the preparation of accurate records, and Feilden (1971) considers that 'to embark on any repair or restoration work without accurate plans, sections and elevations is to deny the architect one of his fundamental skills of thinking three dimensionally'.

The information to be recorded by way of plans, sections and elevations varies with the nature of the survey, and is adequately covered by authors such as Reekie (1976), Staveley (1984) and Whyte and Paul (1985). The projections that provide the means of presenting this information are again covered in standard texts.
First and third angle projections are usually employed in combination, so that in relation to the front elevation of an object, end views are placed as in third angle projection and plan views as in first angle projection. Metric projections are used to give the impression of actual three-dimensional appearance, yet in such a way as to allow length, breadth and height to be measured. They are set up from orthographic projections and usually provide axonometric, isometric and oblique views.

Plotting can only be as accurate as the dimensions taken on site. Where the scale of the desired drawing is known, it is usual to measure to a predetermined level of accuracy, such that for a drawing to a scale of 1:100 or 1:50, it is common practice to measure to the nearest 10mm (0.39in.). Were a smaller tolerance to be adopted, much would be lost in the thickness of the drawn line.

The interpretation of measurements and notes made during the course of a measured survey has traditionally been carried out as a separate exercise, to provide the required graphic information. The usual manner in which this is undertaken is by manual draughting, following established conventions and to agreed standards. These, together with comments on graphic representation by computer, are considered by Howard (1988, 41-43).

The use and application of computer-aided design/draughting (CAD) facilities, in general, and computer-aided architectural design/draughting (CAAD), more particularly, continues to generate much interest, though this is beyond the scope of the present work. For current views and developments, attention is drawn to specialist journals, such as CAD/CAM International, Computer Images and 3D.

Confusion persists regarding the difference between computer-aided design and draughting. The late Christopher Strachey (1977, 122), Professor of Computation at Oxford University, defined computer-aided design as being:

-68-
'The use of a computer, typically associated with a visual display, in such a way that a designer can see his design immediately and the consequences of changing it, while remaining free to exercise the unprogrammable qualities of taste and judgement. This generally involves showing a perspective view of a complicated three-dimensional object; often the point of view can be moved, giving the impression that the object is being rotated. More sophisticated systems allow for binocular vision, and the designer may even get the impression of walking inside his proposed design'.

This definition supposes that design is essentially an exercise in problem solving, for which there can be numerous solutions. Computers, however, cannot 'design' because they cannot think: instead they impose order (Roth, 1988, 54). CAD is thus a tool for the presentation of these solutions using powerful graphic routines, which enable the data to be manipulated, stored and retrieved electronically. Whether the information is presented two- or three-dimensionally, it is important to understand that CAD, in all its guises, is a tool that should assist, rather than take over, the conventional processes.

Computer graphics systems may generally be considered as being within one of six broad categories - business, presentation, desktop publishing, draughting, visualisation and building modelling (Ashton, 1990, 2). Each has its particular applications, and has become established within its own right.

Draughting systems, with which this work has been concerned, enable the user to prepare working and record drawings using methods similar to those used on a drawing board. Such systems are mainly of benefit in situations where there is a considerable amount of repetition involved in the drawings to be produced. An important difference between these systems and presentation graphics is the ability to draw to scale.

CAD, in general, is a rapidly developing field that has implications for many professions and industries. Previously, systems used for building design and draughting were based on dissimilar disciplines,
such as mechanical design, which concentrated on drawing regular solids, as opposed to representing spaces. This situation has altered markedly within the last decade to a point where graphics software covers a range of applications and activities from early sketch design to production drawings, including performance analysis and colour visualisation.

Until recently, CAD has been considered by many designers as simply a draughting tool, to produce two-dimensional drawings faster and more accurately than a draughtsman. As a result, many users realise only a small fraction of the potential of their systems. Within the building surveying profession, Olivier (1990, 3) considers that traditional services will be extended, through the use of increasingly sophisticated CAD systems, towards other areas of building design and performance.

CAD, however, is not just a different way to draw. Rather, it represents a significant change in the way graphic design information is handled (Nicholson, 1987, 15-16). This requires a reappraisal of former approaches to design representation, and a degree of planning in order to maximise productivity.

Advice on purchasing a system is widely available, depending on particular user requirements. Nicholson (1988, 22-23) provides a useful checklist of essential and optional requirements for software packages, with explanatory notes for the system features referred to.

Presently, CAD is being applied in many design situations, not just as a graphical aid to the draughtsman, but as an interactive tool that provides a functional line between the various members of a design team. Lawson (1985, 40-41), whilst pointing out the dangers of adopting CAD as a design tool, feels that benefit may accrue to the interior designer when it is used as an aid to communications.

The ability to create a visual interpretation of proposals at various stages of the design process has proved an important watershed (Whitehead and Gentleman, 1988, 20-21; Hall, 1988, 21-25). Simulations
of designs have proved of use in architectural training, especially when combined with photographic images to indicate the appearance of buildings in the urban context (Bridges, 1988, 15).

Computer-aided visual impact analysis, making use of photogrammetry and still or video photography, has been investigated by Bridges (1981, 103-113); and graphic representations of photogrammetrically surveyed buildings and services presented by Palframan (1988, 36-40). Problems of three-dimensional perception and visualisation, however, are prevalent, and can cause problems when three-dimensional objects are presented on a two-dimensional screen (Parslow, 1988a, 12-17; 1988b, 19-22).

The recently developed VERIFIED VISUAL MODEL (VVM) (Chief Executive Assignments Limited) provides visual representations specifically for evaluating the likely impact of proposed designs on the real environment, by combined the sciences of computer modelling and photography. The final product of this system is a spatial montage, that can be readily understood by lay persons and designers alike (Fenton, 1990, Unpub.).

As CAD becomes more widely available, with greater processing power and interactive facilities, many feel that it will soon become an accepted part of a design office, resulting in a two-tier profession: those with CAD, and those without. Overall price/performance levels continue to increase, with emphasis on interactive building modelling and image synthesis (Sanders, 1989, 130-135).

There is, within the corpus of architectural and archaeological surveying, a growing body of opinion that has found such technology to be practically, and often profitably, justifiable. Kronenberg (1987a, 105-110; 1987b; 1988, 31-36) presents evidence for the successful inclusion of CAD in the general dimensional recording of existing buildings, whilst Stewart (1987, 69) and Ridout (1987, 39-43), amongst many, provide evidence for its use in refurbishment projects.
The use of CAD in archaeological surveying for the interpretation of
topographic and geophysical survey data, together with simulation and
three-dimensional solid modelling for presentation and interpretation,
has been considered by Blake (1989, 39-40).

In general, the use of CAD in the processes of surveying and recording
existing buildings can be considered as two separate operations. On
the one hand the system can be used as a means of translating site
measurements into easily accessible visual representations, whether as
conventional architectural graphics or three-dimensional digital
models.

On the other hand, the system can be used as an aid to data
interpretation, with the required dimensional information extracted
from an indirect source, such as a photograph or archive drawing, with
a minimum of direct site measurement.

Neither of these applications can be described as 'design', although
there is the potential for introducing additions and omissions in the
final product. Both are concerned with actualities, the difference
lying only in the classification of the data source. There is,
however, the possibility of using CAD to create hypothetical or
conjectural reconstructions from fragmentary evidence, whether it be
based on excavation or documentary research. This has been
successfully undertaken by the London Division of English Heritage with
Sutton House, providing a record of changing domestic architecture and
a basis for future repair (Milner, 1989, 25).

One advance that has great potential for architects, surveyors and
archaeologists is the improvement in the price/performance ratio for
scanners, together with the development of editorial software for
rasterised images and of raster/vector translation that will allow
existing drawings to be converted into computer data for manipulation
without the need for digitising or re-drawing (Ray-Jones, 1989, 81-82).
In analysing built fabric, which would typically involve detailed surveying and recording, all the component parts should ideally be dissected to reveal the information they might hold (Rodwell, 1981, 170). With the investigation of a wall, the relationship of every stone to its neighbour should, for instance, be recognised, in order to assist in the evaluation of construction techniques, defect diagnosis, or as an aid to petrological analysis or stratification.

The function of any stone under consideration for removal in a programme of repair and maintenance needs to be clearly understood. Decaying stones that have a structural rôle, and on which the stability of other stones and elements of the structure depend, clearly have a priority for replacement (Ashurst and Ashurst, 1988, 9).

Actual removal of stones needs to be carefully specified, using a record drawing or photograph to indicate specific stones. In this respect, Caroe (1982, 13) considers that drawings need not be reproduced at all, with everything being adequately observed on photographs. This form of recording is, however, subject to severe limitations, as noted by Caroe and Caroe (1984, 19). Ireson (1987, 3) considers that photogrammetric surveys offer advantages of accuracy and speed over hand-drawn measured surveys in recording large elevations, and that rectified photography also has its uses.

When using photographic records based on a central projection, the stones directly in front of the lens at the time of exposure appear true in profile, while those viewed at an angle exhibit parallax distortion. Such a problem occurs also when drawing an elevation on site using a string grid, with parallax errors of 10mm (0.39in.) or more being common. For this reason, the draughtsman is advised to position himself about 1,000mm (3.3ft) away from the wall and look squarely at the stones being drawn.

At a simple level, Harris (1990, Unpub.) has successfully employed non-metric photography for recording the walls of a building to be dismantled. By providing overlapping normal-case coverage at a standard distance away from the wall faces, he was able to record and
number each stone with speed and reliability. The mortar joints were, however, not clearly visible due to a lack of contrast and colour, and the outline of each stone was drawn on to the prints whilst on site.

When recording a section of aged wall on a stone-by-stone basis, few stones will possess sharply-defined edges, and many will be rounded in profile. Fissile mortar can easily be disturbed, so altering the apparent edge of the stone. Work of this nature requires a great deal of care and subsequent checking on site, and expectations of what can be produced using a particular technique often need to be tempered by an understanding of the processes and site conditions.

In this respect, and as an example, the photogrammetric recording of the curtain wall and gatehouse at Newark Castle (Notts.) was hampered by vegetation growth and the large number of chipped and fractured stones within the subject sections of masonry (Terrey, 1988, Unpub.). When plotted, these stones appeared as either two stones or entirely the wrong shape, a critical factor as the results were to be used in an extensive programme of consolidation and repair.

On the standard of photogrammetric plotting, related to the architectural or archaeological knowledge of the operator, Feilden (1987, Unpub.) has commented that a decayed column can look like 'a string of sausages', and Rossi (1988, Unpub.) that built-in beam and joist ends appear as 'squiggles which might as well have been plum puddings'. It is, however, noted by Caroe and Caroe (1984, 20) that the best result of all is a photogrammetric drawing that has been expertly revised on site by hand.

Where dimensionally accurate records are required to serve as the basis for further analysis and evaluation, photogrammetry provides a powerful tool. For this reason it has been utilised in recording the west front of Wells Cathedral during a programme of repair, and as an aid to the interpretation of its historic setting-out, relative to the plan form. Accuracy to within a few millimetres was crucial in this work to enable a full and meaningful account of historic building practices to be ascertained (Rodwell, 1988, Unpub.).
In order to complete this section on building interpretation, it is appropriate to mention the possibility of deriving dimensional data from an indirect source through the application of perspective analysis. The use of computer-aided perspective analysis has been investigated by Battle (1985), and Bristow (1985, 25-31) explains the application of basic analysis during the restoration of the Great Drawing Room at Bowood (Wilts.).

4.2 INDIRECT SURVEYING

The terms 'indirect' or 'remote' surveying have become synonymous with techniques developed or devised for obtaining information without recourse to physical contact with the subject. This, in itself, limits their range of application, as certain aspects of surveying, such as assessing the condition of the building fabric, require intimate examination and, often, handling. There are, however, opportunities for placing reliance on non-physical methods of surveying and recording, particularly measured surveys, whether of land or buildings.

Human optics allow us to assess distances according to known formulae. Apart from eye separation or inter-ocular distance, normally about 65mm (2.6ins.), the two criteria of 'convergence' and 'accommodation' contribute to our binocular assessment of distance. A degree of depth perception can be artificially achieved by using a stereoscope to view stereo-photographs. In photographic interpretation, stereo-imaging is often essential for removing ambiguity, although in architectural fields it appears not to be widely used (Biek, 1983, 28).

The camera is remarked upon as never lying. It is, however, selective, and ignorant of the fourth dimension of time, which gives context to the recorded image. This omission need not be critical, dependent on the intended usage of the image. Photographs cannot, and do not, recreate the original subject: instead they preserve a visible record of a moment in time, whether the existence of a scene, an object or a particular quality of the object (Eastman Kodak, 1976, 1). All photographs are, however, distorted versions of reality. The observer
must either understand the distortions and interpret them properly, or
the photographer must introduce modifications, or counter-distortions,
so that the untrained observer can interpret them correctly.

When photography is used as a recording medium, the information can be
qualitative or quantitative. In order to extract the maximum benefit,
enhancement of the photographic record may be necessary. Photographs
taken at normal distances from the subject are 'representations' of a
three-dimensional world in two dimensions. Further 'extension' of the
photographic technique divorces the image produced from a reality that
is easily interpreted by a layman. Such extension has been
investigated by Brooke (1987a; 1987b) in his work on recovering
archaeological information, and may prove useful to architectural
historians involved in recording built fabric.

If the film plane of a camera is set parallel to the subject, and if
the lens is free of distortion, the camera image is an accurate
reproduction of the single plane at a scale given by standard lens
formulae (Equation 4.2). Some form of dimensional control is required
to enable the magnification to be checked. The inherent limitations
are that the resulting image indicates only the direction of the
subject points from the lens viewpoint, and the relative distances can
only be deduced from intuitive considerations. It is possible,
however, to derive measurements using almost any camera, provided that
simple reference objects are included.

Total reliance on photographs, however, presents certain disadvantages,
which Chitham (1980, 1) considers to be those of distortion, subjection
to the vagaries of natural illumination and the inability to produce
records to any degree of detail. It is, however, true that photographs
can record characteristics, such as material contrast, colour and
actual physical appearance, which would be difficult to record by any
direct manual technique.

Both for the initial recording of building construction, and detailed
recording of condition, materials and major defects, photography has
become an essential tool for the surveyor. It can also be used to
provide visual evidence in matters of dispute, with photographs being dated and witnessed by those concerned (Eastman Kodak, 1976, 23; Bowyer, 1979, 16). In certain cases, time is restricted and significant problems need to be identified and recorded before a decision to proceed further can be made (Seeley, 1985, 44). In such circumstances, the production of a photographic record for subsequent analysis and evaluation can offer advantages over written and graphical presentation.

In providing a complete record of a building or structure, photography has become a standard tool alongside measured surveys and the production of scale drawings. Under the Pastoral Measure of 1968, the recording of churches proposed for redundancy makes extensive use of photography. Where work is to be carried out to the fabric or furnishings of a church, a photographic record before, during and after treatment is required by the Conservation Committee of the Council for the Care of Churches as a condition of grant aid (Burman, 1982, 10). With secular buildings, opportunity must be given to the Royal Commission on the Historical Monuments of England to make a full record upon listed building consent being received for demolition (Cooper, 1982, 11). This task makes full use of photography, both internally and externally.

In order to allow the reader to draw useful comparisons between the results of the work being presented, and the attributes of other indirect surveying techniques, some knowledge of their principles is considered essential. The following sections are, therefore, concerned with those techniques and strategies used for recording dimensional information about building façades, which rely wholly, or partly, on photographic data capture.
4.2.1 Photographic surveying

The concept of photographic surveying and recording has commanded the attention of archaeological and architectural surveyors for a considerable period of time. At an early stage within the evolution of the photographic process, buildings were considered an ideal subject, and one that was worthy of pursuit for reasons of academic interest and nostalgia. As such, photography can be considered as a creative form of art, a mode of communication, a vehicle for nostalgia, and tool for other disciplines.

These early records were only reliable in as much as they showed the external appearance of the building or group of buildings at a time prior to destruction or alteration. They did not attempt to record dimensional information in a form that could be later relied upon. The realisation that the photographic process could record such useful information came in the latter part of the nineteenth century, and set the way for some of techniques presently in use today.

In carrying out a photographic survey of a building, the surveyor is forced to consider its form and complexities before wholly acceptable results can be expected. This is especially true when a complete internal and external photographic record is to be made, either to stand alone or form part of an extensive dimensional and conditional survey. Photographic, and measured, surveys carried out by the author during the period of this investigation are included in Appendix B.

It is not enough to casually walk around a building using the camera in an ad hoc fashions: a reconnaissance of the building before hand will allow best use to be made of time and equipment. Dependent upon how the record is to be used, it will be important to plan the coverage given to certain aspects, such as visible defects, features of stylistic or historic importance, and general construction.

In architectural photography, the manner in which the view is composed is a product of how the final image is to be used. Three kinds of architectural photograph have been identified by de Maré (1961, 25;
1975, 7-8) as being pure record, illustration and picture. In this work it is the former that is of concern, providing a visual documentary record with no claim to creativity, but attempting to convey the maximum amount of information to the viewer.

Specific advice on the use of photography for recording aspects of industrial archaeology is given by Bracegirdle (1971, 157 et seq.) and Major (1975, 132-139).

Veltri (1974, 13) provides a checklist of points that are likely to have a bearing on a particular photographic survey. Of those listed, a number are considered as important in this work (Figure 4.1).

A photograph may be simply defined as a two-dimensional representation of a three-dimensional object. Essentially, light rays are reflected from the object and projected through a vertex on to an image plane in order to create such a record. The perpendicular distance from vertex to image plane is termed the 'principal distance', and the position where the perpendicular meets the image plane as the 'principal point'.

This projection of light rays from an object space through such a single point is known as a 'central projection'. It is this form of projection that causes displacement of points in the object space from their natural positions. This, states Sears (1982, iii), causes one of the dimensions of real life to be effectively 'lost' through foreshortening.
Type of building - Building typology can mean many things to many people. Perhaps the most obvious factor that can be affected is size. Other considerations include the form of construction, how it is to be seen in the context of providing an architectural record or a working document, and the standard of equipment to be employed.

Function of the building - The function will determine both the accommodation and the morphology of the building. Internally, this may be represented by a cellular layout, such as a residential unit, or a single open space, such as a barn. Externally, these volumetric characteristics pose little in the way of additional features, except for apertures in the form of doors and windows. Where a building is used in such a way as to require separate or additional spaces, such as a Gothic church, the external appearance increases in complexity as the function dictates.

Orientation of the building - This will have practical consequences in the way in which direct sunlight causes changes in the image contrast, together with emphasis of certain features and loss of detail caused by projected shadow. Buchanan (1983, 40) provides advice on the use of natural light for photographing exteriors.

Relationship of the building to the site - Depending on the purpose of the survey, it may be important to relate the building to its immediate environment. Interaction with the specific locality often provides justification for forms of construction, detailing and choice of materials.

Relationship of the building to surrounding buildings - Where the building forms part of an associated group, with or without a common link, it is important to record it in the context of this relationship.

Problems of construction or obstruction - Certain building types present inherent problems, either due to their specific shape and size, or the manner in which they are related to other buildings or structures. The importance of a reconnaissance, in this respect, is unquestionable in assessing likely vantage points.
The camera is thus an instrument of central projection, with the optical or perspective centre of the lens forming the image plane. The information to be gained from a single photograph exposed in such a manner is thus confined to one plane. Further information relating to depth can only be obtained from a stereoscopic pair, by viewing two photographs of an object, each taken from a different viewpoint, under a stereoscope. The resulting three-dimensional optical model restores the missing dimension, and so creates an impression of object depth.

For the purposes of creating architectural records, Dallas (1980c, 396) considers a single photograph of a façade not to be an accurate source for measurement, and draws attention to four major drawbacks of adopting central projections. These may be summarised as being:

(a) Displacement of the image caused by depth changes within the subject.
(b) Scale changes again due to different depths of the subject plane.
(c) Varying scale across the photograph caused by a lack of parallelism between the image plane and the plane of the façade.
(d) Inaccuracies introduced by the camera or enlarger system that are caused by the light rays being distorted.

and their effects demonstrated in Figure 4.2 (after Dallas):
FIGURE 4.2 LIMITATIONS OF CENTRAL-PROJECTION PHOTOGRAPHY

\[ f = 50\text{mm} \]

\[
\text{Tan angle } X = \frac{1400}{5500} = 0.25\text{mm} \\
\text{Tan angle } Y = \frac{1400}{5000} = 0.28\text{mm} \\
\text{Distance } A = \text{Tan angle } X \times 50 = 12.5\text{mm} \\
\text{Distance } B = \text{Tan angle } Y \times 50 = 14\text{mm} \\
\text{Displacement on negative} = \text{distance } B - \text{distance } A = 1.2\text{mm}
\]

IMAGE DISPLACEMENT ERROR

INCORRECT ALIGNMENT

LENS DISTORTION
In architectural photography, a tall building recorded from ground level exhibits tapering or converging lines, especially if the whole camera is tilted to include the upper parts of the building. These are corrected for in real life by the brain creating a mental image that is based on the previous knowledge that the building does not taper. Photography, however, records these realities, and causes the end results to appear unnatural. In order to reduce the effects of this convergence, the photographic system used for professional architectural recording should include certain items of specialist equipment.

The basic tool for the architectural photographer is, according to McGrath (1987, 26), the view camera. This consists essentially of a monorail supporting a front standard on which the lens is mounted and a back standard containing a ground glass for viewing. The two standards are connected by a flexible bellows, which permits extremely precise placement of the lens in relation to the film plane. Focusing is achieved by moving the standards until the image of the subject appears sharp on the ground glass. View cameras are available as small-format 2\(\frac{1}{4}\) x 3\(\frac{1}{4}\)ins. (6 x 8.3cm), 4 x 5ins. (10.2 x 12.7cm), 5 x 7ins. (12.7 x 17.8cm), and 8 x 10ins. (20.4 x 25.4cm).

A view camera on an monorail has the ability to swing, tilt and offset the lens position relative to the film plane, a facility known as 'camera movement'. These movements allow extra control over image shape and perspective, and also depth of field. Parallel movements of the front and back of the camera have the effect of shifting the position of the image on the focusing screen. Rising and drop fronts move the image vertically; cross fronts move it horizontally. Such shift movements are thus able to produce parallel vertical and horizontal lines.

In 35mm photography, all lenses lack this rising and falling front. As this work is based on the use of such a photographic system, it is to this that further discussion will be addressed.
Where a fixed lens, having no capacity to shift the image in relation to the film, is used in architectural photography, the inherent disadvantages can be overcome by photographing the building from a high viewpoint, or minimised by photographing from some distance away. Rodwell (1981, 102) and others suggest the use of a light tubular-steel tower to gain height.

Photographs taken from a great distance show a flattened perspective, sometimes called the 'telephoto effect'. It is, in fact, not due to the lens in any way, but to the distance at which the print is viewed (Rolls, 1968, 128). In order to create a realistic perspective, the print viewing distance should conform to Equation 4.1.

\[
\text{Distance } K = F \times P_m
\]  

(4.1)

where:  
\(K\) = viewing distance from the print  
\(F\) = focal length of the camera lens  
\(P_m\) = factor of print enlargement

A wide-angle lens has the capacity to approximate to the simplest movement on a view camera, that of the rising front, simply by exploiting its wider angle and cropping the unwanted foreground in printing. Exaggerated perspective of some wide-angle images is due to incorrect print magnification or too great a viewing distance with regard to Equation 4.1 above.

For serious architectural recording using a 35mm photographic system, the most flexible and reliable solution is found through using perspective-control or 'shift' lenses. These provide a degree of translational and rotational movement that allows a corrected image to be made on the negative (Jacobson et al, 1988, 131). McGrath (1987, 22) makes the point that only CANON, MINOLTA, NIKON, OLYMPUS, PENTAX and ZEISS produce perspective-control lenses for 35mm cameras. Of these, 24mm, 28mm and 35mm are the only focal lengths available, being wide to moderately wide in angle of view attained. The CANON lens
incorporate swings as well (Freeman, 1988, 106).

During the recording of buildings for the preparation of Buildings of the Scottish Countryside (Naismith, 1985), Naismith (1987, Unpub.) comments that NIKON perspective-control lenses were used, and were found, through simple tests, to produce slight distortion towards the edges of the photographs. In a building of 9,000mm (29.5ft) in width, for instance, the variation, at the extremes, from actual dimensions taken on sites, amounted to approximately 50-75mm (2-3ins.). As this distortion occurred equally, relative to the central point, making little difference to the proportions of the buildings determined at the diagonals and rectangles, it was not corrected in any of over 40,000 prints used.

In order to correct converging verticals recorded on the negative at the printing stage, manipulation of the enlarging easel or baseboard, and negative carrier, may be made. If the baseboard alone is tilted so that the top of the building is further away from the lens than the bottom, the image is improved. The verticals are thus almost upright, but the building is subsequently elongated and depth of focus affected.

This deformation is due to a condition known as the Scheimpflug Principle: for the image to be in focus, the negative, the lens plane and the easel plane must intersect at the same point (Figure 4.3). Where both baseboard and negative carrier are tilted, maximum correction of converging verticals is possible with a minimum loss of depth of focus, provided also that the lens plane has a compensatory tilt applied to it.

Various photographic accessories are available that may be of use when recording a particular building or structure. Filters are perhaps the most widely adopted, and are effective because they change the quality of light reaching the film (Veltri, 1974, 78). Neutral-density filters change the intensity of the light reaching the emulsion; polarizing filters absorb rays of light vibrating in certain directions; and coloured filters absorb, to a greater or lesser extent, some wavelengths of light and freely transmit others.
Coloured filters are almost always used in black and white photography to accentuate colour contrasts where, for instance, a building has patterned brickwork or is constructed of different materials. Thus the light passing through them is modified so that yellow darkens a blue sky and lightens yellow stonework; green darkens red brickwork and lightens green foliage; orange darkens blue sky and lightens red brickwork; and red darkens blues and greens, lightens red brickwork and increases image contrast.
4.2.2 Rectified photography

The process of photographic rectification is one that is used essentially for the correction of image displacements, caused by the effects of perspective, occurring in data required for dimensionally accurate representation. As such, it provides a useful means of further enhancing the photographic image without recourse having to be made to complex methods of restitution.

The term 'rectified photography' was originally derived from aerial survey, where image deformations, caused by camera tilt, were eliminated by a process of re-projection through a rectifying enlarger. It has since come to be regarded by many involved in the recording of buildings as a useful technique for producing photographs of building façades at predetermined scales with a minimum of specialist equipment. Dallas (1980c; 1982 and 1989b, 11-12) provides guidance on the theory and practice of rectified photography for architectural recording.

It is, perhaps, indicative of the broad manner in which this technique is viewed that it should also be referred to as photo-mosaic, photo-montage, photo-drawing or square-on photography. Chambers (1973, 2) makes the point that rectified photographs are more useful, and refine other techniques of photographing to scale, by assuring greater accuracy. This, however, remains subject to certain limitations.

A photograph is, as previously discussed, a central projection. By relying on this optical condition, there are circumstances where the recorded data will not truly represent the subject, and consideration must be given to revised field procedures or adopting an alternative recording methodology. Dallas (1980c, 396-398) suggests that good results may be obtained through appropriate application of the technique, where the façade is flat, the camera is accurately set up parallel to the façade in both horizontal and vertical planes, and the photographic equipment introduces only negligible distortions.

In order to achieve the best results using this form of indirect recording, it is important that its limitations are understood and
related to the façade in question. Where there are projections from, and recesses into, the plane of the building, such 'normal-case' photography will be subject to scale changes and displacement error. The integrity of the photographic record has thus to be qualified in these cases, unless a revised methodology is employed, namely photographing and scaling such elements of construction separately.

The correct alignment of the camera for producing a photographic image suitable for rectification is based on the use of one plane of a one-point perspective. Deviation from parallelism in the film plane introduces perspective to two vanishing points, resulting in a non-uniform scale. Such tilts that are present can be rectified on an enlarger, in accordance with the Scheimpflüg Principle, but this is a skilled operation that requires professional equipment, and should be avoided where possible.

In order, therefore, to achieve precise alignment of the film plane with the plane of the building, Chambers (1973, 10-12) describes a method of alignment that makes use of survey targets secured to the façade in a predetermined arrangement. The targets ideally coincide with the intersections of a previously-gridded ground glass, various measured grids being prepared in order to provide a basis for rectification to a known scale. The accurate positioning of the targets provides the dimensional control, and assures the correct alignment of the camera.

Although this form of control, developed initially by the Canadian Department of Indian Affairs and Northern Development, has been successfully used by Chambers and the United States Department of the Interior, it presents certain practical difficulties. Clear access is required to enable the markers to be accurately located and secured on to the wall surface, and subsequently to be removed, and the procedure is reliant on a gridded glass mounted within a medium-format camera.

Generally, with 35mm photography, the camera is set up by first levelling it so that the film plane is horizontal and vertical, and then simply rotating it so that the film plane is parallel with the
façade. This latter operation can be performed in a number of ways, including the use of a constructed 3,4,5 triangle or optical square to establish a right angle from the centre of the façade, or rotating the camera until a horizontal feature of the building, such as a parapet or string course, lies parallel with the grid lines of the internal screen.

The scale of the resulting image, taken normal to the façade, is determined by Equation 4.2:

\[ \text{Scale } S = \frac{f}{h} \]  

(4.2)

Where:  
- \( S \) = Scale  
- \( f \) = Focal length of the camera lens (mm)  
- \( h \) = Taking distance (mm)

The easiest way in which to ensure that the photographs are printed to scale is to take control measurements on the façade. Usually these are taped dimensions, one vertical and one horizontal, which provide a check when the image is enlarged and printed. Control measurements may also be taken using a theodolite, but this is unlikely to increase the overall accuracy of the rectified photograph, whilst at the same time increasing the complexity of the survey.

Every factor involved in the process of recording and producing a scaled photographic record of a building introduces its own variables. By using good quality equipment and technique, a relatively high order of accuracy may be obtained on a façade with little or no depth variation. Dallas (1980c, 398) considers an accuracy of ±40mm (±1.6ins.) at a scale of 1:50 to be so attainable.

Given these restrictions, the technique of rectified photography provides a useful means of recording the façades of buildings and monuments. During the repair and partial restoration of Sutton Palace, Surrey (1521), for example, the architect was required to identify
individual bricks and pieces of terracotta. This was done using rectified photography on which each damaged brick was individually marked for repair or replacement (Cruickshank, 1988, 18).

There are certain situations in which rectified photography would be wholly inappropriate, whether for the reasons given above, or due to the nature of the building and its location. Experience in using the technique will undoubtably enable such decisions to be made early on, but for the surveyor who may, by necessity, rely on the scaled prints as the only source of dimensional information, understanding of the basic principles must be increased.

Photographic surveying, whether in the form of rectified photography or not, provides an important additional source of information for other surveying procedures. Dependent on the amount of detail to be included on elevational records, photographs can play an important role in the successful completion of the record. The rectification of the photographic image, in certain cases, will reduce the amount of interpretation necessary, and provide a check on data derived from other means.

In this respect, a rectified photograph will, therefore, provide a dimensional check during the manual interpretation and plotting of measured surveys. For this reason, the Historic Buildings and Monuments Commission for England makes use of rectified photography as an aid to drawn elevational reconstruction (Buchanan, 1988, Unpub.).

The use of rectified photography, together with limited digitising, for environmental and visual impact analysis, has been successful in work undertaken by the Turnbull Jeffrey Partnership of architects in Edinburgh. Street panoramas showing the effects of proposed infill developments have been produced to accuracies of ±40-50mm (±1.6-2.0ins.), which are deemed adequate for such purposes (McClaren, 1988, Unpub.).
4.2.3 Close-range stereo-photogrammetry

Photogrammetry, taken in its widest sense, is defined by the American Society of Photogrammetry as being 'the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electro-magnetic energy and other phenomena'. This may be compared and contrasted to the discipline of remote sensing which has been defined by Wolf (1983, 530) as 'any methodology employed to study the characteristics of objects from a distance'.

Although both may deal with photographic data, the determining factor lies in their relative applications. Remote sensing, on the whole, is concerned with the collection and use of data about the earth from remote sources such as aircraft, balloons, rockets and satellites. Photogrammetry, by comparison, provides a tool for localised recording and dimensional analysis.

As a recognised measuring technique, photogrammetry has become established in a wide variety of other disciplines, each with many applications. The disciplines cited below (Figure 4.4), whilst not offering a definitive study on the use of photogrammetry, instead give an indication of its potential and scope:

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Hydrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archaeology</td>
<td>Land surveying</td>
</tr>
<tr>
<td>Architecture</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Astronomy</td>
<td>Medicine</td>
</tr>
<tr>
<td>Cartography</td>
<td>Military intelligence</td>
</tr>
<tr>
<td>Dentistry</td>
<td>Mineralogy</td>
</tr>
<tr>
<td>Ecology</td>
<td>Mining and quarrying</td>
</tr>
<tr>
<td>Engineering</td>
<td>Oceanography</td>
</tr>
<tr>
<td>Forestry</td>
<td>Town planning</td>
</tr>
<tr>
<td>Geology</td>
<td>Traffic management</td>
</tr>
<tr>
<td>Geomorphology</td>
<td></td>
</tr>
</tbody>
</table>
It is, thus, evident that photogrammetry can be applied at many practical levels, ranging in both size and complexity. In whatever discipline, photogrammetry offers certain advantages that have a direct effect on both its application and operation:

(a) Speed of data capture.
(b) Convenience of photography over direct measurement.
(c) Direct physical contact avoided.
(d) Inaccessible areas covered.
(e) Impracticable measurements taken, such as sea-wave formations, growth rates and erosion rates.
(f) Non-rigid and small items measured.
(g) Unstable and dangerous objects measured.
(h) Safety of operatives.
(i) Economy.
(j) Accuracy.
(k) Complexity of detail.
(l) Archival value.

In spite of the work of Dr. Brook Taylor on linear perspective, and J. H. Lambert (d. 1772) on the use of perspective in the preparation of maps during the early eighteenth century, it was only with the development of a practical photographic process by Daguerre in 1839 that the actual process of photogrammetry, as we understand it, could occur. Thus, as a recognisable discipline, photogrammetry is considered to have originated with the work of Aimé Laussedat (1819-1907) in the mid nineteenth century (Eder, 1945, 398; Tait and Atkinson, 1973, 821).

During this period, Laussedat experimented with perspective and intersection as a means of conveying topographic information, continuing the work of the hydrographer C. F. Beautemps-Beaufré (1766-1854) from the previous century (Landen, 1952, 854; Battle, 1985, 18), and so earning himself the title of 'Father of Photogrammetry'. His work with various cameras and lenses included, in 1861, a photographic survey of the village of Buc, near Versailles. Working from eight exposures, he was able to produce a plan at a scale of
Technical advances in optical science allowed a geometrically-exact perspective image to be formed using the Busche Pantoscope lens in what was referred to as the 'Great Photogrammeter'. This instrument, dating from around 1865, possessed an integral horizontal circle, and with the Busche lens, gave a field of view of $105'$ (Pike, 1983, 4). One of its first applications was by a Major Elsdale during 1880-7, who experimented with the camera suspended from a free balloon.

Interest in the photogrammeter was taken up by the Prussian, Albrecht Meydenbauer (1834-1921), who, in 1885, founded the Königliche Preussische Messbildanstalt, with the task of recording the architectural and historic monuments of Germany. This work has since come to be regarded as the first systematic photogrammetric recording of architecture (Borchers, 1977, 8) and, as such, popularised the developing technique (Ragey, 1952, 23). Much post-war reconstruction in Germany was subsequently based on this work (Battle, 1985, 18).

In 1909, Dr. Carl Pulfrich (1858-1928) of Germany began to experiment with pairs of photographs. This work, according to Wolf (1983, 2), formed much of the foundation for the development of many instrumental photogrammetric mapping techniques in use today.

As photogrammetry developed, architectural subjects were among the earliest to be analysed, due possibly, states Miskin (1961, 450), to the numerous detail features that could be easily identified. It was at this time, also, that the study and recording of architecture was progressing at a frantic rate, as seen by the work of the many Victorian photographers who were prevalent in the field. For this reason, architectural recording would have enjoyed great patronage and emphasis.

The invention of the aeroplane by the Wright Brothers in 1902 freed the photogrammetrist from the limitations of terrestrial photography, and led to the first use of aerial photography for mapping purposes in 1913. Aerial reconnaissance was used extensively during both World
Wars, and provided an impetus to stereo-photogrammetry for topographic mapping applications.

It is useful at this stage to differentiate between some of the various branches that make up the science of photogrammetry. 'Close-range' photogrammetry deals with photographs taken with cameras located on the surface of the earth, whereas aerial photogrammetry, by definition, makes use of photography taken from aircraft or helicopters. Many of the close-range applications of photogrammetry, which are of a 'non-topographic' nature, may also be termed as 'terrestrial', this having been defined by Karara (1972, 447) as having an object distance less than 1,000ft (304.8m). In practice, the terms 'close-range' and 'terrestrial' have, to a certain extent, become interchangeable.

Presently, almost all architectural photogrammetric surveys are performed using close-range stereo-photogrammetric techniques, including metric photography. This has been endorsed by Dallas (1988, para. 1.2) in his specification for architectural photogrammetric surveys of historic buildings and monuments. For the purposes of this study, such work shall be referred to simply as photogrammetry, with the inference being that it conforms to the general requirements of this recognised standard.

In principle, photogrammetry can be thought of simply as the use of photography for dimensional analysis (Atkinson and Newton, 1968, 273; Arnold et al, 1971, 387). Within this process, it is the photographic image, rather than the actual object, that is measured, so distinguishing between direct and indirect methods of measurement (Harwood, 1982, 71).

Photogrammetry allows a distinction to be made between the processes of recording and measuring (Tait and Atkinson, 1973, 823). It is, in this respect, that conventional direct methods of surveying can fail to be properly implemented, as the distinction between the two tasks can become easily obscured.

-94-
The underlying optical principles of the technique are based closely on those which control our own sense of vision and depth perception. The human eyes are set at a reasonably constant distance apart, which allows each to receive a slightly different view of an object. These two sets of information are fused to create a mental image that gives us an impression of three-dimensional perspective and depth.

With this inherent appreciation of base distance and the corresponding angles of view, sufficient information is known to allow the brain to calculate the remaining geometric values of the triangle, and so assess distances. Beyond distances of approximately 450m (492yds), such geometric calculation fails due to the short fixed base of the human focal length (Thomas, 1980, 14), and recourse has to be made to other depth-perception mechanisms (Section 5.2.1).

It has been stated that the process of photogrammetry achieves with the camera all that is attainable unconsciously with the eyes, nervous system and brain (Harwood, 1982, 71). By this, the powers of observation, visual information storage and distance assessment are implemented by mechanical means for a variety of tasks. The general principles of stereo-photogrammetry for architectural recording are covered by Dallas (1980a, 81 et seq.; 1980b, 249 et seq. and 1983, 5 et seq.), and guidance on practical application offered by Dallas (1986 and 1988).

Photographs taken at a known base distance apart to provide overlapping coverage of a façade, termed 'stereo-photography', are viewed in such a way as to reconstruct the optical geometry that existed at the time of data capture. The resulting three-dimensional mathematical 'model' provides the operator with all the information necessary to produce a graphical representation, defining separate planes and showing individual positions. In this way, plans, sections and elevations may be produced, together with profiles, contours and other dimensions for use by the architect or archaeologist concerned.

At the present time, the majority of architectural photogrammetric recording is carried out using 'metric' cameras. These specialist
instruments possess several characteristics over and above those expected in an amateur or 'non-metric' camera, such that the relationship between camera body and lens is fixed and stable. The main features of a metric camera are that the value of the principal distance is accurately known; the principal point can be located, usually by the intersection of lines joining fiduciary marks placed in the focal plane; the lenses used possess high resolving power and nominally zero distortion; and the film has minimal deformation.

On the question of photogrammetric semantics, it appears easier to define what constitutes a non-metric camera than what does not. Faig (1976, 48) considers a non-metric camera to be 'a camera whose internal orientation is completely or partially unknown and frequently unstable', or else a camera that lacks fiduciary marks. Karara (1972, 448) is less specific in his definition as 'one not designed especially for photogrammetric purposes'. It is, however, worth pointing out that the terms 'non-metric' and 'simple' do not, according to Faig (1976, 48), imply any quality statement and have, as such, nothing to do with accuracy, information content or other characteristics.

A large body of opinion has been generated on the question of non-metric photography in photogrammetry. In terms of accuracy, photogrammetrists have tended to believe that optical distortions and the uncertainties of an unstable interior orientation preclude the use of non-metric cameras in close-range work.

For many applications, high orders of accuracy remain critical. In others, however, they are not required, and cannot be justified on the grounds of cost or necessity. Welch and Dikkers (1978, 546) found that the accuracy attainable using a close-range analogue photogrammetric system based on a 35mm camera was sufficient for measuring dynamic landforms, and represented an improvement over results obtained using conventional field procedures.

Although this case is not related to architectural recording, it does indicate that non-metric photography can provide useful results, given the limitations imposed by such a choice. This aspect of the present
work has been expanded upon elsewhere (Watt, 1990b). Dallas (1980a, 92) makes the point that for the majority of architectural surveys, the low levels of optical distortion achieved with metric photography are not fully exploited, and may not always be necessary. The most useful attributes for such work are, instead, good construction, reliability, light weight, flexibility and manoeuvrability.

In considering the practical implications of employing non-metric cameras, Torlegård (1976, 73-74) finds that such usage can present both advantages and disadvantages for the photogrammetrist (Figure 4.5).

Despite such disadvantages, Karara (1972, 448) believes that use could be made of non-metric cameras in precise architectural photogrammetry, provided that they are appropriately calibrated, sufficient object-space control data is obtained in the form of target co-ordinates, distances and directions, and an analytical approach to data reduction is adopted.

---

**FIGURE 4.5 PRACTICALITIES OF NON-METRIC PHOTOGRAPHY**

**Advantages**

- General availability.
- Flexibility in focusing range.
- Motor drive.
- Hand held for simple orientation.
- Lower price.

**Disadvantages**

- Lenses designed for high resolution at the expense of high distortion.
- Instability of interior orientation.
- Lack of fiduciary marks.
- Absence of level bubbles and orientation provisions.
At the present time, a number of 'partial-metric' cameras have become available which strive for a balance between the accuracies of metric cameras and the advantages of non-metric photography. Their use is considered by Dallas (1988, sect. 2.0) as being suitable for close-range work only when carefully controlled, typically for small commissions or parts of larger projects, and this has been recognised in the Standard Specification for Architectural Photogrammetric Surveys provided for surveys of HBMC 'Properties in Care' sites (Historic Buildings and Monuments Commission for England, 198?).

Those available have largely been developed for use with CAD-based stereo-comparators, such as the ADAM TECHNOLOGY MPS-2 Micro Photogrammetric System, the LEITZ Elcovision 10 non-contact measuring system, the PENTAX Photogrammetric Analytical Measurement System (PAMS), and the ROLLEIMETRIC MR Image Analysis System. Recently, PENTAX have released two versions of a small-format partial-metric camera (PAMS 645/645P) using 220 roll film, incorporating a vacuum back, to ensure film flatness, and a réseau grid.

The usual conditions demanded during a photogrammetric survey may cause problems if only a single metric camera with a fixed focal length is available. The application of such a photogrammetric surveying system frequently leads to blind areas and disadvantages of view caused by buildings and topography. In such instances a useful method of achieving a partial-metric camera has been established by equipping a non-metric photographic system with a réseau glass plate in front of the film surface (Kotowski et al, 1988, 863). In this way the basilica of San Francesco in Siena, Italy, has been recorded using a ROLLEIFLEX SLX Réseau medium-format camera with four different camera body/lens combinations.

One of the consequences of architectural photogrammetry developing, in part, from established cartographic applications, is that much has been produced using existing analogue photogrammetric stereo-plotters. These essentially operate as an extension of the operator's eyes, with a mechanical link translating input from the hand and foot wheels into analogous movement for a drafting pen.
With the increases in micro-processing power, analytical plotting has opened up the possibility of deriving data from previously incompatible sources, and providing numerical output. This has the potential for delaying the final hard-copy output until required, and retrospective CAD manipulation and enhancement. The recent photogrammetric work at Lincoln Cathedral (Dallas, 1989c, 22) has provided digital data from which different layers of information may be abstracted for selective reproduction.

It can, thus, be concluded that for the foreseeable future, photogrammetry will continue to employ metric photography. It is, however, the case that developments in plotting facilities have led to substantial advances. Previously, non-metric cameras would have invariably caused problems unacceptable to the photogrammetrist. The new generation of analytical plotters can achieve much with swung and convergent coverage, and there is now scope for the use of non-metric and partial-metric photography in architectural photogrammetry.

Architectural photogrammetry has achieved widespread recognition as a specialised discipline in its own right since the formation of the International Committee on Architectural Photogrammetry (CIPA) in 1969. Such a move by the International Council of Monuments and Sites (ICOMOS) and the International Society of Photogrammetry (ISP) compounded the wishes of both photogrammetrists and architectural practitioners alike. Before this time, however, such work was undertaken on a quasi-experimental basis, with a degree of acceptance coming with the creation of the Photogrammetric Unit at York by the Royal Commission on the Historical Monuments of England in 1968. There is, as yet, however, no architectural photogrammetric facility based within the Historic Buildings and Monuments Commission for England, although the Photogrammetric Survey Unit at York is wholly funded by English Heritage.

Photogrammetry has many potential applications in the work of the architectural or archaeological surveyor. Of these, several are of direct relevance to the conservation of historic buildings and ancient monuments.
Jachimski et al (1975, 147 et seq.), in their commentary on the use of photogrammetry for the Canadian Inventory of Historic Building (National Historic Sites Service), draws attention to its use as a supplement to hand recording for the following tasks:

(a) Preliminary reports as planning tools to conservators.
(b) Reference data surveys for the purpose of comparative studies and cataloguing reference material.
(c) Detailed precision recording used as the basic data for restoration or conservation.
(d) 'As built' records after restoration as final archival documentation.

The requirements of the end-user must always determine what is produced, as needs vary with the processes to be implemented. As noted above, the requirements of, and applications for, working, record and interpretative drawings differ considerably. It is, thus, important that these uses, within the discipline of architectural photogrammetry, be clearly defined, so that best use is made of finite resources. Within this discipline, the following applications have been identified:

(a) Reconstruction.
(b) Research.
(c) Quantity surveying.
(d) Deformation measurement/monitoring.
(e) Repair.
(f) Rehabilitation.
(g) Historical evaluation.
(h) Assurance assessment.

The geometry of photogrammetry is the same for all applications, the only change being one of scale (Miskin, 1961, 450). This statement can be applied, in particular, to architectural photogrammetry, in that the variety of problems, in terms of size and complexity, can lead to a desire for solutions of varying accuracies (Atkinson, 1972, 496).
When a photogrammetric record is commissioned, its dimensional accuracy must lie within accepted tolerances. This will depend upon the task for which it has been commissioned, and should be clearly expressed in the photogrammetrist's brief. Accuracies may become a product of the ease with which the photogrammetric process is implemented (McDowall, 1972, 403). This, in itself, is acceptable in so far as recognition of the factors involved is open for discussion.

Although much has been written about the advantages of using photogrammetry in architectural and archaeological recording, few of those writing have considered the problems and limitations inherent in using such an accurate recording technique for certain tasks. It should, therefore, not be considered as the answer to all survey problems, but rather a component part in the process of surveying, providing a useful tool in certain situations. There are other methods available, and the merits of the different approaches have to be judged so as to 'optimise the entire process of which the measurement often is just a minor component' (Torlegård, 1976, 77).

The key to this dilemma may lie in the fact that photogrammetry is seen by many as a solution only to special survey problems. This was clearly demonstrated by the responses given to a questionnaire organised by Mr. R. Dallas, Chief Surveyor for the Photogrammetric Unit, Institute of Advanced Architectural Studies in 1982. Such an attitude is largely due to the unfamiliarity with which architectural practitioners see the technique. Of the responses analysed, Dallas (1983, 12) concludes that only 15% of the sample considered themselves 'quite familiar', whereas 53% possessed only a 'little knowledge' and 32% were 'not at all familiar'.

Although no further research has been carried out on this subject, it is apparent that misunderstanding, and a degree of apathy towards personal and practice involvement, persist within the architectural and archaeological surveying disciplines. If this deficiency is to be redressed, and photogrammetry applied in those situations that warrants its use, further information needs to reach those involved in surveying and recording buildings. Torlegård (1976, 78) is of the opinion that
further use would also come if requirements on accuracy, time, cost and type of output could be optimised.

In order to understand the practical requirements of photogrammetry, it is necessary to consider the criteria that potential commissioners use in their decision making. Dallas (1983, 14) found that the majority of surveys carried out were for large and complicated façades, or for exact record drawing purposes, representing an overall spread across both building types and survey requirements. It could, thus, be concluded that most would balance the cost and complexity of the technique against the speed and quality of output, and that only such surveys would warrant its use.

Certain problems can best be resolved by using photogrammetry, and McDowall (1972, 401) considers shapes with elaborate detail, curves, irregularities and sculptural qualities involving many different planes as being most appropriate. The application of photogrammetry to the recording of complex shapes and forms cannot be better illustrated than with the work on the Baroque and Rococo ceilings of Austria and southern Germany, or the elaborate organ cases of Holland. Both offer examples of recording perspective on curved surfaces (Harwood, 1978, 14).

Discussion with architectural and archaeological surveyors during the course of this investigation has highlighted the fact that many consider it impractical to involve photogrammetry, when their requirements can be achieved with sufficient accuracy and attention to detail using manual techniques. Direct comparison between hand survey and photogrammetry cannot, however, be strictly valid, as the latter introduces new factors into the equation (Dallas, 1980a, 97). Time must, therefore, be spent studying and understanding photogrammetry to know when it is most appropriate, and so derive the maximum benefit from its use. An ideal solution would involve photogrammetry providing a framework to complement direct measurement, into which local and intricate detail would be fitted according to need (McDowall, 1972, 403).
Regarding the question of direct measurement, it has been said that no drawing is correct unless done by the architect himself, knowing that he will have to work to it (Thompson, 1962, 118-119). This may be thought admirable in theory, except that the challenge set by a large or complicated building may present difficulties which, without elaborate and extensive scaffolding, could reduce the process of measurement down to little more than intelligent guesswork.

The rise in the use of architectural photogrammetry can be set, according to Dallas (1980a, 82), against the desire for more thorough and accurate drawings, and the subsequent increase in the cost of traditional hand surveys and the decreased availability of architectural draughtsmen and surveyors.

Much of the criticism that arises from architectural photogrammetric output does so because of the failed expectations of the persons who commission its use. The majority of photogrammetric stereo-plotter operators are trained on cartographic work, and so without an understanding of the requisite application, and its particular 'grammar', mistakes can arise. Dallas (Ibid., 92) makes the point that such an operator, unless suitably trained, is not qualified to make decisions as to which detail to draw and which to omit. Badly-eroded stonework and heavily pointed joints can easily be misinterpreted. Such input is required from the surveyor who is involved with the project, and understands what is needed in order to satisfy the particular end-user requirements.

This observation is also valid for the work of archaeological photogrammetric recording. Where the recording phase is critical, as is often the case with salvage excavations and rescue archaeology, photogrammetry can provide an ideal method of data capture where potentially what is not recorded is lost for ever (McFadgen, 1971, 71; Stewart, 1973, 275 et seq.).

Subsequent analysis and reproduction requires an archaeological expertise in order to maximise the benefits to be gained from such a thorough data source. As many archaeologists turn their attentions to
the challenges posed by standing structures, a distinction needs to be made by photogrammetrists between the requirements of architectural and archaeological records. This can only be achieved by skilled operators working to a carefully-defined brief.

Where work is to be carried out on a building or structure that has the status of an ancient monument, a condition is generally imposed on the granting of Scheduled Monument Consent by the Department of the Environment that suitable and accurate records are made prior to the commencement of the work. These are sometimes published, but always deposited in the county Sites and Monuments Record and in the National Monuments Record (Fairclough and Streeten, 1987, 5). Photogrammetry has been instrumental in fulfilling this condition on numerous occasions.

Craven (1981, 1-2) considers, with such work, that the accuracy and detail of plans, sections and elevations produced is critical in the process of decision-making. The work of Plowman, Craven and Associates Limited, for example, has been widely publicised in this area, with early work including the recording of 400,000sq.ft (37,161m²) of Hampton Court Palace in 1968/9.

Full elevational recording, whether for analytical, archive or practical purposes, is sometimes not required. The recording techniques already mentioned may be used to provide a variety of specific records, dependent upon the brief and circumstances. Photogrammetry was chosen by Rodwell (1988, Unpub.) for interpretative studies at Fulham Palace, a brick-built structure dating from the Tudor period. Here it was sufficient that only the main features were plotted, with details and apertures recorded in outline. Brick courses were represented by a series of ticks on the final plot to act as control for later fabric analysis and evaluation.

A combination of photogrammetry and photography can also provide a suitable form of recording giving acceptable results. The complex eastern face of the cloister at Wells Cathedral was recorded by plotting photogrammetrically the main outlines of the walls and
features, so providing a reliable matrix on to which the rubble and minor details could be filled in from close-range photographs (Rodwell, 1981, 87). A similar technique which employs a photogrammetric reference sheet on to which rectified photographs are superimposed can similarly give useful results.

Photogrammetry has also been proved by many to be a useful technique for the recording of deformation patterns in buildings (Borchers, 1968, 71-76; Atkinson, 1972, 496; Atkinson and Proctor, 1970, 25-33; Uren, Studer and Wren, 1985, 130-133; and Uren and Robertson, 1987, 340-344). These records not only provide an accurate representation of the distress suffered by the fabric at the surface, but can allow the effects of continuing movement to be monitored through a programme of recording. In this manner, crack propagation can be studied through the use of 'crack maps'.

4.2.4 Other techniques

Although this section is not wholly concerned with techniques capable of providing dimensional data, it refers, instead, to practices that adapt existing science for the observation and interpretation of built fabric.

It would seem that a technique which was based on simple photographic data capture, but which was subject to the accuracy of the photogrammetric process, would hold many advantages (Seeger, 1976, 625-635; Dallas, 1980a, 99-100). The process of orthophotography achieves this by photographing minute segments of a photograph that are individually corrected to scale when the stereo-model is viewed. As such, the technique requires photography with a metric camera, a stereo-plotting instrument and an orthophotoscope attached to the stereo-plotter.

The resultant image may be subject to discontinuances, especially at changes in depth, where the plotting operator, or automated process, fail to adjust consistently for such changes. It is, thus, a recording
technique that favours flat façades. Limited orthophotographic facilities are available in this country, and have been little used for architectural recording (Dallas, 1980c, 399).

The technique has, in the past, been commissioned by Central Surveys Branch, Directorate of Civil Engineering Services (DCES) of the Property Services Agency (DoE) (Dallas, 1988, Unpub.). Its use was generally for aerial photography produced at mapping scales (say 1:1,250) with contours superimposed. By way of experimentation, the DCES attempted to record architectural façades using orthophotographic techniques, but with minimal success (Brown, 1988, Unpub.).

Remote sensing is the general name given to the acquisition and use of data about the earth from sources such as aircraft, balloons, rockets and satellites. Recent developments in sensor and communications technology, and computing, have made possible the effective handling and transfer of data and rapid processing of imagery (Stirrat, 1988, 17-18; Sugden, 1988, 22-27). The various disciplines involved in remote sensing have been brought together and promoted as a whole by the Remote Sensing Society, with further distinction given by the International Society for Photogrammetry and Remote Sensing (ISPRS).

In the past, the application of such techniques to archaeological problems has, in the main, been limited to conventional aerial-photographic techniques, with some experimentation using well-established multi-spectral imaging methods (Van Genderen, 1976, 1-8; Madry, 1983, 18-19; Colwell, 1984, 1305-1307; Shafer and Degler, 1986, 833-837). Recent work by Brooke (1987a; 1987b), into archaeological information recovery, has taken established remote-sensing technology and applied it, using a 35mm photographic system, to record surface and sub-surface details within a sample of churches.
Non-destructive surveying techniques include 'those testing methods for the inspection of buildings (with various degrees of refinement) which do not cause damage to or impair the future life of existing original material so that the architectural, historical and archaeological integrity of the fabric remains unharmed yet analysed' (Fidler, 1980, 3).

Whilst recording physical, rather than dimensional, properties, the various methods available allow an insight to be obtained into certain aspects of the fabric prior to action being taken that might have an effect on the subject materials or assemblies. These are commonly employed in work involving historic buildings and structures (Hum-Hartley, 1978, 4-17; Feilden, 1982, 206). The most commonly-used methods are:

(a) Radiography.
(b) Thermography or infrared detection.
(c) Ultrasonic testing.
(d) Microwave analysis.
(e) Magnetometry.
(f) Fibre-optic surveying.
(g) Structural movement monitoring.
(h) Full-scale load testing.

4.3 SYNOPSIS OF RECORDING PRACTICE

It is not possible to summarise the contents of this chapter without first reiterating the case for adapting the most appropriate recording methods for a specific survey problem. There is no one technique that can, or should, be used to the exclusion of others: each must be chosen on its relative merits in the light of what is actually required for the particular project.

There is inevitably debate over the merits of graphic and photographic presentation, especially related to architectural and archaeological recording. The long history of manual survey has led to an
unquestioned acceptance of graphics, although many feel that this leads to a simplification of what actually exists. Photographic coverage is often preferred when dealing with historic buildings, although this might be limited to surface recording, with graphics used to describe construction lines (Storsletten, 1989).

There is a gradual awareness that recording methodologies should complement one another, and be used as the situation dictates (Sena, 1989; Waldhausl, 1989). The growing acceptance of alternative techniques in the field of architectural photogrammetry has been noted already (Section 4.2.3), and professional education identified as an important area for expansion (Cundari, 1989).

The move towards an integrated concept of recording and interpretation for documentation has fostered the emergence of survey methodologies that are flexible in application, and can be used by the untrained professional in the context of planned physical interventions. This approach has been adopted by Gorbea (1989, Unpub.) with the use of the ADAMS TECHNOLOGY MPS 2 Micro Photogrammetric system for recording and interpreting historic buildings and monuments.

Basic education for architectural and archaeological surveyors should ideally include the principles of indirect recording techniques, so an informed dialogue might be maintained with the specialist employed for specific work. It would appear that the manner in which foreign, and particularly continental, architects practice allows them to acquire such skills as and when required by a particular project, so allowing an individual to become fully conversant with a building through their involvement at various stages. This approach may, it is suggested, lead to photogrammetry becoming an office tool, albeit with limited application, in a similar way to CAD.

Each methodology, from hand survey through to 'classical' architectural stereo-photogrammetry, has its rightful place in specific situations. In order to make the decision as to which techniques are employed, knowledge of their mechanics, and experience in handling the final output, is desirable.
Despite recent advances in photogrammetric surveying, there is no practical solution for recording façades where a high-order accuracy is deemed unnecessary, and yet direct survey is impracticable. Indirect photographic data capture, which makes use of amateur equipment, presents a viable alternative to physical surveying. This is the basis on which rectified photography is undertaken, given its limitations, as discussed earlier (Section 4.2.2). Restitution of the photographic data in a manner that can be carried out by the person(s) involved with the particular project to produce a graphical record again provides an opportunity for integrating skills, and improving the overall understanding of the building or structure in question.

The development of a methodology based on indirect non-metric photographic data capture and CAD restitution presents a solution for this area of architectural recording, which may be implemented with a minimum of specialised equipment and training. The technique of computer-aided mono-photogrammetry has provided a solution for certain survey problems, and its philosophy and application is discussed in detail in the following chapter.
5.0 COMPUTER-AIDED MONO-PHOTOGRAMMETRY

5.1 INTRODUCTION

5.1.1 Justification for investigation

The preceding review of surveying methods used for recording building façades has shown that certain problems might be satisfactorily solved by adopting an alternative, yet complementary, approach based on current low-order technologies. The development and evaluation of such a method has been undertaken, and is presented in this chapter.

Presently, there is little choice of method available to deal with the many survey problems encountered in recording the façades of existing structures. Consequently, elevational records are produced, on the one hand, by manual means, which may prove inappropriate and uneconomic, and on the other hand, by photogrammetry, which results in high accuracies that may not necessarily be required.

There are many processes that seek to impose change on the structure and fabric of an existing building. These have been identified in Section 2.2.1 above, and require the collection of considerable quantities of data, whether dimensional or conditional, to formulate policies or solutions. For the façades, in particular, it is important to determine precisely the nature of the dimensional information that is required, as considerable time may be spent recording elaborate detail when all that may be necessary is an outline elevation showing openings and key features.

The perceived need for an alternative method of dimensional survey has been matched by a demand from both property professionals and craft operatives for a product that fulfils certain criteria, according to the needs of the particular project. Architects require a drawing on which to communicate their ideas and wishes, and contractors for implementing the work, both with clarity and relative precision.
It is also becoming increasingly important for graphical records, along with other documentary material, to be made available to external users. Archives, such as held in the National Monuments Record, serve not only to inform professionals, but also offer an important resource to academics and students alike. Given this wider use of material, often for varying purposes, it is necessary for the information to be presented in a form capable of storage, retrieval, transfer and reuse.

In this respect, it is necessary for there to be a wider understanding of how data can be further used, and where its practical limitations lie. The recent increase in consultancy and bureau services has meant that the basic skills required for measured surveys are becoming less important in professional practice, and traditional work more fragmented.

Professional training and education can obviously assist in this respect, but the problem could also be managed by ensuring that there are means by which such work may be undertaken by those concerned. For this to be practicable, it is necessary for there to be some degree of reliance on the lower-order technologies.

It is first necessary, however, before technical and philosophical issues can be addressed, to define the nature of the subject, and determine the extent to which it is possible for such an approach to be adopted.

This work is principally concerned with the surveying and recording of two-dimensional building façades that are, in effect, planes. Conceptually, a plane has height and width, but no depth. A façade, however, possesses breaks and irregularities that introduce aspects of depth, even if only at window and door reveals. Surface properties, such as embellishments, colour and texture, also create a feeling of three-dimensional form.

As Ching (1979, 34) points out, a plane serves to define the edges of a volume, within which elements add aesthetic and functional interest. Openings in a plane determine the degree to which the interior space
relates to the outside world. Where the plane is articulated, resultant three-dimensional properties define spatial relationships, highlighted by the joints between the individual shapes. Overall, the plane encloses a shape that is identified from its background by the edges or contours, and this is what provides the reference in a line drawing that is without colour, hatching or tone.

Openings in space can offer differing qualities, dependent on their size, shape, location and the important relationship of solid to void. At what stage an opening ceases to be a figure within an enclosing field, and becomes a positive element in its own right, is open to question. Each opening may be considered as either flush, projected or recessed into a plane, with its own practical and visual significance. Where such openings are grouped in a repetitive manner, their size, shape and detail allow them to be mentally assembled, despite individual differences.

Given that the appearance of a façade can be considered as a series of geometric elements, it is natural to question the extent to which this analogy may be pursued, such that these elements might be represented in a form suitable for practical usage.

The visual impression a building makes on the mind is, to some extent, limited to what is externally visible. Other criteria, including massing, contrast and graining can be applied only after thought has been given to other aspects, and relationships acknowledged. External features and ornamentation can be derived from various sources, themselves given meaning by stimuli such as function and fashion. Consider, for example, the move from Renaissance intellectualism to Baroque sensationalism visible at San Pietro in Vaticano, Rome. This can only be appreciated when the rôle of the building is considered in the context of contemporary political and religious thinking.

Training and professional practice, especially in a discipline such as architecture or sculpture, fosters an awareness of three-dimensional space and form, the relationships of solid to void, and light to shade. This is absent from the conscious perception held by many, where
two-dimensional elements, such as planes and lines, provide the key to the visual interpretation of a particular building façade.

Representation of the built form should, therefore, be based on an understanding of the structure and fabric, as each component needs to be interpreted if a graphic solution is to be successfully employed. This is particularly important when plan and sectional information is required, as the relationships of space and form must be established. The external faces of a building are, themselves, open to interpretation, and may require further investigation to determine if, for instance, they are original or a later refacing, as was common with timber-framed buildings during the eighteenth century.

If a façade has, therefore, to be interpreted before it can be recorded, it is the case that those who undertake such work should possess sufficient knowledge to make the connection. This may lead to a difference when records are prepared by architects, archaeologists, engineers or historians, but this, however, poses the question - should one set of drawings be made to perform several functions? In an ideal situation, those who record should form part of the team involved with subsequent works, and be aware of how their records are to be used.

It is apparent that theoretical justification, and practical demand, exist for a robust survey tool suitable for recording and representing dimensional information relating to built façades. This has been addressed in the present work in a manner that provides a means for undertaking surveys without recourse to specialised techniques. It also offers scope for integrating survey documentation through the use of digital data, and providing a permanent photographic record for archive purposes.

5.1.2 Development of methodology

The main purpose of this work has been to test and verify the stated hypothesis, and satisfy the perceived need for a complementary survey tool, which is reliant on low-order technology, for recording the
façades of buildings, monuments and other structures. In so far as this has been satisfied, all aspects of the methodology—computer-aided mono-photogrammetry—have been undertaken without specialised equipment, or further training outside of a background in building surveying and architectural building conservation.

The term, computer-aided mono-photogrammetry, requires some clarification as to its component parts. As with computer-aided design/draughting (CAD), the emphasis is on the assistance given by the various computing processes to what is essentially a human function, whether it be actual building design or recording of existing fabric. These functions can be, and, to a large extent, still are, undertaken without such assistance, but there are benefits to be gained in terms of flexibility of output, speed of processing and manipulation of data.

The inclusion of the word 'photogrammetry' may introduce a preconceived notion of precise recording using a technique of deriving dimensional data from stereo-pairs of photographs. This may, thus, require a reappraisal of such views, as photogrammetry, within the scope of this work, is taken to mean the use of photography for recording building façades for subsequent graphic reproduction to a known scale. In order to qualify this further, the prefix 'mono' has been used to differentiate between stereo-photogrammetry.

The technological basis for this investigation has been of applied, rather than pure research, taking the existing sciences of photographic surveying and computer-aided draughting (CAD) to provide the apparatus for indirect data capture and image restitution. No further development of these sciences has been investigated, nor deemed necessary.

Given that the science base for this work has come largely from existing technologies, it is necessary to clearly define how the aims and objectives of this investigation (Section 1.2) have been interpreted into practical stages for experimentation. Without such explanation, it will not be possible to demonstrate how these sciences have been utilised, and where future research might prove profitable.

-114-
It has been made clear elsewhere (Section 2.1.2) that the processes of measuring and recording existing buildings have rarely been accredited with the status of an intellectual exercise. This, in itself, is acceptable, in so far as the mechanics are well documented and understood. The time for reasoned argument and debate comes when analysing the subject, and using the drawings to interpret what is outwardly visible, and often inwardly concealed.

There are now various ways in which a building may be interpreted: the results and speculations of which need to be presented in a recognisable form, from which comparisons may be drawn using other sets of data. This provides an opportunity for the creation of computerised data bases and, with graphical data, the use of CAD.

There are, therefore, obvious attractions in having an interactive system of recording and interpretation that can be utilised during the analysis of built fabric. This may also be extended, through the use of Digital Terrain Models (DTMs), to take into account local topography and site conditions.

The technique of computer-aided mono-photogrammetry has been developed, and tested, wholly in the context of recording historic fabric, to provide a means for producing dimensional records, and as a tool for controlling physical interventions and illustrating further sets of data. This is not to deny such an approach when dealing with modern fabric, but the need for dimensional records can often be met by extant working drawings, and analysis tends to concentrate more on condition rather than inherent historical or social consequences.

The use of CAD for representing existing, and indeed historic, fabric, remains open to debate, and has been considered in part by Kronenberg (1988, 31-36), Ashton (1988, 10-11) and others. It is obvious that such an approach to survey interpretation cannot provide a realistic answer for all problems: CAD is a tool, rather than a total solution. There are, nevertheless, certain aspects of recording practice that can utilise, and indeed favour, computerisation, this again depending on the purpose and future use of the completed records.

-115-
In order to provide evidence for the practical application of CAD in recording information from a remote source, selected façades have been recorded, and presented with commentary on survey objectives, method and final output. This cannot provide an absolute test for suitability and robustness, but it allows each case to be presented in a manner where comparisons may be drawn with other indirect and direct recording methodologies.

For this work to develop sufficiently for academic and professional recognition, it has been considered important that it should be concerned with an aspect of architectural surveying that is allied to an established discipline, yet make a substantial and relevant departure from it on technical and philosophical grounds.

It became clear at an early stage in the development of this work that the fast rate of computer growth would ensure that the manual stages of the technique, principally in digitising selected information, would be superseded by an automated process in the comparatively near future. The purpose of this work has, thus, been perceived as providing the initial stimulus for further investment of time and resources, and establishing a manual protocol for later work.

The history and practice of architectural photogrammetry have been outlined earlier, together with other forms of indirect surveying, and a case argued in favour of a system of elevational recording that provides tangible benefits over hand survey, but without the penalties of more complex methodologies.

In order to facilitate the process of data recording, it has been considered desirable for the capture of data to be achieved indirectly, that is without physical contact with the subject. Photography allows this to be achieved, with the additional gain of a permanent record at a particular moment in time. The alternative use of optoelectronic surveying equipment to record the façades on a point-by-point basis has been considered unrealistic, although it provides a useful method for
achieving dimensional control.

The choice of photographic system was initially between metric and non-metric, that is, using accepted means of high-accuracy data capture or simple amateur photography. In order to present a flexible alternative to established recording practice, and one based on low-order technology, it was decided to pursue the latter option.

The merits of using either a technical monorail view camera or a single-lens reflex (SLR) camera were considered. There would have been certain advantages to be gained in choosing the former, but it was felt that the 35mm SLR option, being readily available and understood, would provide a realistic basis on which to proceed, with a wide range of lenses and accessories available, as needed. Recent work by Brooke (1987a) serves to demonstrate the versatility of this particular format.

5.1.3 Programme of application

The application of the developed method for practical recording has been on two levels: that carried out purely for academic purposes, allowing for the testing of speculative theories, and as a consultancy service, providing graphical documentation for actual projects. Both have been used to provide evidence for analysis and evaluation.

The studies undertaken for this investigation have concentrated largely on the recording of architectural fabric as a means of validating the worth of the technique with regard to conventional surveying disciplines. The definition of architecture has been taken widely in order to provide practical experience in recording buildings of various ages and types. The recording of monuments and other structures for archaeological purposes is one other use that the author has identified, and within which a small number of studies have been carried out.
Selection of sample façades has been covered elsewhere (Section 1.3.3), and taken as the basis for initial experimentation in the development of computer-aided mono-photogrammetry. A wide approach has been adopted to provide the greatest opportunity for practical application in a variety of externally- and self-imposed conditions.

The studies undertaken by the author as part of the consultancy services offered by the Leicester CAD Centre have been commissioned predominantly by architects to provide drawings for communicating the extent of repairs and material replacement, largely to buildings and structures of historic value. This has generated a variety of survey problems for which established solutions have been considered inappropriate or unattainable.

Background information to the case studies in general, together with commentary on the final output, has been included in Appendix A, together with the respective graphic and photographic information. It is considered appropriate to present this part of the project in such a manner, rather than include it within the main body of the text, as certain studies provide evidence for more than one aspect of the work. Individual studies have been clearly referred to, where appropriate.

It has been stated earlier that survey problems are a product of specific sets of site conditions. These may vary according to the particular building, its location, the degree of site obstruction, surface articulation, and the recording budget (Watt, 1989a, 4; Watt, 1989b, 12), and cannot be easily reproduced.

Involvement in professional projects, and through consultancy work, has made possible the identification and subsequent analysis of particular survey problems faced when producing a dimensional record of a building, and in particular, its façades. There are, nevertheless, many difficulties that have not been identified, and for these, the adoption of a current methodology, or implementation of a new technique, will be needed to provide a workable solution.
Having established a basis on which to approach this work, early findings were synthesised, and a methodology proposed for practical experimentation. This background information is presented in Section 5.2 of this chapter. The manner in which the data generated by the case studies has been analysed is referred to in Section 1.3.2 above, but it is considered necessary, at this point, to present the rationale for such an approach.

Initially the construction of a matrix was considered, where case studies could be set against selected criteria, and a ranked order of suitability for various recording methodologies established. The construction of such a matrix is founded on the ability to isolate and quantify key aspects of the work, in order to determine and test interrelationships between those chosen. The selection of such categories may, however, without due care, result in an artificial representation of certain aspects over others, and hence present a passable, though false, set of values.

With this particular field of experimentation, it is improbable that all aspects would be identified, given the diverse nature of the parent population (i.e. the building stock). Although a matrix of building types against survey criteria could be constructed, its potential usefulness would, it is felt, be limited, and its views potentially confusing.

The adoption, instead, of certain criteria on which to base the analysis of case studies provides an opportunity for comparing output against other techniques, and considering individual survey problems that would have discredited the use of the aforementioned matrix.

5.2 MECHANICS OF COMPUTER-AIDED MONO-PHOTOGRAFMETRY

The two main stages in producing a dimensional record of a façade using computer-aided mono-photogrammetry are data capture and image restitution. The former is essentially concerned with the indirect recording of data using a 35mm SLR photographic system, together with
obtaining sufficient dimensional control by which to magnify the completed digitised image to scale. These aspects of the methodology are covered in Sections 5.2.1 and 5.2.2 respectively; Section 5.2.3 considers the restitution or recovery of the data from photographs using CAD digitisation.

5.2.1 Photography

The way in which a building is perceived by the human eye is related to how it is to be represented. When this representation is based on photography, it is necessary to interpret the data in order to derive the information required.

Perspective may be defined as being the relationship between the size and shape of three-dimensional objects represented in two-dimensional space. In photography, linear perspective is controlled by viewpoint, and is represented by diminishing size and converging planes. A photograph is, thus, said to be in correct perspective if it gives a correct impression of the relative size and position of an object in the camera field (Rolls, 1968, 127).

The focal length of a lens does not directly affect the true perspective of an object, but the correct choice of focal length can make possible a change of apparent perspective by permitting the adoption of a different camera position (Cohen, 1984, 26). Wide-angle lenses include a wider field of view; increase the sense of depth, especially in nearby objects; and reduce the relative size of elements in the picture. This shift in apparent perspective creates a distortion of relative sizes known as the 'wide-angle effect'.

Telephoto lenses take in a narrower field; foreshorten the perception of depth, known as the 'telephoto effect'; and enlarge the relative size of distant subjects. As a result of this flattened apparent perspective, our psychological depth perception is tricked by the lack of size reduction corresponding with increased depth.
Normally perspective is an essential component of any photograph, as it conveys information about subject depth. It is sometimes useful, however, to remove the effect of perspective and produce an orthographic image. Williams (1976, 1131-1133) produces such 'correct' images of medical subjects by using a telecentric system that makes the image size independent of the object distance, and thus orthographic.

Euclid in AD 280 defined depth perception as the ability to receive by means of each eye the simultaneous impression of two dissimilar images of the same object. It is accepted that binocular vision using a pair of eyes is the most important source of depth perception, and any artificial device is secondary to it. Such science is, however, outside the scope of this work, other than to briefly mention the first stages of artificial imaging.

Artificial three-dimensional imaging was pioneered by Giovanni Battista della Porta (1538-1615) in c.1600 with his stereoscopic drawing technique, which allowed two precise pictures of an object to be drawn from two different directions. Such stereoscopic images became commonplace after the experiments of della Porta, but decreased in importance with the invention of photography in the early nineteenth century. Truly three-dimensional imaging techniques gradually show the right side of an object when the observer moves to the right, and the left side when he moves to the left (Okoshi, 1976, 3).

When studying normal photographs, there are several factors that the observer intuitively applies to assess the depth of a subject (Arnold et al, 1971, 368):

(a) The perspective effect gives a strong impression of depth, this being observed in receding object planes and in the apparent reduction in size of distant objects. The camera viewpoint distance is the controlling factor in exaggerating or reducing this effect.

(b) The shape of the subject is usually shown by the modelling effect of the lighting.
Subject resolution is naturally lower for distant objects and any indistinctness, or the presence of atmospheric haze, may be interpreted as being due to increased distance.

When viewing a scene, even with one eye, the necessity for re-focusing on different parts of the scene gives an immediate sensation of depth. The effect can only be suggested in a still photograph by the use of differential focus to concentrate attention on one plane.

We instinctively move our head from side to side when faced with a difficult decision as to the existence of different subject planes. Even in monocular vision, nearby objects apparently move to a greater extent than distant objects.

The principles of architectural photography have already been mentioned, with reference made to the limitations of adopting a central projection for architectural recording (Section 4.2.1). The purpose of this section is to provide a summary of the aspects of photography that have been considered in adopting such a means of data capture for this work. General commentary on photographic techniques can be obtained from standard texts, with specific advice on architectural photography provided by Buchanan (1983).

A photographic image is obtained through the use of recorded patterns of radiated electromagnetic light (Wolf, 1983, 1). Electromagnetic radiation is a form of radiant energy, travelling through space in what is known to be a wave motion. This type of energy may be subdivided into various categories, of which visible light is the name given to that part of the spectrum to which the human eye is sensitive. The wavelengths of the electromagnetic spectrum are shown in Figure 5.1 below, using the units micro-metre (μm = 10^{-3}mm) and nano-metre (nm = 10^{-6}mm).

There is, in reality, no sharp division between adjacent wavebands, just as there are no sudden changes of colour in the visible spectrum. The characteristics of the various wavelengths are well known to those involved with remote sensing and non-destructive surveying (Section 4.2.4), and their uses within architectural and archaeological
recording noted by Brooke (1987a, 53-63; 1987b, 1040).

**FIGURE 5.1 ELECTROMAGNETIC SPECTRUM**

<table>
<thead>
<tr>
<th>Waveband</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio waves</td>
<td>100mm-10km+</td>
</tr>
<tr>
<td>Microwaves</td>
<td>100μm-100mm</td>
</tr>
<tr>
<td>Infrared</td>
<td>1μm-1mm</td>
</tr>
<tr>
<td>Light</td>
<td>100nm-1μm</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>1nm-100nm</td>
</tr>
<tr>
<td>X-rays</td>
<td>10⁻³ nm-10 nm</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>10⁻³ nm</td>
</tr>
<tr>
<td>Cosmic ray photons</td>
<td>10⁻⁸ nm</td>
</tr>
</tbody>
</table>

The science of photography is concerned with optics and chemistry, both of which are specialist disciplines in their own rights. With regard to the former, it has been sufficient to consider only how film selection may be optimised to achieve satisfactory results during data capture.

Although enlargement factors are kept relatively small when producing prints for digitising, the potential problem of graininess must be understood and guarded against. The photographic image is formed by a chemical process in which the silver halides that form the film emulsion ripen and grow (Sutton, 1987, 40 et seq.). These silver halides are compound salts of silver, like silver bromide, silver iodide and silver chloride, and will break down under the action of light to form tiny grains of black metallic silver. Generally speaking, sensitivity of an emulsion increases with grain size, so that faster emulsions are generally of coarser grain, and fine grains are therefore achieved at the expense of speed.

The silver grains of a developed emulsion are distributed at random, resulting in areas of relatively high and low concentrations. These relate to areas of higher and lower optical density respectively. On
magnification, the variation in density can be seen as a mealy or granular effect, known as 'graininess'.

Film ratings or speeds are specified under various international standards in order to relate the light sensitivity of one film to another. The three series in use are ASA, the American Standards system by which a doubling of speed is shown by a doubling of the number; DIN, the German system that denotes the doubling of speed by a rating increase of three; and GOST, the Russian system that uses a similar arithmetical increase to ASA. Presently, an international standard has been adopted, where ISO (International Standards Organisation) is equivalent to ASA. Film speeds can, thus, be classified according to arithmetic or logarithmic forms (i.e. ISO 100 or ISO 21') (Figure 5.2):

FIGURE 5.2 FILM SPEED RATINGS

<table>
<thead>
<tr>
<th>Film speed</th>
<th>ISO rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>16 - 50 ISO</td>
</tr>
<tr>
<td>Medium</td>
<td>50 - 160 ISO</td>
</tr>
<tr>
<td>Fast</td>
<td>160 - 800 ISO</td>
</tr>
<tr>
<td>Ultra-fast</td>
<td>800 - 2000 ISO</td>
</tr>
</tbody>
</table>

For this work, a medium-speed panchromatic film has proved to be acceptable in terms of graininess and exposure requirements. ILFORD FP4 medium-speed black and white film, rated at ISO 125/22', has been found to give good results when the camera is tripod-mounted in a variety of lighting conditions, allowing enlargements to be taken up to 8 x 10ins. (20.3 x 25.4cm) without noticeable loss of detail.

Panchromatic film (blue-green-red sensitive) possesses an emulsion that is sensitive to all the colours of the visible spectrum, and to a certain amount of ultraviolet light. This records colours as tones of grey, with approximately the same relative brightness as they appear to
the observer. The resultant range of tones, or densities, representing the light and shade of the original scene, means that evaluation is more subjective than with colour photography.

Specialist film emulsions are available that are sensitive to certain wavebands. All conventional photographic materials are sensitive to ultraviolet radiation, but practical application requires extension of the usual processes, as discussed by Conlon (1973, 283 et seq.) and Denstman (1979, 24 et seq.). On black and white film, such radiation has the same effect as light, in that it causes increased density within the developing emulsion.

Infrared film is sensitive to invisible light only by the use of deep-red filters or, without any filtration, sensitive to all light as any normal black and white film (Molitor, 1976, 29). It is the in-between effect of light-red or orange filters that make this film useful in architectural photography.

Normally a black and white film reproduces greens as dark greys and blues as a very light grey or white. Red, too, is rendered medium to dark, depending on the value and hue. With infrared film, the reds are very light, the blues almost black, and the greens almost white. This shift of values can be used to emphasise building materials, and enhance the image for a particular applications.

The quality of the photographic print from which data is selected during restitution can be critical in cases where interpretation is necessary. An important consideration in this respect is the contrast that is displayed by the image.

Contrast has been defined by Hedgecoe (1977, 326) as being a subjective judgement on the difference between densities or luminosities, and their degree of separation in the subject, negative or print. Contrast control in photography is a product of several factors, and has, for this work, required further consideration.
The inherent contrast of a subject is determined by the contrasting areas of dark or light tone that make up its appearance. This can be affected by the contrast in lighting, whether natural or artificial, creating bright spots and dark shadows. Harsh oblique light can form an intense contrast across a textured surface, even though it is of one tone. This phenomenon has been put to good use in the detection of sub-surface anomalies in buildings, through the application of raking light in a contrast/contour enhancing illumination (CEI) technique (Brooke, 1987a, 194).

Non-image-forming light that is scattered by the lens, or reflected from the camera interior, can affect the film, so causing a lowering of image contrast. Such flare is controlled to a certain extent by the use of anti-flare coatings evaporated on to the surface of each element during manufacture.

High-contrast films, or even ones of medium contrast, if over-developed, will increase the contrast of the image. This is a popular technique, but requires adjustment to be made when the photograph is being taken (Buchanan, 1983, 16).

Photographic printing paper carries a light-sensitive emulsion, similar to that which coats the actual film, though much slower and finer grained. The most common types of printing paper are conventional high-quality wood-fibre papers and plastic- or resin-coated papers. The paper for printing is classified or graded according to contrast, ranging from 0 to 5 (i.e. soft to very hard). Similar grade numbers do not necessarily have equivalent contrast characteristics on paper from different manufacturers. The actual print surface greatly influences the degree of image contrast, with glossy paper appearing a deeper black than matt-surfaced paper. For presentation work, light at an oblique angle can also enhance print contrast.

Sensitometry is the science of measurement concerned with the sensitivity of photographic materials. An assessment of the behaviour of a negative material is given by a graph showing the relationship between the logarithm of exposure (log E) and density (D) under given
conditions of development. This graph is termed the 'characteristic curve', and for every negative material will be different, dependent upon processing.

Contrast, the difference between densities, is measured as the increase in density with increase in \( \log E \), being the slope of the characteristic curve. A negative given minimal exposure, so that densities lie on the foot of the curve, has less contrast than a more fully-exposed film, with contrast rising to a maximum when the whole of the negative densities lie on the straight-line portion.

Consideration of the optical components of the photographic system has been prompted by the use of simple or non-metric photography for data capture, in contrast to the metric cameras used in 'classical' architectural photogrammetry. The arguments for and against this have been covered above (Section 4.2.3), but further attention has been paid to the distortions that are inherent in the use of non-metric equipment.

The inability of a lens to render a perfect image of the subject is termed an aberration. This failing often occurs at the edges of the lens field, as light rays fail to converge to one focus. There are seven basic chromatic and spherical lens aberrations common in simple lenses that can be reduced by compound construction. A summary of these aberrations is reproduced in Figure 5.3 below, based on that by Rolls (1968, 103).

Pinhole cameras, by their very construction without the benefit of variable focus, give images free from curvilinear distortion, and thus have certain specific uses outside of this work (Rolls, 1968, 162; Brooke, 1987a, 135).
FIGURE 5.3 SUMMARY OF LENS ABERRATIONS

<table>
<thead>
<tr>
<th>ABERRATIONS</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astigmatism</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Spherical</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Coma</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Axial chromatic</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral chromatic</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Curvilinear distortion</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Curvature of field</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

A = Aberration that has an effect on the centre of an image.
B = Aberration that has an effect on the margin of an image.
C = Aberration that is improved by reducing the f/no.

One of the most common aberrations is that of distortion, where straight lines at the edge of the field are caused to bend towards the lens axis. A lens thus suffering from distortion reproduces straight lines in the object space as curved lines on the film. In asymmetrical lens construction, this is caused when the diaphragm or adjustable aperture is placed in front of the optical system.

A lens suffers from 'barrel' distortion when the image of straight lines appear as concave lines relative to the centre of the film. Conversely, 'pincushion' distortion causes the lines to be reproduced with convexity. The effects of distortion are greater when using wide-angle lenses, and may prove too great to provide useful results (McFadgen, 1971, 76).

Although the effects of lens aberrations are normally regarded as insignificant in conventional photography, with general-purpose lenses usually having about a one per cent distortion (Jacobson et al, 1988, 64), it is considered important in this work to quantify such distortion in order to provide a check on all variables present within the recording and measuring process.
Thompson (1977, 93) contends that the significant feature of distortion is the test of whether or not a straight line projects as a straight line. This can be assessed to varying degrees of accuracy through simple lens testing.

Cox (1974, 204) recommends that two plumb lines are photographed so that they lie at the edges of the field which the lens will cover. Where the image of the lines is concave, the lens suffers from pincushion distortion; where it is convex, then the lens suffers from barrel distortion. By comparing the increase or decrease in the width of the image against the total width of the picture, this distortion of the lens, expressed as a percentage at the corner of the field, can be calculated. Pincushion distortion is counted as positive and barrel distortion as negative using Equation 5.1, as illustrated in Figure 5.4.

\[
\text{Percentage distortion} = \frac{x}{b} \times \frac{a^2 + b^2}{ab} \times 100\% \tag{5.1}
\]

where:  
\(a\) = width of picture  
\(b\) = height of picture  
\(x\) = increase or decrease in width of image

For a similar test, Rolls (1968, 152) considers that a number of white cords stretched horizontally and vertically across a dark background make a good test object.
In testing for distortion in quantitative photomicrography, Curtis (1968, 494) considers the use of a grid with regular intersections, from which distortion is measured in relation to an origin. The measured co-ordinates of each intersection are compared with the co-ordinates of the same intersections on the grid, and errors for the former defined by relation to Equation 5.2:

\[ dx = x_{\text{measured}} - x_{\text{given}} \]
\[ dy = y_{\text{measured}} - y_{\text{given}} \]  

(5.2)

The grid provides a number of circles that pass through the intersections, and the distortion at each of these radii, assuming the errors to be rotationally symmetrical, can be calculated.
Dallas (1982, 15) advocates the undertaking of a trial survey, or 'office block' test, to check the accuracy of the recording process, and in particular the degree of error present due to lens distortion. By photographing a modern flat-fronted building, horizontal and vertical lines can be compared to a superimposed grid at both the negative and printing stages. Non-parallelism of these lines, resulting in the image appearing as a trapezium, may be interpreted as misalignment of the camera in relation to the façade. Where the image exhibits barrel or pincushion distortion, it is a product of the lens construction.

For the purposes of this work, a comprehensive test was devised to assess the nature of the distortion inherent in the construction of a number of lenses based on a 35mm photographic system. The intention of this series of tests was to identify and record the amount of distortion suffered by a sample number of lenses in regular use for architectural surveying and recording.

As this project has made extensive use of CAD, these tests were designed to utilise the inherent dimensional analysis characteristics present in such a system.

Throughout this project, lenses of different manufacture have been used. The distortion tests have therefore been undertaken on four lenses in use by the author for such work. The sample lenses were:

(a) OLYMPUS ZUIKO 35mm f2.8 63° (max. 83°) perspective-control lens.
(b) SUPER-PARAGON PMC 28-50mm f3.5-4.5 zoom lens.
(c) TAMRON 35-70mm f3.5 CF Macro 64'-34' zoom lens.
(d) VIVITAR MACRO FOCUSING 70-150mm f3.8 34'-16' zoom lens.

A 50 x 50mm (2 x 2ins.) grid was constructed and plotted at full-size, producing an A1-size regularly-gridded sheet. This was mounted and positioned so that it was vertical in plane, and perpendicular to the floor surface, and photographed using the sample lenses on a standard tripod-mounted camera body. The subject distance was varied to ensure complete coverage by the lenses, dependent upon their focal lengths,
but centred on the grid.

Cox (1974, 205) makes the point that in measuring distortion, the lens should be stopped down to about half the full aperture, so giving the best definition. Distortion is not changed when the lens is stopped down.

It is important to note that the resultant distortion characteristics apply to the optics of the entire equipment. The lens manufacturers' nominal value for focal length, engraved on the lens, can usually be relied upon to within 1% or less (Ibid., 32). Various tests may be carried out in which the focal length can be determined, but such detailed investigation into lens construction is beyond the scope of this work. For the purposes of these tests, the nominal values taken from the lenses have been assumed to be correct.

Distortion introduced at the printing stage due to aberrations in the enlarger lens is taken to be negligible, being a product of the standard of equipment used. Printing was on to resin-coated paper with a gloss finish in an attempt to minimise paper distortion due to changes in relative humidity, and to enhance image contrast.

Grid intersections were digitised from the resultant photographic prints, and the corresponding co-ordinates logged in relation to the central point of the grid. This is similar to the measurements made by Adams (1981, 53) from negatives using a stereo-comparator in a mono-comparator mode. Measurements of XY co-ordinates made by digitisation are subject, in themselves, to error. This, however, was found by Adams (Ibid., 57) to be minimal, although the resolution is coarse in comparison with a photogrammetric stereo-comparator. For this work, and the purposes of these tests, the relevant error factor has been quantified elsewhere (Section 5.2.3) and has been ignored.

Assuming that image distortion is analogous to the distance from the origin, the eight co-ordinates nearest to the central point were used to provide an idealised position and distance for each point relative to the origin. A statistically-correct location for each point was
then calculated and used as a reference for the actual co-ordinates determined.

For each lens, at varying focal lengths, the deviations from true grid position were calculated and vector displacements (mm) plotted against the distance from the origin (mm). This relationship has been represented in a series of graphs as scatter points indicating relative displacement. These graphs have been included in Appendix C (II) to provide a visual comparison of distortion between the sample lenses.

Hedgcoe (1977, 29) states that there is a limit over which a lens will project a sharp, distortion-free image, and hence why lenses are designed for a particular format (negative size) camera. Bearing this in mind, it can be stated that for each of the lenses tested, there is an optimum format coverage, outside of which the image is subject to distortion. In practice, making predominant use of the perspective-control lens, digitising has thus been limited to an area within the middle fifty per cent of each print.

In recording an image 'true to life', there is, inherent within the photographic process, a latent scale capability, that allows dimensional data to be accessed under certain conditions. The single most critical aspect of such a situation is that of the optics used to record the image.

The adjustable diaphragm or 'stop' in a camera lens allows the diameter of the transmitted beam to be reduced. This adjustment is necessary in practice for the following reasons:

(a) Reduction of image illuminance.
(b) Increase in depth of field.
(c) Minimising the effect of lens aberrations.
(d) Increase in lens covering power.
The light collecting power of a lens is described by the f/number (Equation 5.3), where:

\[
\text{f/no.} = \frac{\text{Focal length of lens (F)}}{\text{Effective diameter of lens (d)}}
\]  

(5.3)

It will be realised that a larger f/number represents a smaller lens diameter, and therefore a lower light transmission. Each successive f/number in a series gives a reduction of image illuminance by a factor of two; this is commonly called a one-stop difference.

The façades recorded in the sample for this work have been predominantly external, and hence naturally illuminated. In recording internal subjects, it has proved successful to rely on the natural illumination available and record an image with a long exposure, rather than rely on artificial lighting. In order to achieve acceptable results from which to digitise, however, the problem of reciprocity failure needs to be understood and taken into account in timing such an exposure.

In normal photo-chemical reactions, the formation of a developed emulsion is directly proportional to the total exposure, measured as a product of intensity and time, in accordance with Equation 5.4. Halving the time of exposure may thus be compensated for by doubling the intensity.

\[H = Et\]  

(5.4)

where:  
\[H = \text{chemical product}\]
\[E = \text{illuminance (lux = lx)}\]
\[t = \text{exposure time (lux seconds =lxs)}\]

This reciprocity exists only over a limited range of intensities and times for the exposure. At very high intensities (very short
exposures) and very low intensities (very long exposures) the photographic process works much less efficiently than at intermediate exposures. It is, thus, necessary to alter the actual exposure time for such predetermined exposures by a certain factor. Very short exposures tend not to present a problem for the recording of architecture, whereas very long exposures, often necessary in low-light conditions, require extended exposure times.

Problems noted by Meyer (1980, 31) for interior photogrammetry are those of space restrictions and lighting. With difficulties associated with shadows, diffuse light is recommended. Such work is often complicated by light coming through windows that is so bright that even artificial in-fill lighting fails. The only practical advice offered is to postpone the recording until such a time as artificial light prevails, such as night time.

5.2.2 Dimensional control

The minimum requirement for adequate dimensional control has been found, through experimentation, to consist of one vertical dimension and one horizontal dimension, taken on the face of the subject. On an idealised single-plane façade, this can be easily obtained with a steel tape and rod. Convention dictates that horizontal dimensions are usually taken at chest level, unless plans are to be prepared at varying heights to record changes in planarity, such as experienced with a stage-buttressed wall. This expedient presupposes that the external and internal angles to which the dimensions are taken rise in a truly vertical manner.

Where a building is to be surveyed single-handed, it is often the case that measurements are taken at ground level to allow the tape to be secured by an arrow or peg. This would seem a satisfactory practice, except that such low-level fabric can often be obscured by vegetation and debris on the photograph, preventing the location of exact dimension points. Vertical dimensions require similar consideration, in that ground levels may be obstructed, and high points may be
obscured by eaves projections or cast shadow on the final photograph. In preference, vertical dimensions should be taken from a fixed datum, such as a levelled plinth line, up to a distinct horizontal feature, such as a string course or platband. Taking such dimensions up to the underside of a projecting cornice or window sill, again, poses the problem of the point being obscured by the projection or shadow.

For both horizontal and vertical dimensional control, an object of known scale, such as a level staff, may be included on the photograph. Practical problems arise in securing the staff to the face of the building in a truly horizontal or vertical position, such that it can be said to lie in the same plane as the wall surface. It is common, even in archaeological recording, to see the staff leant up against the wall in such a way as to introduce scale error. Problems of obstruction and location of dimension points can, again, reduce the desired scale qualities.

In order to provide an accurate horizontal datum, some form of levelling is usually required in order to allow both ground level and vertical dimensions to be referenced back on the photograph. Although this is not, in itself, a difficult task, it requires the help of an assistant and levelling equipment, which could take the form of either a water-filled tube, a line and spirit level, or an optical device such as an automatic, quickset or dumpy level. A spinning laser may also be used, but would not, it is considered by those familiar with such equipment, produce a line visible on the photograph.

The determination of accurate vertical control thus relies on the accuracy to which a datum is established, and this should therefore be accorded due importance. Where access into the building is possible, vertical dimensions may be taken between points of vertically-aligned windows on different floors using a weighted tape.

The introduction of complex surveying methods may, however, prove costly and, in many instances, unnecessary. Such methods can be replaced by the relatively inexpensive and simple practice of providing taped measurements between identifiable markers or natural features on
Where access to the building face is straightforward, survey targets may be affixed to the surface in order to provide accurate checks to both horizontal and vertical dimensional control. Such targets are easily visible on the photograph, and provide ideal points between which to measure with a tape, or locate diagrammatically using a theodolite. Much has been written on the idealised positioning of such targets for the purposes of photographic rectification (Chambers, 1973, 10-12), but this is of little concern for present purposes. The most important consideration is that the targets are visible on the photograph, and not obstructed by the projection of a buttress, for instance.

The securing of such targets to the surface is best carried out using a rubber-based adhesive that can be removed with minimal disturbance to the fabric. Care must be taken where the surface is friable or powdery, and in such instances, targets may be secured by fine wire masonry nails driven into the joints.

In order to set the camera up such that the film plane is parallel to the facade in both axes, in order to avoid the convergence of horizontal and vertical lines. This has been satisfactorily achieved by using the dual-plane bubble levels built into the tripod head, or when the camera is used in portrait format, with a small spirit level held on the camera body.

In order to provide a check on the parallelism of the film plane to the facade, the horizontal lines of the focusing screen are aligned to a convenient horizontal feature, such as a parapet or cornice, by rotating the levelled camera on the tripod. The resulting angle that may be present between the building and the camera base is normally very small, and the error lies within the required tolerance limits. Ozdural (1975, 162) argues the case that as the cosine of such a small angle is almost negligible, the difference between the length of the
building and its orthographic projection will be insignificant.

In order to set up a camera base truly parallel to the face of the building, it is necessary to undertake some form of measurement based on the construction of right-angles. The simplest solution is to construct a right-angled triangle using two tapes configured in the proportions 3-4-5, with the camera located over the resultant line. This is theoretically possible, but obstructions on site normally prevent such accurate setting out being achieved.

Use may be made of an optical square, which allows a right angle to be constructed by means of internal prisms, but this ideally requires an assistant to move a ranging pole until it is correctly located, so establishing a line at right angles to the façade. It is usual, in practice, to rely, instead, on visual approximation or lining up on a reliable horizontal feature, as discussed above.

This does not, however, hold true for multi-plane façades, as the existence of even a very small angle between the camera base and the building will lead to significant errors in the relative positions of the orthogonal projections of the wall faces to each other. Again, as Ozdural (Ibid., 162) points out, this variable coefficient is the sine of the angle, and the sine of a small angle gives a significant value. It is thus impossible to avoid this error factor without making the camera base parallel to the building in a very precise manner.

In order to establish a vertical reference by which to judge the true plane of a façade, and to assist in setting up the photograph for digitising, success has been gained with a conventional plumb-bob. Where access to high-level accommodation is prohibited, a simple wheeled-device, marketed under the name of 'Giraffe', may be used to take a line up to a reasonable height with a predetermined offset. The advantage of using a plumb-bob lies in the fact that it is readily visible on the photograph and can be operated single-handed. Wind-borne oscillations may be reduced by avoiding exposed corners, or dampened by suspending the weight in a container of water.
Where the façade is punctuated by projections from, and recesses into, the main plane, separate control is required for each of the planes concerned, as these will be represented at different scales on the photograph. The enlargement or reduction factor may also be theoretically quantified by considering the geometric properties of similar triangles (Figure 5.5). Each plane can then be digitised directly from the same photograph, patched and then magnified by its unique X- and Y-axis factors. These planes may then be brought together to form a complete scale elevation.

In certain cases it is impracticable to take direct measurements on the face of the building, and methods of indirect measurement must be adopted. This will typically make use of optical instrumentation that measures angles, rather than linear distances. The instrumentation used in such instances is specified in Appendix C (III).

**FIGURE 5.5 CALCULATION OF MAGNIFICATION FACTORS**

\[
\begin{align*}
\text{Camera station} & : \quad X_p = 5500\text{mm} \quad Y_p = 300\text{mm} \\
\text{Object} & : \quad X_b = 5000\text{mm} \\
\text{Focal length} & : \quad f = 50\text{mm} \\
\end{align*}
\]

Photographic scale = focal length/distance to facade  
Scale of principal plane = 50/5500 = 1/11  
Scale of projection = 50/5000 = 1/10  
\[
\begin{align*}
Y_b/X_b & = Y_p/X_p \\
Y_b & = Y_p \times (X_b/X_p) \\
Y_b & = 300 \times (5000/5500) \\
Y_b & = 273\text{mm} \\
\end{align*}
\]
Mention has already been made of using survey targets with a theodolite. This, however, requires physical contact with the building, and presupposes that direct measurement would, itself, be practicable. Where no contact is possible, a technique of digital 'mapping' has been adopted with success.

This technique can be applied in one of two ways, either by establishing a base line for two-point theodolite intersection on to specific features, or by recording angular readings from one station. The former is used where the façade is made up of more than one plane, the latter in cases of planarity.

In practice, where a façade is composed of various planes, each plane will be considered either as projecting from or being recessed into a nominated reference place. By establishing a base line, of known length, and recording the distance from each station to the reference plane, points on the secondary planes can be located by two-point intersection, both as X and Y co-ordinates, and also in the Z axis. This practice is based on the geometric properties of similar triangles, and was used to control the magnification of images from the south-west transept of Ely Cathedral (Case Study XVII).

Points on single-plane façades can be recorded simply by determining their X and Y co-ordinates from a single station that is located a known distance away from the façade.

By using a total-station theodolite for measuring angles and distances in such cases, data has been logged directly into a field computer, and down-loaded into the CAD system once back in the office. Reconstruction of the site geometry has been undertaken by semi-automated procedures, giving a reference file on which to base the magnification of the completed digitised files.

Where a façade is partially obstructed, or square-on photography impracticable, the total-station theodolite has been used effectively as a 'field digitiser'. Numerous points are logged as features are traced around, providing a basis for the subsequent addition of
two-dimensional elements to complete the elevation. This technique of
data capture was used to record the east façade of the Grammar School
in Coventry, due to the close proximity of adjacent buildings (Case
Study XVI).

5.2.3 Image restitution

The basis of image restitution used in stereo-photogrammetry has been
covered elsewhere (Section 4.2.3), and offers a useful reference to the
present method of digitisation. In this section, the methods by which
information is derived from single photographs to produce scaled line
drawings are examined.

The use of a digitising tablet, and a single photograph, instead of an
analogue or analytical plotter and stereo-pair, cannot be compared,
either in terms of point accuracy or control of distortion. Given that
a photograph, taken as a central projection, provides an image of a
planar subject that is correct to a scale, apart from aberrations
introduced by the lens construction, then such a data source should be
capable of supplying dimensional information for subsequent recovery or
restitution.

It is understood that, whilst the CAD system used for this work, GABLE,
offers a particular means of digitising which has proved suitable for
this work, other CAD systems present alternative facilities that may
prove as good, or better. It is the belief of the author that by
utilising a typical draughting system, this work has provided a
protocol for application with other software. The Historic Buildings
and Monuments Commission for England is presently undertaking limited
digitisation from photographs using AUTOCAD, though as a secondary
means of data input to conventional linear measurement and draughting
(Fagan, 1988, Unpub.; Blake, 1990, Unpub.).

The method by which information is taken from photographic prints has
been developed over the period of this project, and represents the
personal approach of the author. The tablet used has an active area
for digitising of 297 x 297mm (11.7 x 11.7ins.), and so is of a suitable size for using standard 10 x 8ins. (254 x 203mm) prints.

Given that a façade is represented as a photographic orthographic projection, it is first necessary to attach the print to the tablet in a manner that allows horizontal and vertical lines to be drawn as such. This is simply achieved by aligning a horizontal or vertical line on the façade to the horizontal or vertical lines of the tablet menu before it is attached. This can be made easier by incorporating a plumb-line in the composition. Alternatively the print may be gradually rotated so two points on a straight line can be digitised in their true positions.

Where one print is to remain on the tablet for a period of time, it is advisable to tape all sides and cover when not in use to avoid distortion due to changes in temperature and humidity, and also soiling.

The CAD system used has a digitising command, whereby the tablet is sensitised within a given area, and acts as an electronic tracing pad. Once the command is issued, the operator is prompted for two reference points, bottom left and top right, and a digitising scale. These reference points provide the boundary within which the digitised image appears at the selected scale, and should be recorded on the print, so that subsequent digitising sessions may similarly be set up.

The menu of two-dimensional elements is essentially geometry-based, and appears in Appendix C (I). By analysing the façade prior to digitising, it is possible to identify certain repetitive features, and establish a programme for digitisation, whereby the elevation is constructed from the appropriate elements, given the purpose of the record. If, for instance, a hatching or colour is required to identify stone types, then the stones will need to be added as shapes, rather than as individual chains or lines. Figure 5.6 illustrates a part-completed digitised file in which the various elements have been
specified in order to identify how the image has been built up.

FIGURE 5.6 ELEMENTS OF DIGITISED ELEVATION
Once all required information has been digitised, it is then necessary to compare the image scale with the control dimensions taken on site, and magnify the composition to its true scale. The resultant magnification factors are applied to the composition by enclosing it with an activated patch, and specifying individual X- and Y-axis magnification factors.

In order to quantify the amount of error introduced at the digitising stage, a simple test was devised similar to that used for assessing lens distortion (Section 5.2.1). A 10 x 10mm (0.39 x 0.39in.) gridded sheet was produced at full-size, and the intersections digitised part way through a working day after a number of hours of actual digitising to simulate a typical level of concentration. By relating these to their true positions, an average digitising accuracy to 0.30mm (0.12in.) was confirmed, with a sample standard deviation of 0.15mm (0.06in.). A histogram has been prepared to show the frequency of X- and Y-axis errors, and this is included in Appendix C (I).

Where a curved line needs to be digitised, it may be traced on a point-by-point basis using a chain or possibly a shape. Alternatively, an arc may be added over the line by specifying three points, start, finish and intermediate, so establishing the radius heuristically. This latter method is particularly useful when constructing an arch, as it can be built up symmetrically about a central construction line, repeating and handing one half to form a complete semi-circular arc, for instance, and radially repeating it as necessary.

Where an arch is constructed of voussoirs, such an arc may be radially repeated back to an origin, this then giving a point on which to snap individual chains to represent voussoirs. By this means each wedge-shaped stone is accurately formed and represents a realistic part of the arch construction. Figure 5.7 illustrates this technique:
The possibility of building up a series of related curves by specifying three-point arcs provides a flexible solution to recording tracery and other such constructions. In order to determine the practical significance of this aspect of image restitution, a comparative study has been undertaken by manually measuring and recording a traceried window and arched doorway, and digitising the same purely from photographs. Further details, together with a breakdown of times for each method, are presented in Case Study XVIII.

There are occasions when normal-case photography is impracticable due to obstruction or particular site conditions, and oblique photography becomes the only way of recording the façade. This particular condition introduces two-point perspective distortion, and so restricts the techniques of image restitution so far discussed.

The process of analytical rectification is an accepted and well documented method of retrieving information from oblique sources, developed initially for rectifying aerial photographs which show the
effects of tilt.

A simple matrix transformation system, using standard algorithms, has been developed by Mr. J. Haigh at Bradford University (Departments of Mathematics and Archaeological Sciences), and made available for the rectification of oblique aerial photographs (Haigh, 1982, p. 1; Chamberlain and Haigh, 1982, 142-143; Haigh, 1988; Haigh, 1989, 22-23). The specific program, AERIAL, is presently in use by a small number of archaeologists, including those working within the three Royal Commissions.

The rectification of oblique ground-based photographs, recording the vertical planes of architectural subjects, has been undertaken by Dr. J. Williams at Lancaster University (Cumbria and Lancashire Archaeological Unit), notably with the recording of Brougham Castle (Cumbria) (Williams, 1986, p. 3-4, Unpub.). In this work, AERIAL was used to recover dimensional information from oblique sources, and so provided a complementary survey tool alongside photogrammetry, rectified photography and hand survey.

Field trials undertaken by the author have shown that AERIAL provides an acceptable method of restitution in circumstances where normal-case photography is impracticable. In general, the program operates at a simple level, but is reliant on high-accuracy grid references for control, reflecting its origins within aerial archaeology. It is understood that the program performs satisfactorily on data presented up to an angle of approximately 45°, though responding poorly to conditions of convergence in both planes (Williams, 1989, Unpub.).

AERIAL has been used by the author in the production of a record drawing showing the individual stones making up a section of Norman masonry, taking all graphic information from an oblique photographic print taken in 1861. The historical background and approach to this particular problem have been covered by Watt and Ashton (1988, 9-14), a copy of which is included in Appendix D; specific details concerning the technique employed are provided in Case Study XIV.
Further work on the rectification of oblique photographs has been undertaken by Mooney (1988), performing a transformation based on an initial assumption that regular features are present on the subject façade, before magnifying the image to scale.

Recently, a program that seeks to provide a more direct approach to rectification and correction has been made commercially available (WARP), allowing greater flexibility by offering digitisation and rectification as integrated parts of the system (Shepherd, 1989, 50 et seq.). It would appear possible to use this program to correct digitised information taken from an oblique photograph, provided that adequate dimensional control has been obtained.

Where a façade is not composed of flat planes, additional difficulties arise. In practice, the occurrence of curvature or battering in the faces of buildings poses certain problems in recording using computer-aided mono-photogrammetry. Solutions have been considered, although not put into practice. For both cases, any projection or recession of building planes would introduce serious complications, requiring additional hand survey or adoption of stereo-photogrammetric techniques.

With curved surfaces, the considered approach to recording is to take the smallest segment of a chord, for instance 1/10 or 1/20 of the radius, photograph each segment square-on to the face, either by accurately setting up camera stations or approximately sighting on to markers, and digitising each strip in turn. Strip widths may be increased to take account of features, such as windows or doors. These strips may be joined together to form an 'unrolled' or 'developed' drawing, or applied to the segments of a three-dimensional CAD element, this then being viewed to give a true-to-eye 'rolled' drawing.

The recording of an interval tower, semi-circular in plan, in the York City wall was carried out photogrammetrically to allow for the exact reconstruction of the structure after structural intervention (Nursey
and Dallas, 1984, 127-128). As an illustration of the above approach, it would have been possible to drop cords down from the top of this structure to define the segments, and provide normal-case photography for each segment to digitise from. The projection of the plinth at the base of the wall would have required further photographic coverage, or independent hand survey to provide a complete record.

Where the subject building has battered sides, it is feasible to undertake normal-case photography by tilting the camera sufficiently to align the building face with the grid lines seen in the viewfinder, and ensure that the film plane is parallel with the wall. The resultant photographs may then be digitised in the normal manner and presented as individual elevations, or applied to the faces of a three-dimensional element, and viewed to give a true-to-eye drawing.

As an alternative to the input of photographic data by digitisation, there is the possibility of scanning the photographic print to produce the desired image. Input can be by line scanning using cathode-ray tube (CRT) rasterisation or as a frame-grabbing procedure. The latter technique offers the least expensive method of inputting data, but reproduction is in the form of a raster-graphics bit map comprising individual pixels. This has then to be converted into vector co-ordinates for manipulation by the rectangular or Cartesian co-ordinate-based CAD system.

Brooke (1987a, 403) makes the point that, for the analysis and interpretation of remotely-sensed data, photographic images may be coded into digital form using a videographic frame-grabbing system or, for higher resolution, a charge-coupled device (CCD) scanner.

Bureau services exist for scanning existing drawings to provide graphic files for CAD storage and manipulation. For organisations, such as the British Railways Board and commercial banks, who occupy and maintain large stocks of buildings for which drawings exist, this provides an economic solution. Where distortions have occurred, rectification can
be undertaken, making use of WARP or some such program.

A monochrome photograph is essentially a collection of varying contrasts, ranging from black to white, such that a subject is identified not by edges or contours, but by the differences in density. Scanning such a photography would, therefore, result in a bit map, with no identification of individual elements for conversion into vector co-ordinates.

There are programs that can enhance the image by altering contrast, applying various 'masks' to highlight or subdue particular levels of information, or define edges. This has been demonstrated by Clark (1979, 13 et seq.), and a similar course of action used by the author in relation to Case Study XIV.

Further work into this particular aspect is being undertaken by Mrs R. Smedley at the Leicester CAD Centre, making particular use of desk-top publishing (DTP) packages.

5.3 ANALYSIS OF PROJECT DATA

As stated in the introduction (Section 1.3.2), it has not been possible, nor has it been considered necessary, to produce a comparative record, using either direct or indirect means, for those buildings that have provided the case study material for this work. In certain instances, feedback from clients and others involved with the particular buildings has provided anecdotal data, concerning the merits of computer-aided mono-photogrammetry, with reference to the products of other methods of surveying and recording. In other cases, comment has been on the relative qualities of the record drawings for particular uses.

In analysing the products of this work, it is important to consider that this project has relied on the products of two existing sciences, photographic surveying and CAD, to provide the apparatus for undertaking experimentation and, later, practical surveys.
Developments in these parent disciplines will, undoubtedly, alter the way in which computer-aided mono-photogrammetry is used and may, in the longer term, make present aspects of the technique redundant.

Initial consideration was given to a means of capturing dimensional data in a form suitable for later restitution and reproduction. Basic photographic theories and techniques were studied that would give results appropriate to the underlying aims and objectives of the work.

Investigation of specific aspects of photographic practice provided evidence for decisions regarding survey methodology. These related to contrast enhancement through the use of colour filters, and optical distortion characteristics. Photographic surveys undertaken by the author (see Appendix B) on a variety of building types have assisted in developing a robust methodology for use when adopting techniques of photographic data capture.

The chosen method of image restitution is reliant on a working knowledge of computer-aided draughting and, to some extent, an understanding of three-dimensional modelling. This latter aspect has been found to assist in acknowledging the three-dimensional nature of the subject being recorded. It was therefore necessary for the author to acquire such skills, this being achieved through a combination of tutorials and practical tasks.

Digitisation of selected data from photographic prints has been used throughout this project as the method of restituting information in a manner suitable for scaled reproduction. The accuracy of this method has been assessed and its limitations acknowledged. Methods of rectifying data presented in oblique photographic sources have also been investigated, and the chosen technique of analytical rectification tested and applied.

The means by which the controlling dimensions for scaled restitution have been taken and recorded have relied on both traditional and advanced methods of direct and indirect measurement. This has required an understanding of the science and operation of optical and electronic
instrumentation, specifically the total-station theodolite and field computer.

During the course of this work the author has discussed, in detail, the principles and practice of measured survey with architects and archaeologists involved in the recording of existing buildings and monuments. Their comments regarding present methods, and the potential for improving such practices, have helped to understand both practical needs and restrictions. In these discussions, the appropriateness of the record for a particular task has been continually stressed.

The mechanics and practice of current indirect recording techniques, notably stereo-photogrammetry and rectified photography, have also been studied, and their uses for particular recording tasks analysed and set in the context of what is required of them. An important aspect of this has been to set down the practical advantages and disadvantages of these, widely misunderstood, techniques, and relate their application to particular aspects of architectural conservation.

Whilst the wider implications of computer-aided mono-photogrammetry in the context of architectural recording are considered in the following chapter, it is appropriate here to set down the practical value of this work, with reference made to the results that have been achieved.

In its application, computer-aided mono-photogrammetry is capable of single-handed usage, without the need for specialised skills or equipment. This allows it to be used by persons involved in a particular project to produce their own records, whether as digital files or conventional drawings, for further use.

It is understood that there is much to be gained from undertaking one's own surveys, especially when the alternative is to rely on records produced by external consultants. This latter practice often means that there is no opportunity to become fully conversant with the building or monument in question before work is specified or actually
commences on site.

It is, however, the case that many architects, surveyors and archaeologists consider the acquisition of CAD to be inappropriate, especially for those smaller practices that deal predominantly with historic buildings and ancient monuments. The general opinion is that the costs of the hardware, software, maintenance and training outweigh the benefits that would accrue in the longer term.

Better value for money is often seen to be gained from employing specialist skills for particular tasks or updating existing office equipment that is regularly used. In this respect, computer-aided mono-photogrammetry may remain a technique that is appropriate only to those who already possess CAD, or as a service offered to others by consultants.

The processes of indirect data capture, with later restitution, mean that computer-aided mono-photogrammetry is appropriate in cases where the subject is in a dangerous state, when it is being recorded in adverse weather conditions or where access is restricted or impracticable. Field Cottage, Ratcliffe-on-the-Wreake (Case Study XXI) was recorded at a time when the building was in a poor structural condition, during extreme weather conditions. Access to King's Mill Viaduct, Mansfield (Case Study V) would have required extensive scaffolding if the structure were to have been manually measured and recorded.

In a number of studies undertaken, notably the Church of St Mary and St Laurence, Bolsover (Case Study IV); Bagshaw Hall, Bakewell (Case Study VIII); the Kirby and West Building, Leicester (Case Study IX); Aylsham market place (Case Study XIII); the Grammar School, Coventry (Case Study XVI); and Ely Cathedral (Case Study XVII), full scaffolding or, at least, a scaffold tower, would have been required to achieve, to a similar standard of accuracy and detail using manual techniques, the results gained from using computer-aided mono-photogrammetry.
In the cases of the blocked doorway and carved tympanum at the Church of St John the Baptist, Ault Hucknall, and the doorway at Tickhill Castle (Case Study VII); the Gazebo at Kelham Hall (Case Study X); Flacketts, Sudbury (Case Study XII); the balustrading at Castle Ashby House (Case Study XV); and details at Loughborough Cemetery (Case Study XX), extensive hand survey and measurement would have been required. In particular, it is unlikely that similar results could have been achieved at the Norman cellar in Guildhall Lane, Leicester (Case Study XIV) without recourse to extensive photogrammetric or composite techniques.

In such conditions it is important that all the relevant information is identified and recorded in as short a time as possible. It is often the case that return visits to site are not possible, or the building or monument is to be altered in some way that makes its recording of greater importance. The application of computer-aided mono-photogrammetry for threatened buildings recording is of significance as it allows photographic records to be made and, with limited dimensional control, used to provide graphical documentation if and when required.

It is also possible to use computer-aided mono-photogrammetry for creating graphical records of streetscape and aspects of urban composition. The merit of such records in carrying out visual impact analyses is unquestionable, and an example of this application is given with regard to the fine Georgian market place at Aylsham (Norf.) (Case Study XIII).

Computer-aided mono-photogrammetry may be used to record levels of surface detail that would normally require extensive hand recording and measurement. Whether as a particular project in itself, or forming part of a façade, it is possible to select a level of information from a photograph that is appropriate to the particular application.

In the cases of the Hawthorn Building, Leicester (Case Study I); the Church of St John the Baptist, Ault Hucknall and Tickhill Castle (Case Study VII); Flacketts, Sudbury (Case Study XII); the balustrading at
Castle Ashby House (Case Study XV); the Church of St Mary de Castro, Leicester (Case Study XVIII); and details at Loughborough Cemetery (Case Study XX), high levels of detail have been economically recorded with particular use made of the CAD system facilities for repeating, magnifying, handing and moving parts of the compositions.

Similarly, computer-aided mono-photogrammetry may be used to produce records of façades on a stone-by-stone basis. This has been successfully achieved with work at the Jewry Wall, Leicester (Case Study III); the Church of St Mary and St Laurence, Bolsover (Case Study IV); King’s Mill Viaduct, Mansfield (Case Study V); Bagshaw Hall, Bakewell (Case Study VIII); the Grammar School, Coventry (Case Study XVI); and Ely Cathedral (Case Study XVII).

For both the Jewry Wall, and the Kirby and West Building (Case Study IX), Data Management System (DMS) data survey/analysis routines have been executed to provide information for quantitative studies. This facility has been of particular interest to archaeologists concerned with aspects of former construction practices.

The creation of records for specific applications is possible, and provides a flexible means of presenting information for further usage. The petrological analysis of part of the Jewry Wall, Leicester (Case Study III); the outline elevational record, showing former roof pitches and openings, on the principal façade of Lacock Abbey (Case Study VI); and the stone-by-stone drawing and contextual view of the west wall in the Norman cellar in Guildhall Lane, Leicester (Case Study XIV), illustrate how computer-aided mono-photogrammetry may be used to provide such records with speed, and a greater flexibility of output.

Once the necessary information has been digitised from the photograph it is possible to present it in a variety of ways, dependent on the particular use of the record. If, for instance, one drawing has to serve a number of purposes, it is possible to provide 'layers' of information on a base drawing to communicate specific information to various persons.
Similarly, digitised information can be manipulated in many ways to create different types of record. The eight digitised building façades that make up the west side of the market place at Aylsham (Case Study XIII) were brought together to form a continuous elevational record, with each façade being capable of individual reproduction if necessary. With the octagonal gazebo at Kelham Hall (Case Study X), the eight faces were first recorded from photographs and later arranged around a central plan to form a presentation drawing.

Certain architectural features and details are difficult to record manually with any degree of dimensional accuracy. Photography can provide an appropriate solution, but often a graphical record is required with which to communicate information, such as the extent and nature of repairs. This is certainly the case with traceryed openings, especially if dealing with flowing, rather than bar, tracery. The extent to which computer-aided mono-photogrammetry is capable of producing accurate records of such features is illustrated by the work at the Grammar School, Coventry (Case Study XVI) and the Church of St Mary de Castro, Leicester (Case Study XVIII). Once completed, these records may then be reproduced to a variety of scales and arranged with other digital information in the form of a composite sheet.

It is important, at this stage, to point out the limitations of the technique in its response to practical survey problems. Reliance on central-projection photography using non-metric equipment causes certain difficulties during the process of data capture; mono-imaging restricts the amount and nature of detail that can be restituted; and manual digitisation is susceptible to the skills of the operator and the standard of the tablet used. These issues have been addressed in Section 5.2 above, but it is appropriate here to relate specific problems to case studies undertaken.

It is obvious that with total reliance being placed on the photographic prints as the main data source, the standard of photography is of considerable importance. Black and white, rather than colour, imagery has been used in this work, as it offers a more flexible media for the varying light conditions experienced. It is also less susceptible to
degradation, which may cause colours to fade and so reduce the value of such photographs as archive records.

In a number of the studies undertaken it has been necessary to provide further photographic coverage as a source for visual interpretation. Where the surface of the subject is irregular, as with the Jewry Wall, Leicester (Case Study III), parts of the masonry may lie in shadows cast from projecting stones.

Surface growths, such as were present at the time of recording at Lacock Abbey (Case Study VI) and Burleigh Cottage, Loughborough (Case Study XIX), and obstructions to normal-case photography, as were present at King's Mill Viaduct, Mansfield (Case Study V); the Grammar School, Coventry (Case Study XVI); and Field Cottage, Ratcliffe-on-the-Wreake (Case Study XXI), may also force reliance on photographic interpretation from oblique photographs, though without scope for analytical rectification, as demonstrated at the Eyre Chapel, Newbold (Case Study XI), and applied during the recording of the west wall in the Norman cellar, Guildhall Lane, Leicester (Case Study XIV).

Elements that exhibit extensive projection or recession from the principal plane of the façade, or curvature, present problems that cannot be overcome with the present method of image restitution from single photographic prints. In this respect, the author was not able to record with any degree of dimensional accuracy the projecting circular drums and urns on the doorcase of the Hawthorn Building, Leicester (Case Study I); the domed roof of the gazebo at Kelham Hall (Case Study X); or the ornate urns of the terracotta balustrading at Castle Ashby House (Case Study XV).

Where there are obvious projections into or from the main plane of the façade it is possible to digitise and magnify these secondary planes using different magnification factors derived from direct measurement or calculation, and insert them into the surrounding digitised fabric. The projecting buttresses at the Church of St Mary and St Laurence, Bolsover (Case Study IV); Lacock Abbey (Case Study VI); and the Grammar School, Coventry (Case Study XVI) were all recorded in this way.
It is the opinion of the author that computer-aided mono-photogrammetry provides a robust technique for recording architectural façades within a defined range of conditions. In its application there are advantages to be gained over manual techniques in terms of the time spent producing the record and in the dimensional accuracy achieved. It is subject, however, to certain limitations that restrict its useful range, although these would generally infer the necessity for a complex recording technique, such as stereo-photogrammetry, to be applied.

Computer-aided mono-photogrammetry has been proved, through application, to provide a complementary recording technique, for use principally with smaller-scale buildings and monuments, and aspects of streetscape. It is suitable for producing base drawings on which to communicate the nature and extent of physical interventions, and to provide graphical records with the possibility of restituting information from archive sources. Above all, it provides a flexible method of recording that offers specific advantages for those persons wishing to produce their own drawings or digital files using widely available and understood technologies.

It was stated in Section 1.3.2 that the products of the case studies are a form of information. Information may be defined as consisting of 'any form of communication that is both meaningful and valuable to the recipient and adds to their knowledge' (Kirkwood, 1984, 303).

In order to assess the value of the graphical information produced, each case has been assessed using criteria that are relevant to this particular field of study. Longley and Shain (1985, 163) consider information to be useful if it is timely, relevant and unexpected. These value judgements have been extended to reflect the nature of architectural recording, and have been taken as accuracy, appropriateness, content, and cost.

In relation to the provision of graphic architectural records, accuracy may be considered as the dimensional accuracy that is achieved for each
subject; appropriateness reflects the ability of the technique to satisfy the demands of the project concerned; content questions the level of detail presented in the drawing and its relevance to the task; and cost offers an indication of how the technique performed in relation to established direct and indirect solutions.

These criteria have been applied to the individual case studies undertaken, and the findings presented for each study in Appendix A. In order to analyse the products of this work as a whole, aspects of the technique have similarly been judged according to the same values.

The initiative for this investigation arose in response to a perceived need, and practical demand, for a means of indirectly recording architectural façades. In its development it has, however, been necessary to view the resulting technique as providing a solution for certain common surveying problems. Specific situations will, as indicated above, require differing solutions. It is the opinion of the author, in this respect, that education, and a greater understanding of present techniques, would ensure workable solutions for a large proportion of everyday recording tasks.

In discussing the rôles played by architects, administrators and historians in recording historic buildings, Cooper (1988a, 44) considers that an architectural record will, by its very nature, be subjective, and that analysis and interpretation must precede recording in order to include evidence or facts relevant to a particular use. There is, thus, no form of record that is appropriate in all circumstances, the most suitable depending on the reason for making it.

In the light of this, it is pertinent to consider the wider applications for computer-aided mono-photogrammetry in architectural, and archaeological, recording. In many instances, the initial use for a record of an historic building or monument is to understand the form and technique of its construction, together with all subsequent developments. From this it is possible to consider how the fabric is to be repaired or maintained, and how the structure, as a whole, can withstand change.
Throughout these processes, reliance is placed on the available graphic and photographic documentation. In this respect, it is advantageous to have the dimensional information in a form that is interactive with other levels of data. This is becoming common with the use of alphanumerical files within surveying offices. The potential for storing and retrieving graphical information in a similar way therefore presents important opportunities for interpretative record-making, allowing increased flexibility in analytical study and, potentially, more useful and complete results.

In conclusion, the technique of computer-aided mono-photogrammetry provides a means by which façades may be recorded to a standard of accuracy that is appropriate for the documentation involved in planned interventions to historic buildings and ancient monuments of a limited size and complexity. The completeness of the record is a product of the time allocated for record making, and the interpretative skills of the operator, and this is reflected in the cost of using the technique in favour of other appropriate direct and indirect methods.
6.0 SUMMARY AND CONCLUSIONS

6.1 RATIONALE FOR INVESTIGATION

The aims of this work, as defined in Section 1.2, have been to identify the problems associated with surveying the façades of buildings, monuments and other structures, to propose a convenient and economic means of recording these façades, and present evidence for the application of such a technique in providing elevations that are accurate and useful. In order to focus activity towards these targets, it has been appropriate to consider, in detail, the purpose of surveying, and how historical methods of recording have given rise to current practices.

Measured building surveys, involved with the collection and processing of dimensional data, have constituted an important aspect of the wider practice of surveying, and one that has developed through various phases to become central to the imposition of change affecting extant built fabric. It is for this reason that emphasis has been given to the methods by which such records are prepared and presented.

Manual or hand surveys, and the preparation of measured drawings, remain fundamental to the recording of architectural façades. Such techniques have been developed over many years, and are now accepted and generally understood.

As the study of buildings and monuments increases in complexity, however, it has become necessary to adopt more sophisticated forms of survey in order to provide the requisite levels of data. This has resulted in greater reliance being placed on high-order technologies and, in particular, the application of indirect survey techniques.

The increased use of indirect techniques has also been brought about by the decline in the standards of draughtsmanship, especially with regard to historic forms of architectural construction and detail. A lack of relevant training within the architectural profession over the last
decade has given rise to a number of short courses and competitions being conceived, to increase awareness and promote such skills. The English Heritage Stowe Park Summer School for recording historic buildings, and the recently initiated Folly Fellowship measured drawing competition, are cases in point.

The division between direct and indirect forms of survey therefore continues to increase, as demand ceases to be adequately met by manual methods, and specific requirements necessitate the further use of specialised techniques.

Despite an increase in the use of indirect methods of survey, there remains a lack of knowledge, and a general misunderstanding, concerning the application of such techniques to practical problems. This was highlighted, in particular, by the responses given to a questionnaire organised by Dallas (1983, 14), concerning the use of photogrammetry and rectified photography for architectural recording (Section 4.2.3). It has been partly as a response to the failed expectations that have arisen in such circumstances that specifications, such as that produced by Dallas (1988), have been produced to cover these services.

There is, however, concern held by some who have had experience in using indirect survey methods for architectural and archaeological recording, that techniques such as photogrammetry and rectified photography do not always represent the most appropriate means of providing a dimensional record. In such instances, consideration should be given to manual and other techniques for certain buildings or parts of buildings.

Photogrammetry provides a highly accurate product that has many uses within both architectural and archaeological disciplines. It is not realistic, however, to consider its use on a wide scale, as there are only a small number of companies offering photogrammetric services within the United Kingdom at the present time.
Rodwell (1981, 87) considers that, although extremely accurate, photogrammetry is prohibitively expensive if it has to be charged to an archaeological research budget. This comment also holds true for the majority of projects involving architects and building surveyors, where detailed elevational records are required. For this reason, most photogrammetric recording is confined to large and important buildings and monuments, often in the ownership or guardianship of the State.

Rectified photography represents a useful technique for recording essentially planar façades, although it is not as widely used as it might be, often being rejected in favour of the graphical output of photogrammetry or hand survey.

It has become necessary, at a time when historic buildings and monuments are seen as valuable commodities within our cultural heritage, to further consider the importance of recording, at both architectural and archaeological levels. The necessary human skills are limited, and indirect methods used for recording external façades provide only tools for collecting and presenting dimensional information to assist in further analysis. It would seem, therefore, that a technique of producing dimensional records to an acceptable degree of accuracy using widely understood and available technologies would offer a potential solution to recording problems currently being encountered by those dealing with existing buildings and monuments.

The development and application of computer-aided mono-photogrammetry has been covered in preceding chapters. It is the purpose of this present chapter to summarise the work that has been undertaken, and consider the advances made in the field of architectural recording.

6.2 A SOLUTION TO A RECOGNISED PROBLEM

The underlying philosophy that has lain behind this work has been to develop and progress a solution to a recognised problem with which acceptable results may be obtained without recourse being made to
external specialists. This statement may, on its own, seem to reject what is obviously an acceptable and appropriate course of action in a particular situation, that of consulting and seeking external advice. It is hoped that by now, however, the reader will have been made aware of the problems and limitations inherent with present recording methodologies, and appreciate the need for a complementary tool that satisfies a need in the 'middle-ground' between photogrammetry and hand survey.

The technique of computer-aided mono-photogrammetry offers a solution to certain recording problems: it is a tool in the hands of the architectural or archaeological surveyor. When, and to what extent, it is relied upon can only be decided with knowledge of the particular subject, and the use to which any elevational records are to be put.

Where a façade is comprised of one predominant plane, or has clearly defined projected or recessed planes, it is appropriate to consider the use of computer-aided mono-photogrammetry. In such a situation, rectified photography might also provide an acceptable solution, or even hand survey, depending on problems of access and obstruction. In more complex cases, it might prove necessary to involve photogrammetry, either as the sole recording technique, or as a solution to a particular aspect of the work. It may also be used to provide an accurate matrix within which to build up information using other means.

The advantages and disadvantages to be gained from using computer-aided mono-photogrammetry vary with each particular case. In general, they may be considered to be (Figure 6.1):
### Advantages

- Ease in application.
- Low-cost solution.
- Flexibility of presentation.
- Digital data storage and retrieval.
- Indirect methodology.
- In-house operation.
- Possibility of restituting information from archive sources.
- Creation of a photographic archive, together with graphical output.

### Disadvantages

- Selective practical application.
- Limitations inherent with simple small-format photographic data capture.
- Problems of restituting information from multi-planed and curved façades.
- Errors due to manual digitisation.

It is important that those who commission surveys of properties, and indeed the surveyors themselves, are fully aware of the decisions that have to be made, and the options available, in each instance. Figure 6.2 provides a summary of the decisions that have to be made by both the client and the commissioned surveyor, leading to the production of an acceptable survey solution.

Critical evaluation of the case studies undertaken for this work has provided evidence for the successful application of computer-aided mono-photogrammetry in the indirect recording of certain buildings, monuments and other structures. This success must, however, by qualified by stating that in certain cases, alternative recording methods would have yielded similar or better results, and computer-aided mono-photogrammetry was not wholly appropriate due to the nature of the façade or the specific requirements of the end user.
FIGURE 6.2 SUMMARY OF SURVEY CRITERIA

<table>
<thead>
<tr>
<th>BUILDING, MONUMENT OR OTHER STRUCTURE</th>
<th>Architectural Heritage</th>
<th>Industrial Heritage</th>
<th>Archaeological Heritage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPOSED WORK</td>
<td>Dynamic Intervention</td>
<td>Static Intervention</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conservation</td>
<td>Preservation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitation</td>
<td>Consolidation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Restoration</td>
<td>Interpretation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Repair</td>
<td>Maintenance</td>
<td></td>
</tr>
<tr>
<td>CHARACTERISTICS</td>
<td>Condition</td>
<td>Access</td>
<td>Scale</td>
</tr>
<tr>
<td></td>
<td>Dangerous</td>
<td>Difficult</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>Structurally stable</td>
<td>Limited</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scaffolded</td>
<td>Large</td>
</tr>
<tr>
<td>FAÇADES</td>
<td>Plane</td>
<td>Curvature</td>
<td>Ornate</td>
</tr>
<tr>
<td></td>
<td>and Recesses</td>
<td>Detail</td>
<td>Features</td>
</tr>
<tr>
<td>DRAWINGS REQUIRED FOR:</td>
<td>Listed Building</td>
<td>Scheduled Monument</td>
<td>Statutory Interpretive</td>
</tr>
<tr>
<td></td>
<td>Consent</td>
<td>Consent</td>
<td>Archive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Approval</td>
<td>Documentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Record</td>
<td></td>
</tr>
<tr>
<td>METHODOLOGY</td>
<td>Direct</td>
<td>Combination</td>
<td>Indirect</td>
</tr>
<tr>
<td></td>
<td>Hand survey</td>
<td>Stereo-photogrammetry</td>
<td>Rectified Photography</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Computer-aided</td>
<td>Photographic Interpretation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mono-photogrammetry</td>
<td></td>
</tr>
<tr>
<td>SURVEY TO BE CARRIED OUT:</td>
<td>In-house</td>
<td>Bureau services</td>
<td>Consultants</td>
</tr>
<tr>
<td>ANALYSIS OF DOCUMENTATION</td>
<td>Accuracy</td>
<td>Appropriateness</td>
<td>Content</td>
</tr>
</tbody>
</table>
It is, however, to be stated that computer-aided mono-photogrammetry has been successful in producing graphical records of an acceptable accuracy and content, with which it is possible to communicate and implement changes affecting existing built fabric, and to record certain façades for archive purposes. In this respect, the objectives laid down for this work have been satisfied, and it has been possible to expand the body of knowledge concerning the recording of architectural façades in furtherance of the aims defined at the start of this chapter.

6.3 ASPECTS CONCERNING PRACTICAL APPLICATION

The limitations inherent within the technique of computer-aided mono-photogrammetry, as presented in this work, may be considered at both technical and practical levels. Firstly, there are points to be raised concerning the indirect capture of data by photographic means, the ways in which dimensional control is achieved, and the manner in which the image is restituted by manual digitisation.

In considering the use of a 35mm SRL photographic system for data capture, Feilden (1989, Unpub.) considers that improvements in distortion reduction and image definition would be gained by adopting a larger format: a 4 x 5ins. (10.2 x 12.7cm) monorail view camera was considered to be appropriate, based on personal experience in its use for architectural recording.

Medium-format photography is considered by noted writers and photographers, including Freeman (1988, 6), to be the most appropriate tool for architectural recording. It does not, however, provide the flexibility and ease of use that are to be gained from adopting the smaller 35mm format. In this respect, Dalton (1989, Unpub.) considers 35mm photography to provide a more realistic basis for photographic surveying when dealing with architecture and standing archaeology.
A medium-format system may also be considered inappropriate for data capture for other reasons. Cruickshank (1990, Unpub.) considers that the physical bulk of the equipment makes it vulnerable to the effects of the weather when used externally, whilst its weight prohibits easy transportation by hand. Instead of using roll film, such cameras require dark slides that are both heavy and easily damaged. Exposures have to be carefully timed in order to avoid the effects of reciprocity failure.

Given the additional time required to set up and accurately level a monorail view camera, and the problems of manoeuvring such equipment in the field, site times may be doubled or even trebled. For these reasons, Cruickshank (Ibid.) considers that it would be more appropriate to adopt a 120 or 130mm photographic system if 35mm photography were not to be used.

In the above, there has been no mention made of the advantages of using metric photography for data capture. The use of such equipment has been considered in Section 4.2.3 with regard to photogrammetric photography. The present method of image restitution cannot, however, justify the low distortion characteristics of such equipment, and its high cost is prohibitive for such work.

The complexity of the dimensional control is related to the nature of the façade being recorded. Where it is essentially planar, with no obstruction or hindrance to normal-case photography, then single measurements in both X and Y axes are satisfactory. Where there are secondary planes, additional control will be required.

If a façade is composed of numerous planes of substantial projection or recession from the principal plane, it is impracticable to control each, especially if the fabric is inaccessible. This particular problem was encountered in the recording of the south-west transept of Ely Cathedral (Case Study XVII), where the window apertures were composed of a series of recessed planes, each with elaborate carving on their surfaces.
On façades that are divided by secondary elements, such as buttresses, or are obstructed, it is satisfactory to provide fragmentary control for later restitution, provided that some form of overall control has been obtained. This may be achieved by extensive manual measurement, or through the use of a theodolite to provide graphical control.

The provision of satisfactory dimensional control requires careful consideration of the subject, and may necessitate the use of sophisticated optical surveying instrumentation. It has, however, been generally possible to achieve satisfactory results by relying on direct measurements for the majority of façades recorded.

Successful image restitution, based on manual digitising, can only be achieved with clear photographic prints, which provide data at a reasonable scale. As the process of image restitution does not require the images to be printed at a particular scale, it is appropriate to limit the subject to the middle fifty per cent of the frame, to avoid the worst effects of distortion, and enlarge when printing to provide the best image.

Certain shortcomings have arisen from the particular CAD system used, both in respect of the software and hardware in use. The arc is an important element, and one that has been used in many of the case studies undertaken. When a digitised composition is magnified differentially to comply with its particular X- and Y-axis control dimensions, arcs become irrevocably distorted. In such instances, it is possible to add trim a chain or shape over the arc, so substituting this fixed-geometric element with one that can be distorted. This, however, results in the loss of a smooth line, and leaves a segmented line that may prove unacceptable at large scales.

The puck used for digitising has a transparent disc, incorporating a cross-hair. The thickness of this disc, and width of line that forms the cross-hair, are considered to be too great for high-accuracy work. The specification for such items will vary according to the hardware used, and better tolerances may be obtained with other equipment.
Manual digitisation is time-consuming and laborious, although for this work it is considered to have presented the most appropriate means of data input from a photographic print. A point accuracy of 0.30mm (0.12in.) ±0.15mm (0.061in.) has been achieved, but such precision cannot be maintained for long periods of time. It is important, in this respect, to consider the ergonomic characteristics of the work-station at which this work is undertaken.

It is the view of the author that advances may be made to the present methodologies employed in computer-aided mono-photogrammetry through further investigation of methods for data input from photographic prints into the CAD system. Current scanning facilities are capable of recording photographic image for CAD manipulation: the use of desk-top publishing (DTP) facilities, in this respect, is presently being investigated by the Leicester CAD Centre.

The main problem to be overcome, in this respect, is in enhancing the photographic image to allow a line drawing to be prepared. A preliminary study of scanning photographs has been undertaken by the staff of the Leicester CAD Centre, and initial use made of image-processing routines, in respect of work undertaken for Case Study XIV.

6.4 A CONTRIBUTION TO THE DEVELOPING PRACTICE OF RECORDING ARCHITECTURAL FAÇADES

In previous chapters, consideration has been given to the ways in which methods and practices of recording architectural façades are being advanced and developed. This has been set in the context of achieving an acceptable record of a façade for use by professionals concerned with its condition, construction or historical content.

Advances in existing methods of recording have lain largely with the increased use of computers for data processing and, lately, graphical presentation. This can be seen in the use of analytical plotters for
architectural photogrammetry, land-surveying instrumentation and field computers for measurement and recording, and CAD for the draughting and modelling of existing buildings and sites.

A case has been argued in favour of an alternative, yet complementary, recording technique that provides a solution, at a known level of complexity, for the production of elevational records (Watt, 1989c). In its concept, it adopts a particular approach that has moved away from that displayed by advances in current techniques. It seeks to provide a solution to a particular surveying problem by taking what is already available, and applying it in a controlled and effective manner.

It has also been stated above that there is no technique for recording architectural façades that allows the surveyor to maintain full control of the processes involved, and yet is capable of producing a graphical record to an acceptable dimensional accuracy without recourse being made to extensive physical measurement and interpretation. Computer-aided mono-photogrammetry provides a solution, and has been shown, through application, to be suitable for work that lies within a specific range of complexity and content.

The technique of computer-aided mono-photogrammetry, as developed in this work, has proved to be of practical use, and has generated interest within both architectural and archaeological disciplines. Aside from providing actual graphic and photographic records of building façades, the author has advised on the recording of historic fabric, where an alternative technique has been sought for specific reasons. Such contacts have assisted in providing the stimulus for further investigation, and have given an opportunity for evaluating the theoretical performance of this present method against specific survey problems.

The monitoring of the ancient city walls (dated between the twelfth and fifteenth centuries) at the Great Zimbabwe National Monument, a site of some 720ha (1,779 acres), lying 300km (186 miles) north of the South
African border, is intended to provide information relating to the present structural integrity and predicted collapse mechanisms (Walker, Dickens and Mansell, 1990). Some sections of the walls are sited on the tops of cliffs, and others are battered and curved. A graphical record of the dry-stone walls is therefore needed on which to plot movement and other defects (Dickens, 1989, Unpub.).

The initial input into this project, together with technical advice, has been given by Loughborough University of Technology (Department of Civil Engineering). In considering the particular aspect of recording, it is obvious that one technique would not be appropriate for all aspects of the work. For those sections of the walls that present conditions of planarity and unrestricted access, computer-aided mono-photogrammetry has been suggested as a means by which the requirements of easy field operation and use of existing technologies can be met. Photography already plays an important part in this programme of work, and a CAD system is available on site, currently used for presenting information from topographic surveys.

The problems of recording the fabric of ancient monuments, predominantly for interpretation and programmed consolidation, have been considered by CADW (Welsh Historic Monuments), particularly in respect of circular castle towers, such as found at Rhuddlan Castle (Clwyd). The wish to present a 'developed' elevation, whereby the circular fabric is presented in an 'unrolled' manner, remains unanswered by present techniques, and advice was sought in this respect (Watkins, 1989, Unpub.; Avent, 1989, Unpub.). Although computer-aided mono-photogrammetry can, theoretically, provide such a record, the conditions of height and uneven access encountered at Rhuddlan were considered problematic.

In undertaking works of repair and consolidation, it is first necessary for the scope of the work to be communicated, and the mechanics to be indicated for implementation on site. Often the manner in which the former is performed prevents it from being used for the latter.
The Church Conservation Division of Furse Specialist Contracting Limited (Nottingham) has sought advice concerning methods by which graphical records may be produced for use by stonemasons on site (Coonie, 1989, Unpub.). This may be in relation to the repair of a church spire, or the curtain wall of a castle. Stereo-photogrammetry provides a solution, but Furse have recognised the benefits to be derived from preparing such a record in-house, by a person who understands the practicalities of masonry replacement and repair.

Current research being undertaken within the Department of Archaeology and Prehistory at Sheffield University is investigating the reuse of Roman stones, taken from York, and used in the churches of its hinterland (Buckland, 1988, 171 et seq.). A practical solution has been sought for recording the individual stones that make up the walls of a sample number of churches where such reuse has taken place, and to enable quantities to be determined.

Foster (1989, Unpub.), who is undertaking this work as a doctoral project, has commented that computer-aided mono-photogrammetry provides the 'best professional alternative to total photogrammetry as a low-cost solution', and considers the potential for area and volume statistics (as demonstrated in Case Studies III and IX) to be of use in defining the structural history of ancient buildings.

In conclusion, it is important, when comparing and contrasting computer-aided mono-photogrammetry with other techniques, to consider what it is capable of offering, and the potential it offers for further use, including integration with other processes. This may be when dealing with the fabric of existing buildings, monuments and other structures, for architectural, and perhaps, archaeological, purposes. It is only through the continued use of computer-aided mono-photogrammetry for practical surveying, and further investigation of aspects concerned with its wider application, that such potential benefits will accrue.
As an academic work, this project has provided a vehicle by which the author has developed, not only as a building surveyor with specific interests in historic buildings and monuments, but also at a professional level, through the rigours of undertaking an original piece of research. It is hoped that this project will provide a useful development in the field of architectural, and archaeological, recording, specifically in the production of elevational records.
The contents of this section are presented in two parts - bibliographic references cited within the body of the text, and references made to unpublished sources of information. The latter, distinguished as 'Unpub.' in the text, refers to private and personal communications made to the author as anecdotal commentary on specific aspects of this work. Details of these have not been included within this work to respect the confidentiality of the sources, and requests for further information should be made to the author. All books are 1st edition unless otherwise stated.

**BIBLIOGRAPHIC REFERENCES:**


ATKINSON, K.B. (1972). 'Special Applications of Photogrammetry', *Chartered Surveyor*, 10(104), April, 495-497.


-175-


-182-
INTERNATIONAL COUNCIL ON MONUMENTS AND SITES (ICOMOS) (1966). Venice
Charter. Venice: ICOMOS.

Wells, Powys: Attic Books.

'The Recording of Canadian Historic Monuments',
Photogrammetria, 30(3-6), 147-161.


JANSON, H.W. and JANSON, D.J. (1982). The Story of
Painting: From Cave Painting to Modern Times. London: Thames
and Hudson.

Council for British Archaeology/Rescue.

KARARA, H.M. (1972). 'Simple Cameras for Close-Range
Applications', Photogrammetric Engineering, 38(5),
447-451.

Buildings', English Heritage Conservation Bulletin,
Issue 7, February, 7-9.

Techniques. BSc (Hons), Leicester Polytechnic: School of Land
and Building Studies.

KIRKWOOD, J. (1984). Information Technology and Land

'Bundle Triangulation in Architectural Photogrammetry:
The Basilica of San Francesco in Siena', Photogrammetric Record,
12(72), October, 857-871.


presented at EFFECTIVE COMPUTER SOLUTIONS: proceedings of Royal
Institution of Chartered Surveyors (RICS) Building Surveyors
Division Conference, STS, University of Manchester, 23
September.

International, 7(3), March, 31-36.

Photogrammetric Engineering, 18(5), 854-898.

-183-


PROPERTY SERVICES AGENCY (198?). Requirements for PSA Historic Buildings Inspections. Birmingham: Conservation Focal Point (PSA Midlands Region).


-188-


---000---
UNPUBLISHED SOURCES:


BLAKE, W. (1990). Discussion on the use made by the HBMC(E) of digitising tablets and plan variographs for extracting information from photographs. 1 May 1990.


