UNIVERSITY OF DERBY

LIFE CYCLE COSTING METHODOLOGY FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

Olufolahan Ifeoluwa Oduyemi

Doctor of Philosophy **2015**

TABLE OF CONTENTS

TITLE PAGE…………………………………………………………………………………......i
TABLE OF CONTENTS ………………………………………….……………………….....ii
LIST OF TABLES……………………………………………………………………….....viii
LIST OF FIGURES…..xi
LIST OF APPENDICES……………….……………………………………………….……........xiii
LIST OF ACRONYMS…………..………………………………………………………….…xiv
LIST OF CONFERENCE PAPERS…………………………………………………………………xv
ACKNOWLEDGEMENTS………………………………………………………………….....xvi
ABSTRACT ……………………..………………………………….……………………….…….xvii

CHAPTER

I. INTRODUCTION

1.0 Background……………….…………….….………………………..…………………1

1.1 Project Rationale and Justification of the Research………………………………………1

1.2 Aim and Objectives of the Research…………………………………………………...7

1.3 Thesis Organisation……………………………………………………………………….8

II. LCC ANALOGY AND ITS APPLICATION IN THE CONSTRUCTION INDUSTRY

2.0 Introduction………………………………………………………….………...…….......11

2.1 The concept of life cycle costing in sustainable commercial office buildings..................11

2.1.1Definition of life cycle costing in sustainable commercial office buildings………........12

2.1.2 The elements of life cycle costing for sustainable commercial office buildings….......14

2.1.2.1 Initial capital costs…………………………………………………………………...15

2.1.2.2 Operating and maintenance costs………………………………………….………...…16

2.1.2.3 Residual costs……………………………………………………………………..17

2.1.2.4 Service life of sustainable commercial office buildings…………………………….17

2.1.2.5 Discount rate…………………..……………………………………………………19

2.1.2.6 Risk and uncertainty………………………………………..……………………...20

2.1.2.7 Economic performance measures…………………………………………………23

2.1.2.8 Key performance indicators……………………………………………………….24

2.2 Level of Application and Awareness of life cycle costing in the construction industry…25

2.3 Summary of chapter……………………………………...……………………….27

III. THE BENEFITS OF LCC APPLICATIONS ON SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

3.0 Introduction……………………………………………………………….……………29

3.1 The concept of sustainable commercial office buildings……………….……………..30

3.1.1 Classification based on building grade…………………………………………...30

3.1.2 Classification based on location……………………………………………………….30

3.1.3 Classification based on accreditation…………………………………………….31

3.1.3.1 BREEAM………………………………………………………………………31

3.1.3.2 Energy performance certificate…………………………………………………...31

3.1.3.3 Passivhaus………………………………………………………………………..32

3.2 Application of life cycle costing in sustainable commercial office buildings…………..32

3.3 Limitations of life cycle costing in sustainable commercial office buildings…….……37

3.4 Overview of existing LCC models…………………………………………………...41

3.4.1 Applications of Neural Networks…….……………………………………………….44

3.5 Summary of chapter………………………………………………………………….44

IV. DRIVERS AND BARRIERS IN LCC APPLICATIONS ON SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

4.0 Introduction…………………………………………………………….…………..47

4.1 The interrelationship between LCC and sustainable commercial office buildings…......47

4.2 Economic and social drivers of sustainable commercial office buildings………………49

4.2.1 Economic drivers…………………………………………………………………50

4.2.1.1 Return on investment………………………………………………………...…51

4.2.1.2 Incentives……………………………………………………………………….…51

4.2.1.3 Increased rental rates…………………..……………………………………………52

4.2.1.4 Filling aesthetic integrity…………………………………………….……………52

4.2.1.5 Cost effectiveness…………………………………………………………………52

4.2.1.6 Reduced liability…………………………………………………………………..53

4.2.1.7 Ease of leasing…………………………………………………………...…….….53

4.2.1.8 Mitigate risk…………………………………………………………………….....53

4.2.2 Social drivers………………………………………………………………..….54

4.2.2.1 Increased productivity………………………………………………………….54

4.2.2.2 High retentions rate…………………………………………………………..…55

4.2.2.3 Clients requirements……………………………………………………………56

4.2.2.4 Tenants attraction………………………………………………………….....56

4.3 Barriers of sustainable commercial office buildings…………………….……………57

4.3.1 Technological barriers……………………………………………………………58

4.3.1.1 Low demand for sustainable materials and products……………………………...…58

4.3.1.2 Lack of readily available and reliable information and guidance……………………58

4.3.1.3 Lack of LCC………………………………………………………………….59

4.3.1.4 Lack of knowledge/experience and understanding about energy-efficient buildings..59

4.3.1.5 Lack of appropriate UK certification……………………………………………60

4.3.2 Non-technological barriers……………………………………………………..60

4.3.2.1 Financial barriers……………………………………………………………..60

4.3.2.2 No perceived consumer demand for sustainable commercial office buildings………61

4.3.2.3 Learning period…………………………………………….………………...62

4.3.2.4 Status quo in rules and regulations……………………………………………..62

4.3.2.5 Sustainability measures are not considered by government…………………………63

4.4 Summary of chapter…………………………………………………………..65

V. RESEARCH METHODOLOGY

5.0 Introduction……………………………………………………………………...67

5.1 The research process..…...67

5.1.1 Literature review……………………………………………………………....67

5.1.2 Methods of data collection……………………………………………………….67

5.1.2.1 Pilot study for questionnaire…………………………………………………...67

5.1.2.2 Questionnaire survey…………………………………………………….…68

5.1.2.3 Primary data from Interserve construction Limited, Leicester………………………69

5.1.2.4 Secondary data from the Building cost information service……………………....71

5.2 Sample size determination for the main survey……………………………………….72

5.2.1 The main survey…………………………………………………………………..74

5.2.2 Response rate……………………………………………………………………...75

5.3 Data Analysis………………………………………………………………………..75

5.3.1 Descriptive statistics analysis……………………………………………….…..75

5.3.2 Factor analysis……………………………………………………………..……….76

5.3.3 Anova…………………………………………………………………………......76

5.3.4 Theory of Wilcoxon signed-rank test……………………………………………….77

5.3.5 Artificial neural network modelling…………………………………………..….......78

5.3.6 Stochastic modelling for historical costs………………………………………......78

5.3.7 Stochastic modelling for economic performance measures……………………….........81

5.3.8 Test of hypothesis……………………………………………………………........83

5.4 Validity and reliability of the questionnaire and mathematical models……………….…84

5.5 Objectivity testing of the research field……………………………………………...86

5.6 Summary of chapter……………………………………………………………..........86

VI. PILOT AND MAIN SURVEY ANALYSIS

6.0 Introduction……………………………………………………………………..........87

6.1 Applications and limitations of LCC in sustainable commercial office buildings……..........87

6.2 LCC awareness…………………………………………………………………....…….90

6.3 Ranking of the drivers and barriers of sustainable commercial office buildings……………..90

6.4 Measure of skewness and kurtosis……………………………………………………90

6.5 Main survey results……………………………………………………………..…….96

6.6 LCC awareness and related actions……………………………………………………..96

6.7 Hypothetical statements relating to LCC…………………………………………………..99

6.7.1 Key performance and economic performance measures need to be integrated into LCC…..99

6.7.2 The current LCC techniques are suitable for calculating the whole life costs of buildings...100

6.7.3 It is important to consider the initial, operating and maintenance costs of buildings……..…101

6.7.4 Historical cost data is very accurate…………………………………………………102

6.8 Test of hypothesis for key performance for key and economic performance measures……….103

6.9 Test of hypothesis for the suitability of LCC methods……………………………………104

6.10 Test of hypothesis for the elements of LCC……………………………………………..105

6.11 Test of hypothesis for the accuracy of historical costs…………………………………...........106

6.12 Applications of life cycle costing…………………………………………………………...107

6.13 Limitations of life cycle costing……………………………………………….…………….109

6.14 Technological and non-technological barriers of sustainable commercial office buildings..….112

6.15 Economic and social drivers of sustainable commercial office buildings………………...…….116

6.16 Summary of chapter…………………………………………..…………………..……120

VII. DEVELOPING A CONCEPTUAL FRAMEWORK FOR LCC, HISTORICAL COSTS AND ECONOMIC PERFORMANCE MEASURES

7.0 Introduction………………………………………………………………………………123

7.1 Development of a conceptual framework……………………………………………………..123

7.2 Case study one: Office block, Penllergaer business park, Swansea, west Glamorgan.................124

7.2.1 Step one: Identify the objectives…………………………………………………………….124

7.2.2 Step two: Develop the cost breakdown structure…………………………………………....124

7.2.3 Step three: Determine the length of the study period, discount and the inflation rate……..…124

7.2.4 Step four: Modelling of historical operating and maintenance costs…………………………125

7.2.5 Step five: Forecasting with artificial neural networks……………………………….……127

7.2.5.1 Data acquisition and analysis……………………………………………………………128

7.2.5.2 Configuration of the network……………………………………………………………128

7.2.5.3 Training of the network…………………………………………………………………129

7.2.6 Discounting using net present value (NPV)………………………………………………134

7.2.7 Quantitative risk analysis of the maintenance and operating costs………………………...…137

7.2.8 Application of economic performance measurement and key performance indicators……….138

7.2 Case study two: Interserve construction limited, Leicester…………………………………..…141

7.2.2.1 Step one: Identify the objectives…………………………………………………………141

7.2.2.2 Step two: Develop the cost breakdown structure……………………………………………141

7.2.2.3 Step three: Determine the length of the study period, discount and the inflation rate……….142

7.2.2.4 Step four: Modelling of historical operating and maintenance costs………………………..142

7.2.2.5. Step five: Forecasting with artificial neural networks…………………………………….143

7.2.2.5.1 Data acquisition and analysis…………………………………………………….…143

7.2.2.5.2 Configuration of the network………………………………………………………………….144

7.2.2.5.3 Training of the network……………………………………………………………………….145

7.2.2.6 Discounting using net present value (NPV)………………………………………………….149

7.2.2.7 Quantitative risk analysis of the maintenance and operating costs…………………………...152

7.2.2.8 Application of economic performance measurement and key performance indicators……....153

7.3 Comparative analysis between the two case studies……………………………………………….154

7.4 Summary of chapter…………………………………………………………..…………….155

VIII MODEL VALIDATION AND DISCUSSION

8.0 Introduction…………………………………………………………………………………….157

8.1 Error autocorrelation test……………………………………………………………………….157

8.2 Performance test………………………………………..………………………………..159

8.3 Regression and mean squared results………………………………………………...………160

8. 4 Summary of chapter……………………………………………………………………….……162

IX SUMMARY, CONCLUSION AND RECOMMENDATIONS
9.0 Summary……………………………………………………………………………………….164

9.1 A comparism with other models…………………………………………………………….….165

9.2 Specific contribution to knowledge…………………………………………………….……167

9.3 Limitations of the research…………………………………………………………….…..169

9.4 Recommendations for future research………………………………………………………….170

REFERENCES……………………………………………………………………………....171

LIST OF TABLES

Table 2.1: Data Structure for Standardised Method of Life Cycle Costing for Construction Procurement (SMLCC)……………..……………………………………………………………16

Table 2.2: Methods for handling improbability and risk in the economic assessment of building investments…………………………………………………………………….…………………...22

Table 3.1: Applications of LCC in sustainable commercial office buildings…………………………34

Table 3.2: Applications of LCC in sustainable commercial office buildings…………………………36

Table 3.3: Limitations of LCC……………………………………………………….………..41

Table 4.1: Economic and social benefits of sustainable commercial office buildings………………..56

Table 4.2: Barriers to achieving sustainability……………………………………………………..63

Table 6.1: Summary statistics of the analysed variables…………………………………….…..........88

Table 6.2: Model Summary……………………………………………………………..……….89

Table 6.3: Anova………………………………………………………………………………….90

Table 6.4: Descriptive statistics of the analysed variables………………….…………….………..92

Table 6.5: Key performance indicators…………………………………………………….......97

Table 6.6: Economic performance measures……………………………………………………….97

Table 6.7: Risk assessment techniques………………………………………………………….98

Table 6.8: Forecasting methods……………………………………………………….…...99

Table 6.9: Key performance indicators and economic measures need to be incorporated into LCC..100

Table 6.10: The current LCC techniques are suitable for calculating the costs of buildings………..101

Table 6.11: It is important to consider the initial, operating, maintenance and disposal costs of building when conducting LCC analysis………………………………………………………......102

Table 6.12: Historical cost data is very accurate…………………………………….……………102

Table 6.13: Wilcoxon Signed Test……………………………………………………………...103

Table 6.14: Wilcoxon Signed Test……………….…………………………………………………105

Table 6.15: Factor Analysis……………………………………………………………………….107

Table 6.16: Total variance……………………………………………………………...…109

Table 6.17: KMO and Bartlett's test……………………………………………….……….109

Table 6.18: Factor Analysis…………………………………………………...…………….109

Table 6.19: Total variance…………………………………………………...………………111

Table 6.20: KMO and Bartlett's test……………………………………….………….111

Table 6.21: Technological and Non-technological barriers of sustainable commercial office buildings…………………………………………………………………………….....112

Table 6.22: Model Summary…………………………………………………………………..114

Table 6.23: Anova…………………………………………………………………………...115

Table 6.24: Correlation tables for economic and social drivers of sustainable commercial office buildings……………………………………………………………………………….…..117

Table 7.1: Initial capital costs of the office block, Penllergaer Business Park, Swansea, West Glamorgan…………………………………………………………………...……………124

Table 7.2: Historical cost breakdown structure of the operating and maintenance costs of the office block, Penllergaer business Park, Swansea, West Glamorgan……………………………………..124

Table 7.3: Newly generated values for the historical cost breakdown structure of the operating and maintenance costs of the office block, Penllergaer business park, Swansea, Glamorgan………….127

Table 7.4: Shows the forecasted values for thirty years extracted from ANN input simulations……131

Table 7.5: Shows the discounted values for thirty years extracted from ANN input simulations…...134

Table 7.6: Quantitative risk analysis ANN input simulations…………………………………….138

Table 7.7: Variables for non-construction costs………………………………………….......139

Table 7.8: Key performance indicators………………………………………………...…140

Table 7.9: Initial capital costs of Interserve Construction Limited, Leicester……………………….141

Table 7.10: Historical cost breakdown structure of Interserve Construction Limited, Leicester........141

Table 7.11: Newly generated values for the historical cost breakdown structure of the operating and maintenance costs of Interserve Construction, Limited, Leicester……………………………...…143

Table 7.12: Shows the forecasted values for thirty years extracted from ANN input simulations...146

Table 7.13: Shows the discounted values for thirty years extracted from ANN input simulations…149

Table 7.14: Quantitative risk analysis ANN input simulations……………………….…..…………152

Table 7.15: Variables for non-construction costs…………………………………….…..……….153

Table 7.16: Key performance indicators………………………………………………………..154

Table 7.17: Comparative analysis between the two case studies…………………………………….155

Table 8.1: Regression and mean squared results for case study one…………………………….. …160

Table 8.2: Regression and mean squared results for case study two……………………………...…161

LIST OF FIGURES

Figure 1.1: Methodological procedure……………………………………………...…………………10

Figure 5.1: Side view of Interserve Construction, Limited, Leicester……..…………………………69

Figure 5.2: Durosil blocks with built in thermal and acoustical insulation made from the waste timber shavings…………………………………………………………………………………..…………70

Figure 5.3: The heat recovery ventilation plant……………………………………………….……70

Figure 5.4: Screens located around the office as part of the BMS……………………………………70

Figure 5.5: Intelligent lightening and large area of glazing……………………………………………...71

Figure 5.6: Office Block, Penllergaer Business Park, Swansea, West Glamorgan…………………...72

Figure 6.1: Measure of Skewness…………………………………………………………………..91

Figure 6.2: Measure of Kurtosis……………………………………………………………………91

Figure 7.1: MAPLE probabilistic input simulations………………………………………………...126

Figure 7.2: Data acquisition and analysis……………………………………………………….....128

Figure 7.3: Collecting data in ANN……………………………………………………………….129

Figure 7.4 Training data in ANN……………………………………………………………….....130

Figure 7.5 Probability input simulations…………………………………………………………....140

Figure 7.6: MAPLE probabilistic input simulations……….……………………………………….…142

Figure 7.7: Data acquisition and analysis…………………………………………………………144

Figure 7.8: Collecting data in ANN………………………………………………………………144

Figure 7.9: Training data in ANN…………………………………………………………………145

Figure 7.10 Probability input simulations…..153

Figure 8.1: Case study one autocorrelation results………………..…………………………………158

Figure 8.2: Case study two autocorrelation results…………………………………………………..158

Figure 8.3: Performance test of case study one……………………………………………………..159

Figure 8.4: Performance test of case study two……………………………………………..………160

Figure 8.5: Case study one regression results……………………………………………………….161

Figure 8.6: Case study two regression results……………………………………………………..…162

LIST OF APPENDICES

Appendix one: Data collection for sustainable commercial office buildings………………………194

Appendix two: Consent letter for questionnaire survey ……………………………………….…196

Appendix three: Modelling of operating and maintenance costs…………………………………….202

Appendix four: Modelling of economic performance measures…………………………………….208

Appendix five: Overall ranking corresponding to their mean approximated value of the main questionnaire…………………………………………………………………………….……..214

Appendix six: Table containing Cronbach alpha values for each variable of the main questionnaire……………………………………………………………………………………219

Appendix seven: Factor analysis of the main questionnaire ………………………………………..224

Appendix eight: Descriptive statistic of the variables of the main questionnaire………………..…228

Appendix nine: Graphical representation of the distribution of data for the main questionnaire……236

Appendix ten: Descriptive statistics (frequency tables) of variables of the pilot survey ……………………………………………………………………………………………..258

LIST OF ACRONYMS

ANN-Artificial Neural Networks

ASF- Annual Sinking Fund

BCR-Benefit/Cost Ratio

BREEAM- Building Research Establishment Environmental Assessment Methodology

BRE- Building Research Establishment

CBS- Cost Breakdown Structure

EPC- Environmental Performance Certificate

KPI- Key Performance Indicators

EPM-Economic Performance Measures

IRR-Internal Rate of Return

LCC-Life cycle costs

ROM- Ratio of maintenance to capital cost

ROC- Ratio of operation to capital

PFI- Private Finance Initiative

PHPP- Passivehaus Planning Package

PPP- Public–Private Partnerships

SCOB- Sustainable commercial office buildings

SMLCC-Standardised Method of Life Cycle Costing for Construction Procurement

LIST OF CONFERENCE PAPERS

Oduyemi, O; Okoroh, M and Dean, A (2014), An Integrated Life Cycle Costing Methodology for Sustainable Commercial Buildings, Proceedings of the CIB W107 2014 International Conference, Lagos, Nigeria, 28th-30th January, 2014

Oduyemi, O; Okoroh, M and Dean, A (2014), Barriers to LCC Usage. In: Raiden, A B and Aboagye-Nimo, E (Eds) Procs 30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 783-791.

Oduyemi, O; Okoroh, M and Dean, A (2015), Economic Performance Measures for life cycle costing in buildings, 2015 RICS Cobra Sydney, Australia, 8-10 Jul 2015.

Oduyemi, O, Okoroh, M and Dean, A (2015) Developing an artificial neural network model for life cycle costing in buildings In: Raidén, A B and Aboagye-Nimo, E (Eds) Procs 31st Annual ARCOM Conference, 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 843-852.

ACKNOWLEDGMENTS

First and foremost, I would like to my express my most sincere gratitude to my supervisor, Professor Michael Okoroh. I consider myself extremely privileged and fortunate to have had the opportunity to work under the guidance of a gentleman, and a scholar. His expertise, intellect, persistence and motivation have provided me with the foundations with which to build my skills as a researcher. His supervision has not only equipped me with the necessary academic skills, but his integrity, honesty and sense of fair play and justice have guided me morally throughout my postgraduate training. He has instilled in me a sense of diligence and academic rigour, which very few postgraduates will ever receive to such a high standard, and I am only left feeling that words are simply not enough to express the thanks I owe him.

I would also like to thank Professor Angela Dean for the highly professional technical support she has provided throughout the research. Without her skills, competence and willingness to help, I feel my progress would have been hampered severely.

To my mother Olufunmilayo, who has shown us the true meaning of love, loyalty and commitment to the ones she cares for most. Her steadfastness and resolution in the face of all challenges have made her into a truly remarkable person, and one whom is looked upon with the greatest of respect and admiration, not only by family, and myself but also by her friends and colleagues. Without her support and providence, this research would never have been completed.

To my father Oludayo, his academic intuition and unending desire to provide support and guidance in all I strive for has been a constant source of inspiration to me. I for one, feel privileged to be able to refer to him as "my dad".

Furthermore, to my siblings, who have impressed me with their maturity, intellect and loyalty to the family, throughout my university career, they have always been there to offer words of encouragement.

ABSTRACT

The need for a more authoritative approach to investment decision-making and cost control has been a requirement of office spending for many years now. The commercial offices find itself in an increasingly demanding position to allocate its budgets as wisely and prudently as possible. The significant percentage of total spending on buildings demands a more accurate and adaptable method of achieving quality of service within the constraints on the budgets. By adoption of life cycle costing techniques with risk management, practitioners have the ability to make accurate forecasts of likely future running costs.

This thesis presents a novel framework (Artificial Neural Networks and probabilistic simulations) for modelling of operating and maintenance historical costs as well as economic performance measures of LCC. The methodology consisted of eight steps and presented a novel approach to modelling the LCC of operating and maintenance costs of two sustainable commercial office buildings. Finally, a set of performance measurement indicators were utilised to draw inference from these results.

Therefore, the contribution that this research aimed to achieve was to develop a dynamic LCC framework for sustainable commercial office buildings, and by means of two existing buildings, demonstrate how assumption modelling can be utilised within a probabilistic environment.

In this research, the key themes of risk assessment, probabilistic assumption modelling and stochastic assessment of LCC has been addressed. Significant improvements in existing LCC models have been achieved in this research in an attempt to make the LCC model more accurate and meaningful to estate managers and high-level capital investment decision makers

A new approach to modelling historical costs and forecasting these costs in sustainable commercial office buildings is presented based upon a combination of ANN methods and stochastic modelling of the annual forecasted data. These models provide a far more accurate representation of long-term building costs as the inherent risk associated with the forecasts is easily quantifiable and the forecasts are based on a sounder approach to forecasting than what was previously used in the commercial sector.

A novel framework for modelling the facilities management costs in two sustainable commercial office buildings is also presented. This is not only useful for modelling the LCC

of existing commercial office buildings as presented here, but has wider implications for modelling LCC in competing option modelling in commercial office buildings.

The processes of assumption modelling presented in this work can be modified easily to represent other types of commercial office buildings. Discussions with policy makers in the real estate industry revealed that concerns were held over how these building costs can be modelled given that available historical data represents wide spending and are not cost specific to commercial office buildings.

Similarly, a pilot and main survey questionnaire was aimed at ascertaining current level of LCC application in sustainable construction; ranking drivers and barriers of sustainable commercial office buildings and determining the applications and limitations of LCC.

The survey result showed that respondents strongly agreed that key performance indicators and economic performance measures need to be incorporated into LCC and that it is important to consider the initial, operating and maintenance costs of building when conducting LCC analysis, respondents disagreed that the current LCC techniques are suitable for calculating the whole costs of buildings but agreed that there is a low accuracy of historical cost data.

Keywords: Artificial Neural Networks, Commercial office buildings, Economic performance measures, Life cycle costing, Sustainability.

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND.

There has been a growing need to consider building costs and develop financial methods to evaluate its life cycle costs (LCC). Prior to 1970, many clients, developers and consultants made investment choices solely on the basis of the initial capital costs (A1-Hajj and Homer, 1998). A number of reports including those of Egan (1998) and Latham (1994) have upheld the necessity to think through the long-term cost of project choices. Present regulation for projects procured by means of the Private Finance Initiative (PFI) route supports the application of LCC methods precisely as they deliver an evaluation of the long-term cost evaluation of projects (Jones, 2000).

Hence the need for comprehensive frameworks to analyse the long-term cost of ownership for sustainable commercial office buildings is long overdue. The costs of running and maintaining these buildings make up a significant portion of their entire outlay (Barlow and Fiala, 2007).

Similarly, the green building drive has surmounted difficult economic and technical obstacles in recent decades. Nevertheless, the implementation of sustainable building practices across board is still at its lowest ebb. This research provides a bird’s view on the suitability of LCC for calculating the whole life cost of sustainable commercial office buildings with emphasis on the barriers (technological and non-technological) and drivers (economic and social) of these buildings.

1.1 PROJECT RATIONALE AND JUSTIFICATION OF THE RESEARCH

Construction industry professionals have laid emphasis on the amount to be expended on building operations and maintenance over the life of a building (Dhillion, 2013). The blend of economic theories and computer know-how presents more cutting edge methodologies to the subsequent design and construction of facilities.

As an alternative, facilities should not be viewed only in terms of costs to design and building. Rather, building users could widen their outlook and consider other key variables such as operations, maintenance, renovation, replacement and end of life costs. Contemporary study has indicated that for every £1 spent on capital costs, £50 is spent on maintenance costs and £200 is spent on operational costs (Langdon, 2007). Thus, it can be deduced that the precision of LCC is strongly associated with the precision of the operational cost forecasts.

Consequently, LCC is widely recognised as a method by which a holistic view of long-term costs can be adequately considered. It has been used extensively in the decision-making process when, for example, comparing several alternative project designs at the pre-construction phase. Research work by Hunter and Kelly (2009) and Boussabaine and Kirkham (2006) all focused their assessment on residential or non-commercial buildings with little or no consideration for commercial office buildings which according to Miller and Buys (2008) make up the greater part of commercial/office accommodation and accounts for 20% of the carbon dioxide (CO_2) emissions in the UK (Barlow and Fiala, 2007).

Owing to growing awareness among the stakeholders from the project owners and suppliers to end users and facility managers in contemporary building projects, precise assessment of cost is a challenging undertaking. Most times, there is neither sufficient data nor adequate time and resources obtainable to make an accurate cost estimate. In response, quite a number of conceptual frameworks have been introduced to provide practical ways out to the glitches encountered in accurately predicting costs and quantifying risk (Choong and Sharratt, 2002; Kirkham et al., 2002).

Nevertheless, LCC is still bridled with inadequate forecasts of future operational and maintenance costs and insufficient quantitative risk assessment measures (Hunter and Trufil, 2006). The above submission unmistakeably shows a variance in prevailing cost estimation techniques and underlines the necessity for re-assessment and potential re-evaluation of LCC methodologies (Doloi, 2011).

Consequently, the challenge among practitioners is to develop a framework for LCC that is not only universal, but more importantly dynamic as clients now ask for structures that exhibit value for money in the years to come and are not fascinated purely by design solutions that are the least costly (Dhillon, 2013).

These modifications have resulted in and underlined the significance of LCC methods to the design, construction, maintenance and operation of facilities (HMSO, 2000). The above substantiation undoubtedly indicates a disparity in existing cost estimation methods across board and stresses the urgency for re-evaluation and potential re-establishment of LCC.

However, problems such as the lack of comprehensive approaches and universal layouts for determining life cycle costs, the complexity in the incorporation of operating and maintenance approaches at the drawing and design period, the degree of the data gathering, data discrepancy and the need for an autonomously managed databank on cost, maintenance and performance of construction elements clearly associated with the non-existence of satisfactory information of LCC methods all add to the confusion.

There may perhaps also be the lack of enthusiasm and commitment from stakeholders to establish suitable techniques to resolve these difficulties (Kirkham, 2005). In actual truth, White (1991) and Kshirsagar et al., (2010) make a case for ‘performance profiles’ and particularly underscore the necessity for a comprehensive building data information approach. One may possibly claim that an overabundance and absolute difficulty of LCC methods lend negligible relevance to real-world use and deters added advancement. Practitioners on their part need to be favourably disposed to persuading potential users and building occupants into embracing a more all-inclusive methodology for maintenance and operating cost control so that measures can be introduced to help all professionals needing LCC cost profiles.

It appears worth observing how the academic and practical ‘schools of thought’ in the construction sector intend to put their houses in order if important and momentous strides are to be put to use in the broader utilisation of LCC. Therefore, the question among practitioners is how to develop a methodology for LCC that is not only robust, but more importantly dynamic. Although researchers are making significant progress in LCC methodologies, it would be fair to say that there is still no real credible standard in place, or indeed an accepted definition.

The interpretation of what would come under a LCC assessment varies between groups and individuals and this is probably why LCC is still viewed with certain mistrust. Reasons for this include time and cost considerations in implementing a LCC exercise but also a key factor that has not been addressed sufficiently is uncertainty (Olubodun et al., 2010). The construction industry has in recent times undergone a paradigmatic alteration in its attitude to the delivery of product, services and the subsequent attainment of customer satisfaction (Dhillion, 2013).

Clients at the moment desire structures that display value for money over the long term of occupation and use and are not fascinated merely in the design solutions that are the least costly. These modifications have resulted in and subsequently underlined the significance of LCC methods to the design, construction, maintenance and operation of buildings.

Rethinking Construction, the government report into the construction industry clearly promoted the necessity to construct appropriately once and always bearing in mind the economic performance and long-term costs of building assets (Potts and Ankrah, 2014). In addition, recent health and safety guidelines have assigned an exact responsibility on users and professionals to think through the conceivable perils of construction, operation, maintenance and disposal all through the entire life of the facilities.

The upsurge in the number of buildings procured under the Private Finance Initiative (PFI) and Public–Private Partnerships (PPP) routes are also noticeable drivers as they have led to users having a higher degree of awareness and taking more interest in LCC decision making (Liapis et al., 2014).

The traditional method of estimating construction projects concentrates and emphasises largely on initial capital costs. Still, with operating costs accounting for up to seventy percent of the whole cost of buildings over its whole life cycle (Boussabaine and Kirkham, 2008), this obsession and preoccupation with initial capital expenses have resulted in designs that fail to present the client with best value for money in the long term.

Furthermore, growing apprehensions with regards to the long term environmental effect of buildings have compelled professionals to take on more all-inclusive approaches and to consider more meticulously the costs incurred over the entire life cycle, from cradle to grave (Edwards et al., 2000).

As earlier mentioned, statistics have shown that commercial office buildings alone account for 20% of the carbon dioxide (CO_2) emissions in UK (Barlow and Fiala 2007), and with the UK's current building stockpile being substituted at a rate of 1–1.5% per annum (Perez - Lombard, et al., 2008), occupants of subsisting offices will need to take action in response to rising temperatures ensuing from climate change with the possibility of internal temperatures exceeding comfort echelons for over a fifth of the productive hours of the day by 2050 (Zavadskas et al., 2008).

It becomes obvious therefore that the position of sustainable commercial office buildings in strategies towards achieving a healthy and sustainable built environment cannot be over emphasised. Fortunately, LCC provides more precise evaluation and cost effectiveness of these projects on the long run than conventional economic approaches that concentrate exclusively only on initial capital costs or on maintenance associated costs in the very short term.

It can also make available essential statistics on projects for instance those procured under Private Finance Initiative (PFI), where the team of construction professionals need long-term cost estimates of service provision that they will be requested to deliver. Similarly, it presents the government with information about the expected economic burdens they will take up when the buildings revert to properties of the state.

Standard cost and value analysis methods are usually applied in measuring and evaluating the economic consequences of construction designs. Despite the fact that these methods do offer a starting point for arriving at project cost decisions, they frequently fail to take cognisance of most factors which could well alter the real project cost. The current techniques also fall short of taking into account risk approximation approaches and formal decision making procedures in carrying out a cost benefit analysis. Investing in constructions is long-lasting and as an aftermath consists of some measure of uncertainty with regards to the running and maintenance costs during the entire life of the structures.

Thus, the existence of considerable improbability and doubt regarding cost and time evidence of an LCC study would have mind blowing implications on final results and consequently have minute bearing on subsequent decisions made. Addressing risk and improbability in LCC ought to be the basis of the professionals' method to LCC decision making. The imprecision of prediction has remained a major issue with construction practitioners, therefore, making available information and measuring the risk components would make professionals more convinced with the information that LCC delivers.

Hence, the application of LCC techniques to these existing buildings has not been sufficiently attempted. Notwithstanding, it is clear that LCC techniques can inform the analyst with the detailed knowledge required to make effective future investment and budgetary decisions. Existing practices do not facilitate a holistic assessment of the total cost ownership of commercial office buildings, nor do they take into account these buildings in the assessment of operational costs.

In response to this, it is argued that what is required is a framework within which these concepts can be interfaced, enabling the analyst to forecast future operational and maintenance costs mutually before integrating quantitative risk assessment and economic performance measures. Hence, this research gives an account on a research to develop a risk integrated generic approach for facilitating the prediction of operating and maintenance costs of two existing UK buildings using Artificial Neural Networks (ANN).

1.2 AIM AND OBJECTIVES OF THE RESEARCH

The aim of this research is to develop a framework that would provide a more reliable, dynamic, robust and easy to use LCC estimation tool for sustainable commercial office buildings.

OBJECTIVES

The objectives of the proposed investigation include the following:

1. To explore the level of application and awareness of LCC in the construction industry.
2. To critically analyse the impact of life cycle costing on sustainable commercial office buildings.
3. To investigate the suitability of LCC for calculating the whole life cost of sustainable commercial office buildings with emphasis on the barriers (technological and non-technological) and drivers (economic and social) of these buildings.
4. To explore a set of economic performance measures for the life cycle costing of sustainable commercial office buildings.
5. To develop a framework for accurately predicting historical costs of sustainable commercial office buildings.

1.3 THESIS ORGANISATION

Chapter One

This chapter provided background information for the research. It explained why the research was undertaken. Research aim and objectives and the methods adopted were highlighted.

Chapter Two

The chapter discussed different definitions of LCC for sustainable commercial office buildings as there appears to be significant confusion regarding the definitions that have been published over the past decade as they tend to show a lack of commonly held acceptance of what life cycle costing actually is. This chapter built a theoretical foundation for the research by reviewing literature and previous research on LCC cost and non-cost elements. Finally, it explored the level of awareness of LCC in sustainable commercial office buildings.

Chapter Three

The chapter discussed the meaning and types of sustainable commercial office buildings. It also examined the benefits of life cycle costing applications on sustainable commercial office buildings from the application and limitation perspective.

Chapter Four

The chapter investigated the suitability of LCC for calculating the whole life cost of sustainable commercial office buildings with emphasis on the barriers (technological and non-technological) and drivers (economic and social) on these buildings.

Chapter Five

Following the review of literature in chapters 2, 3 and 4, this chapter provided a summary of the study method implemented for carrying out this research.

Chapter Six

This chapter presented the results of the pilot and main survey findings regarding LCC awareness and related actions, the suitability of LCC with emphasis on the drivers and barriers of sustainable commercial office buildings and the application and limitations of LCC in sustainable commercial office buildings based on the outcome of the questionnaires.

Chapter Seven

Chapter seven was devoted exclusively to the development of a framework for appraising sustainable commercial office buildings. This chapter also applied developed mathematical models for modelling historical cost data and economic performance measures.

Chapter Eight

The chapter described the validation process and the methodology adopted in the validation procedure.

Chapter Nine

This chapter reviewed the study and stated the conclusions. Conditional statements were made with respect to the use of the conceptual model in the construction industry. Limitations of the research and the likelihood of additional study were also made at the end of the chapter.

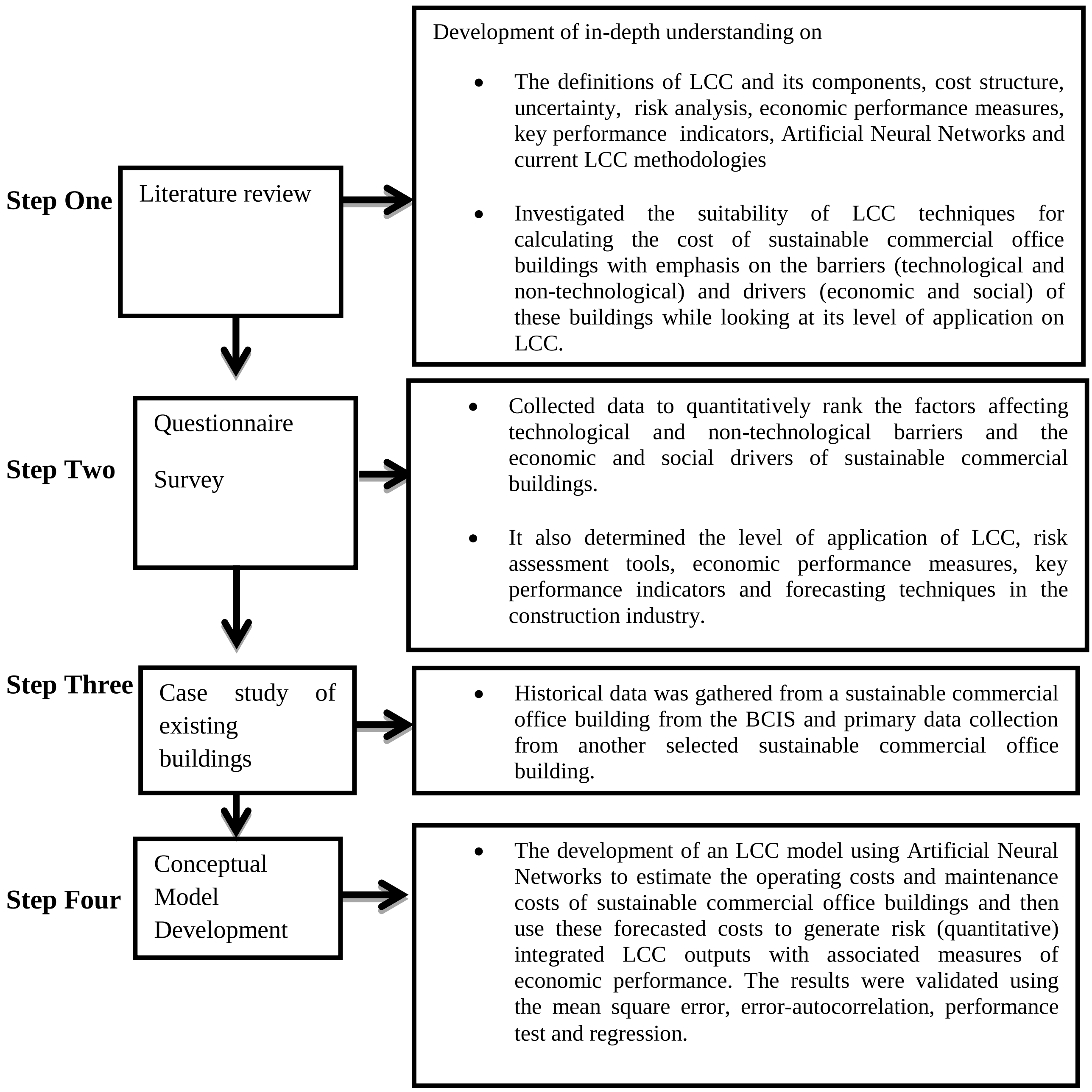


Figure 1.1: Methodological procedure

CHAPTER TWO

LCC ANALOGY AND ITS APPLICATION IN THE CONSTRUCTION INDUSTRY

2.0 INTRODUCTION

This chapter discusses different definitions of LCC as there appears to be significant confusion regarding the definitions that have been published over the past decade as they tend to show a lack of commonly held acceptance of what life cycle costing actually is. Working definitions integrating sustainable commercial office buildings are also proposed in this chapter.

Similarly, the chapter explores the cost and non-cost elements of LCC as it relates to sustainable commercial office buildings as views differ as to what costs need to be incorporated. Hence, the need to build a theoretical foundation for the research by reviewing literature and previous research on these LCC elements which include the initial capital costs, operating costs, maintenance costs, disposal costs, discount rate, service life, economic performance measures, key performance indicators, uncertainty and risk analysis. It is important to explore these concepts in the bid to develop an industry accepted framework for life cycle costing.

Finally, the chapter explores the level of application and awareness of LCC in the construction industry. This is because the knowledge of the state of real-world implementation of LCC within the engineering and construction sector is a crucial pointer to its validity and usefulness and its subsequent application to sustainable commercial office buildings.

2.1 THE CONCEPT OF LIFE CYCLE COSTING IN SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

The life cycle perception can be illustrated in many subjects. Living organisms exhibit a life cycle from cradle to grave. Firms have from formation to liquidation of stakes in the business. Buildings also have a life cycle from the conception of the idea eventually to its disposal. These buildings generate a lot of wastes and pollution and it is acknowledged that a more ecologically responsible method to building design and construction, application and disposal and recycling is essential.

Particularly, commercial office sector buildings are responsible for ten percent of the UK's greenhouse gas emissions (Ozer, 2014). Hence, the advent of sustainable commercial office buildings as these buildings use a carefully integrated design strategy which minimise energy use, maximise daylight, have a high degree of indoor air quality and thermal comfort, conserve water, reuse materials and use materials with recycled content, minimise site disruptions, and generally provide a high degree of occupant comfort throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and demolition (Kozlowski, 2003).

2.1.1 DEFINITION OF LIFE CYCLE COSTING IN SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

A life cycle costing is an economic estimation method that evaluates the entire cost of a building over its operating life, including initial capital costs, maintenance costs, operating costs and the ultimate disposal of the asset at the end of its life (Flanagan et al., 1989). Kirk and Dell'Isola (1995) referred to LCC as a management tool and a decision making tool; a management tool because it can be used to forecast the total costs that will be incurred during a building's life and a decision making technique because it can be used to pick amongst alternate projects.

What makes LCC more significant is because it is central to understanding buildings costs; it is also a treasury green book requirement and Private Finance Initiative (PFI) in the UK. Similarly, it offers the government with information on the expected financial obligations they would inherit when the buildings reverts to that of the state. The crucial fact to be established from these definitions is that life cycle costing extrapolates existing and future costs to convey both as a base for arriving at choices.

In other words, an economic comparison is made by considering not only the initial capital costs of the project, but also the ensuing running costs and eventual replacement or disposal costs. The LCC process can also offer information, for instance, in the calculation of the economic feasibility of buildings, in the recognition of the cost drivers and cost efficiency enhancements and in appraisals of diverse approaches for product asset and review (Ravemark, 2004). Life cycle costing is time and again disregarded when it comes to sustainable commercial office buildings as no standard definition or framework for design is existent (Wu and Low, 2010).

Besides, many developers ignore LCC information as it is believed not to be actual and grounded only on approximations while capital cost is more “real”. Usually life cycle costing will be ignored because most developers are not constructing in order to manage the buildings themselves. Instead, they are considering short term financial profit and will dispose the building on completion (Zhou and Lowe, 2003). This is one of the main shortcomings of LCC with regards to sustainable commercial office buildings as possible decisions are made more on short term profit rather than long term financial benefits.

The techniques for life cycle costing have been available for some time but the impact on decision making in sustainable commercial office buildings is still patchy at best (Kozlowski, 2003). Similarly, it is clear that all these LCC definitions integrating sustainable commercial office buildings fail to consider risk and uncertainty. Dealing with risk, uncertainty and economic performance measures should be fundamental to new approaches of defining sustainable commercial office buildings particularly in today’s extremely unpredictable business environment.

Hence, more appropriate definitions incorporating these concepts are discussed in subsequent paragraphs:

LCC refers to a method of economic estimation which adds up all the costs accruable to sustainable commercial office buildings with emphasis on risk assessment and economic performance measures. Finally, it represents an economic and stochastic assessment of sustainable commercial office buildings bearing in mind all important costs of possession, maintenance and operation over the economic life of each decision, expressed in present terms and with the application of risk assessment techniques to quantify risk and uncertainty.

2.1.2 THE ELEMENTS OF LIFE CYCLE COSTING FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

From the definitions of LCC earlier mentioned (see section 2.1.1), it becomes obvious that the LCC of sustainable commercial office buildings consist of all costs expended in its respect, from procurement until the end of its life. Hence the need to group all elements into separate categories (cost breakdown structure) as this enables the data of sustainable commercial office buildings to be adjusted according to the complexity of the project. Flanagan and Norman (1983) along with many other researches devised LCC category systems in an attempt to standardise the data collection mechanism. Categorisation of the data also enables trade-offs to be identified, which can be used to optimise LCC.

LCC takes account of the assembling and consideration of the addition of all costs credited to a building throughout its life cycle. These costs, described as LCC, happen at various periods all through the life cycle phases, and result from all expenditures associated with numerous undertakings that are accomplished. This could consist of initial capital costs, operating costs, maintenance costs and end of life costs.

Despite the fact that these costs take place all through the life cycle, it has been observed that time and again, the greater part of costs will come from the ownership actions; in particular instances as much as eighty percent of the costs will be incurred all through the working life of the buildings (Kawauchi and Rausand, 1999). The essential viewpoint is that the structure should be drawn up in such a way that the researcher can carry out the necessary LCC analysis to achieve the purpose of the project (Peca et al., 2012).

Hoar (1988) also classified costs as capital costs, financing costs, operation costs, maintenance costs, occupancy costs and residual costs. The categories were further grouped under initial, annual, intermittent and residual costs. Initial costs are those associated with the capital required for the scheme. They include land acquisition, construction costs, professional fees, furniture and equipment and commissioning of the building project.

Annual costs occur throughout the life of the investment and include energy, cleaning, rates, insurance and annual maintenance costs. Intermittent costs include costs such as the redecoration of the exterior and interior, the maintenance of air-conditioning and the rewiring of the electrical installation at appropriate periods. Previous categorisation of costs however failed to integrate non-cost elements into sustainable commercial office buildings as subsequently achieved in this thesis.

2.1.2.1 INITIAL CAPITAL COSTS

These costs are incurred before the occupation of the asset. All initial costs are to be summed up to the LCC total at their highest value (NIST, 1995). The initial capital costs of the project tend to be the ones considered mainly by the client and design team in the feasibility studies of a building project and in the absence of a LCC assessment, the value is most likely to determine whether the project will commence or not. It has a lot to do with project planning, purchase and preparation of asset, amount involved in generating funds and feasibility and viability appraisal examinations. The initial capital costs of a particular project can be categorised into the following sub-groups (Woodward, 1997):

- Land acquisition and associated fees.
- Design team fees and associated costs.
- Construction price.

Capital costs nearly always account for a significantly high proportion of LCC, especially in sustainable commercial office buildings. Although many practitioners are now moving towards a LCC approach, capital costs still account for a high proportion of projects.

2.1.2.2 OPERATING AND MAINTENANCE COSTS

Maintenance costs are programed and anticipated costs involved with the running of the structures. A very good illustration of a typical maintenance cost is the cost of scheduled repairs for building components like sealing of the building's roof penetrations. On the whole, all of these costs are concerned with building facilities and utilities, it is therefore imperative to consider these costs in their holistic form. At the crux of the LCC perception are operating and maintenance costs (see table 2.1). The notion of encompassing the running costs into the overall decision making process will be generally acknowledged when assurances can be made about the precision of the estimates. Operating costs of a building asset can include fuel, rates, insurances and similar on costs, security etc. The estimation of these costs is likely to be based upon the performance of similar assets (Newton and Christian, 2006).

Table 2.1: Data Structure for Standardised Method of Life Cycle Costing for Construction Procurement (SMLCC)

Maintenance Costs	**Operating costs**
Major replacement costs	Operation costs
Subsequent refurbishment and adaptation costs	Utilities costs
Redecorations	Administrative costs
Minor replacement, repairs and maintenance costs	Overhead costs
Unscheduled replacement, repairs and maintenance	Client definable costs
Client definable costs	Cleaning costs
Grounds maintenance	Taxes (if applicable)

Source: BCIS (2013)

2.1.2.3 RESIDUAL COSTS

Residual costs are the net values of structures at the termination of the LCC analysis period. Better put, residual value is the worth of the assets at the end of the building life. It is dependent upon a number of factors, but the site value will often be a significant component. The residual value is different from other imminent expenditures because these values can either be positive or negative.

Zero residual value implies that there is no worth connected to the building at the completion of the life cycle. This unusual occurrence happens when the anticipated use of the construction ceases side by side with the termination of the study phase, the client cannot dispose the structure, but can however give up the structure for free. Should it be decided that the building should not continue to operate for whatever reason, such as those listed above, then costs will be incurred as a result of the subsequent decommissioning process. This can include demolition, scrapping or selling the building and its land.

2.1.2.4 SERVICE LIFE OF SUSTAINBLE COMMERCIAL OFFICE BUILDINGS

This is the time frame during which possession, maintenance and operations expenditures are usually assessed. Characteristically, the study period can range from ten to eighty years reliant on the intensity of use, user's priorities, the solidity of the client's schedule and the envisioned whole life of the asset. Even though the length of the study period is time and again a reflection of the projected life of an asset, the study period is more often than not shorter than the proposed life of the asset.

The NIST (1995) splits the study period into two categories: the planning/building phase and the service period. The planning/construction period is the period from the conception of the idea to build till the time the facility becomes functional. Building life is influenced by obsolescence. Almost all forms of obsolescence are related to economic considerations. Dhillon (2013) identified six different forms of obsolescence and life namely:

● Physical

● Economic

● Functional

● Technological

● Social

● Legal

Physical obsolescence is reached when a building is likely to collapse while physical life is the time during which the building is expected to last without need for major rehabilitation or repair. Economic obsolescence is achieved when occupation of the building is not considered to be the least cost alternative of meeting a particular objective. A good example of a building reaching the end of its economic life would be one used as a driving school office located in a good retail position such that soaring land values render it uneconomic in terms of its present use. The economic life refers to the time when the building becomes economically unfeasible and a lower cost alternative is available.

The functional life of a building ends when it stops to operate for the same reason as that for which it was constructed. An example of this type of change in use is a cinema that has been converted to a snooker hall. The technological life of a building finishes when it is no longer superior to the alternatives. An example would be where a high-tech computing or electronic company for prestige and operational reasons needs an office that can accommodate advancing technology. When a building can no longer do this due to physical constraints, it reaches the end of its technological life. It also refers to the time when new technology controls replacement owing to availability of a greater substitute.

The social or legal life ends when popular or legal obligations instigate a replacement for motives save for economic considerations. The forecasting of component service life is a very essential feature in LCC calculation. Existing methodologies currently in use include the factor method in determining the service life of buildings (Boussabaine, 2013) but this relies on a significant element of subjectivity. More complex methods of service life prediction have also been proposed such as the use of Markovian Chains (Wirahadikusumah and Abraham, 2003) and Artificial Neural Networks (Boussabaine et al., 1999) and failure models (Lair and Chevalier, 2002).

2.1.2.5 DISCOUNT RATE

The life-cycle cost method is involved with the time flow of costs and revenues that stream all through the life of a construction project. In order to use life-cycle costing techniques for construction projects, assumptions may have to be made about the level of future inflation and discount rates and the degree of risk associated with the investment. It is the real long term cost of borrowing the monies in the market place. In other words, it is the real rate at which the investor hopes to generate the funds required for the construction.

In the light of these assumptions, a decision can be made on the appropriate discount rate to be used for the life-cycle cost appraisal. The main drawback in appraising projects over time is that these funds have time value. As 'money today' produces a different value from 'money tomorrow', the discounting technique has to be adopted to convert imminent flows of money to present values. The NIST (1995) interprets the concept of discount rates a mile ahead by categorising them into two kinds: real discount rates and nominal discount rates. While the nominal discount rate does not consider the rate of inflation, the real discount rate on the other hand takes account of the rate of inflation.

The usage of whichever discount rate in its equivalent present value computation obtains the similar outcome. As seems to be the case with the many aspects of LCC, there appears to be a plethora of methodologies (many confusing and inappropriate) as to how the discount rate ought to be derived.

Some possible explanations of how the discount rate should be calculated are suggested by Woodward (1997), Flanagan and Norman, (1983). However, no research has successfully been able to arrive at a reasonable discount rate for LCC calculations. Practitioners will find it considerably simpler to calculate imminent costs and values if they are assessed at today's prices and a rate of discounting is adopted which implies inflation of future costs and values. This procedure considerably simplifies the methodology and is therefore recommended.

While it is observed that there are universal parameters in the choice of a suitable discount rate, there is an urgent necessity for more standardised and comprehensive methods in choosing the discount rate to be applied in the study. Ashworth (1993) stated that the discount rate should be selected by an appropriate and trained professional who is experienced in accountancy or any financial discipline as in this field. In this research, it was considered prudent to solicit the advice of professionals in the building economics industry to determine the discount rate.

2.1.2.6 RISK AND UNCERTAINTY

Any building cost estimate or forecast will involve the client in a degree of risk exposure (Baccarini, 2004). Before any decision to invest capital in a building project or existing infrastructure is taken, it is essential that all stakeholders in the policymaking practice are fully aware of the risks that are inherent. All too often in investment decision-making, risk is either ignored or dealt with in an arbitrary fashion, such as adding a nominal contingency value on to the forecasted cost of the investment decision. Many now see that such an imprudent way of dealing with risk is unacceptable and that a more methodological approach is required.

The weightiest improbabilities normally take place in the early stages of a project, a time also when investment decisions of the maximum effect are made. However, the risks associated with future cost forecasting carry similar risks. Likewise, in post occupancy cost analysis, the risks in future capital spending and LCC forecasts need to be quantified. Ideally, all risks should be assessed and accounted for at the outset of the analysis, and given the continually changing nature of risk; the management techniques used should be dynamic in their nature.

Yet, the real-world implementation of the management of risk is not manifesting in this research advancement (Thunnissen, 2003). Conversations with industry based cost appraisal professionals in the course of conferences and seminars have revealed that the concept of uncertainty is under represented in the industry particularly where decision-making is involved (Langridge, 2010). Occasionally when uncertainty is deliberated upon in the information encapsulating activities, it is hardly ever incorporated in the final decision (Kishk et al., 2003).

Nevertheless, the provision for improbability in cost appraisal and forecasting is yet to be addressed. A main feature of the cost estimation and forecasting method is the gathering and explanation of important information as LCC incorporates an enormous bulk of ambiguity, data inadequacy, unpredictability and vagueness. Merely evaluating risk and subsequently controlling it is not adequate (Ward & Chapman, 1995). Formal techniques of risk analysis are required to make certain that some kind of regularity and standardisation is achieved.

However, most of these methods are usually difficult, complicated and costly and therefore the application of these methods for numerous projects is exorbitant. The absence of understanding and misgivings as to appropriateness within the built environment professions has also been recognised as explanations for the sluggish take up (Zou et al., 2006).

There are three ways of appraising risk and uncertainty (see table 2.2); they are the deterministic techniques which evaluates the influence on project results of altering one undefined significant value or an array of values at a time and the specialist ascertains the level of uncertainty on a biased underpinning while quantitative approaches are established on the supposition that no lone value can sufficiently characterise the extensive possibility of likely results of an uncertain investment (Baker and Reid, 2005).

Instead, a great amount of substitute results needs to be well-thought-out and each likelihood should be complemented by a concomitant possibility from a probability distribution, supported by a numerical and arithmetic examination to quantify the level of uncertainty (Hinge et al., 2006). The qualitative approaches vary from the former methods as they utilise qualitative methods to resolve risk and improbability in LCC examination.

Table 2.2: Methods for handling improbability and risk in the economic assessment of building investments

Deterministic	**Qualitative**	**Quantitative**
Conservative benefit and cost estimating	Risk matrix	Input estimates using probability distribution
Break-even analysis	Risk registers coefficient of variation	Mean–variance criterion
Risk-adjusted discount rate	Event trees (qualitative)	Decision tree analysis and Fuzzy sets theory
Certainty equivalent technique	Likelihood/consequence	Simulation (Monte Carlo/ Latin hypercube simulation)
Sensitivity analysis and Net present value	Risk scoring	Mathematical/analytical Technique
Variance	Brainstorming sessions	Artificial intelligence

Source: Marshall (1999).

Very simply, risk analysis constitutes an essential process in a life cycle costing exercise. It allows the decision-maker to answer a series of 'what if' questions with respect to the various options under consideration. Their practical implementation has been considerably eased now that most LCC is performed by computer analysis (Brandon, 1987).

Still, regardless of the quality of existing data, LCC studies continually contain rudiments of indecision for the reason that part of the input data needs to be clear on the underpinning of various appraisals and suppositions concerning the progression of costs in the long run. It has been acknowledged that probability approaches are valuable in coming to grips with improbability in cost models (Nachtmann and Needy, 2003).

The lack of risk and improbability assessment methods would result in grave restrictions to the use of the LCC methods, as cost computations would be inexact, with non- manageable values not being considered. Applying these procedures and steps would augment the accuracy of cost forecasts, accelerating the integration into the examination of unanticipated happenings all through the life cycle of the building. If the LCC model can introduce some quantitative method of assessing the probabilities of uncertainty, then this kind of barrier can be overcome. This research reflects the concerns noted by some academics that financial risk attracts less attention than other forms such as legal, technical and health (Dikmen et al., 2004)

2.1.2.7 ECONOMIC PERFORMANCE MEASURES

It is merely insufficient to estimate a cost value devoid of offering the forecasters or users with the capacity to obtain conclusion from the outcomes. The need for a variety of economic performance methods in cost examination is a characteristic of organisational control. Organisational control refers to a situation in which firms make certain that they are charting the course of policies, tactics and activities, which will allow it to realise its aims.

Using economic performance measures helps to make available the information that is required for building performance. Therefore, economic performance methods in LCC are especially imperative for users to appraise and distribute recognisable value from initial costs and maintenance costs to important shareholders in the life-cycle of an asset. This will permit the concern of several shareholders' goals in the calculation of the LCC implementation and execution of an asset over a stated time period (Boussbaine, 2013).

The procurement of construction assets comprises of a diversity of users who agree on substitutes that generate capital and on-going costs all through a building's life. These initial capital costs produce value for several users and possibility for earnings to the clients which ought to be lasting over the life-cycle of the facilities.

Common conventional investment evaluation methods which emphasise on cash flows signified by the costs and anticipated proceeds of a development discounted to a general base period fail to reveal the entire value of capital outflow alternatives which consist of intangible and non-monetary remunerations along with decline of imminent costs and monetary incomes (Plenty et al., 1999).

More often than not, these economic measures are not authenticated by any risk assessment study. As a result, economic performance measurement in LCC is very vital for decision makers to assess and distribute recognisable value from initial capital and operating costs to appropriate shareholders in the life-cycle of assets. This research is primarily aimed at moving away from the traditional approaches used in LCC with regard to data output. Most systems that are currently in use return a single LCC value as output (Leicester University, 1999).

However, it is argued in this thesis that a more appropriate measure of the cost effectiveness of the sustainable commercial office buildings is called for. In order to satisfy this, the thesis presents the methodology for the use of a set of economic performance measures (see section 7.2.2.8). This enables the analyst to acquire a transient insight into how the building is performing without having to collate and individually analyse LCC outputs.

These performance measures can then be used to identify efficiently where changes in investment need to be made. Techniques such as total annual capital charge, the benefit/cost ratio (BCR), annual sinking funds (ASF) and internal rate of return (IRR) can be used. However for the purpose of this research, the Income/Cost ratio was used because it is the only indicator that measures overall economic execution and operation in relation to the funds put in the facilities (Li, 2005).

2.1.2.8 KEY PERFORMANCE INDICATORS

This is the assessment and evaluation of performance connected to a LCC cost centre on a large scale. The figures made available by a KPI can be employed to ascertain how the running costs of managing of facilities equate with the existing standard and consequently can develop a main element in a firm’s step in the direction of best practice and value for money.

KPIs can take a range of perspectives which reveal the user’s curiosity. KPIs make up aspects of numerous methods to high-quality financial management and procedures; however, it is imperative to mention that KPIs should not merely be looked upon as a makeshift or temporary tool. The attributes of KPIs implies that they must be repeatedly revised and the information gathered from them applied efficiently to improve output and economic effectiveness. This thus suggests the conceivable usage of KPIs in LCC. Consequently, KPIs is a unique method and hence, a structure ought to be present where these KPIs are frequently revised and fine-tuned if crucial. The ratio of maintenance to capital cost (ROM) and the ratio of operation to capital (ROC) cost were used in this research to ascertain how the running costs of managing of facilities equate with the existing standard.

2.2 LEVEL OF APPLICATION AND AWARENESS OF LIFE CYCLE COSTING IN THE CONSTRUCTION INDUSTRY

Prlngle (1975) and Lindholm and Suomala (2005) believe there is substantial indication to advocate that both private and public sectors make procurements of capital items merely on the basis of initial acquisition cost. With the prominent exclusion of military usages, limited assets appear to be evaluated on the basis of their entire lifetime costs (Schade, 2007). It was discovered that most organisations do not carry out LCC analyses at the procurement phase of a physical asset's life, nor do they gather all costs over their lifespan (Kumaran et al., 2001; Korpi and Ala-Risku, 2008).

Ferry and Flanagan (1991) stated that LCC had earned acceptance in the construction industry, but that real-world application of it had decelerated. Ferry and Flanagan’s opinion is similarly buttressed by Aouad et al., (2003) who define it as a method that “persists to suffer in oblivion"; and by Bakis et al, (2003) who assert that LCC has attained restricted use so far inspite of its significance.

However, studies by El-Haram et al., (2002) believe that the use of total LCC within the construction industry is rapidly snowballing while Lindholm and Suomala, (2004) stated that the implementation of LCC thinking has been sluggish although the public sector has been an important supporter for LCC calculations (Woodward, 1997).

Kirkham et al., (2004) subsequently mention that private finance initiatives (PFI) and public-private partnerships (PPP) are main contributors to the improved application of LCC. This is because the risks, long-term financial implications and contractual partnerships all rest on the contractor. It is thus the contractor's concern to reduce the entire life cost of the facility. Hunkeler and Rebitzer, (2003) and Guinee et al., (2010) mentioned that the snowballing worldwide importance on sustainable development is related to the LCC of buildings. They were of the opinion that this movement will be a foremost growth driver for the application of LCC in years to come.

Given the capacity of LCC to capture essential information associated with the management of an organisation's facilities and the enhancements in decision making competence which it offers, it is rather shocking that these achievements are not replicated in reality where there is an obvious lack of consideration paid to LCC.

Similarly, national surveys have revealed that there are inconsistencies regarding the preparation of cash flow forecasts at the procurement phase, and then discounting the values back to the present using discounted cash flow methods as these methods are not usually adopted (Wong et al., 2005). Argenti (1976) reiterated, "Certain executives feign ignorance to what cash flow is; one can barely envisage they would be capable of discounting it".

Undeniably, numerous analyses notable among is the Building Research Establishment (BRE) in the United Kingdom recognised an important absence of LCC implementation and enumerated numerous likely explanations for this (Ashworth and Larkham, 2013). Prominently, the absence of common and standard formats for calculating LCC was recognised as a main concern (Boussabaine, 2013). Since then, several research works have gone into LCC and its subsequent applications in different sectors of the economy. However, there is still a lack of an up to date knowledge on the level of application of LCC (Ashworth, 2013).

2.3 SUMMARY OF CHAPTER

Sustainability is now widely recognised as a major priority in all sectors of the economy and the building sector is especially important because it is a major consumer of both materials and energy during and after construction. Sustainable commercial office buildings focus on reducing environmental problems and issues associated with built environment and construction activities while maximising the potential benefits to the society and economy. In the process of creating a building, the early decisions have the greatest impact, hence the need for life cycle costing.

This chapter looked at LCC definitions as it relates to sustainable commercial office buildings and it is clear that they all fail to account for the presence of risk and uncertainty. Novel definitions were also suggested as dealing with uncertainty should be fundamental to new approaches of defining sustainable commercial office buildings, this is vital if it is to become a widespread investment decision-making tool. The lack of risk and uncertainty appraisal techniques would cause stern restrictions to the use of the LCC methods, as cost calculations of sustainable commercial office buildings would be inaccurate.

This chapter, while examining the various definitions of LCC as it relates to sustainable commercial office buildings has put down the necessary and important platform for the examination of the various cost and non-cost elements of LCC. Finally, it was deduced that LCC has become a main concern in the whole cost representation, but then has not been integrated in the decision making process to a similar magnitude as the level of application of

LCC is low and thus is an academic instead of a practical tool because of the absolute complexity of many models and the poor quality of data.

CHAPTER THREE

THE BENEFITS OF LCC APPLICATIONS ON SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

3.0 INTRODUCTION

Sustainable commercial office buildings provide an ethical and practical response to issues of environmental impact and resource consumption. They involve a blend of exceptional design with effective strategies for marketability and meeting tenant requirements. This chapter further discusses the meaning of sustainable commercial office buildings and explores its different types.

Similarly, the advantages of applying life cycle costs on these sustainable commercial office buildings are undeniable as it allows researchers consider the long-term effects of decisions and provides the implications of cost on short-sighted economies. The importance attached to applying LCC methods for economic assessment of investment decisions is enormous. Still, limitations occur at a number of stages: improbabilities regarding the long term predictions applied in getting appropriate input data and non-existence of knowledge in applying LCC methods.

Nevertheless, the LCC perception is showing to be most suitable throughout the design stage where the prospects of cost reductions associated with operation and maintenance are huge. Hence, the need to critically assess the benefits of life cycle costing on sustainable commercial office buildings from the application and limitation perspective.

Finally, this chapter gives an overview of existing LCC models with emphasis on Artificial Neural Networks and its applications in sustainable commercial office buildings as there are plethora of models that are involved with the precision of construction performance simulations with respect to predicting a building's life cycle costs.

3.1 THE CONCEPT OF SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

Sustainable commercial office buildings are healthy facilities designed and built in a resource efficient manner using ecologically based principles. It uses resources efficiently; maximises the use of local building materials and minimises demolition and waste in their production or disposal. There is a strong demand for high quality sustainable commercial office space, especially in city centres. Corporate headquarters for banks and other high profile companies require that buildings are built to high architectural and environmental standards. These buildings can be classified based on building grade, location and accreditation.

3.1.1 CLASSIFICATION BASED ON BUILDING GRADE

Grade A commercial office buildings are brand new or have recently experienced a thorough refurbishment within the last fifteen years. These buildings are considered the best of the best in terms of construction and location. Grade B sustainable commercial office buildings refer to properties that fall below the Grade A remit. These buildings might have high quality construction, but with a less desirable location. They are usually maintained and finished to a good or fair standard, with adequate facilities. Materials used in the construction of the building are functional but are not considered to be the highest quality. Finally, Grade C commercial offices provide functional space.

3.1.2 CLASSIFICATION BASED ON LOCATION

These could be Central Business District (CBD) and Suburban commercial office buildings. Central Business District (CBD) office buildings are located in the central business district are in the heart of a city. These buildings would include high-rises and skyscrapers. Suburban commercial office buildings generally include midrise structures of 80,000-400,000 square feet located outside of a city centre.

3.1.3 CLASSIFICATION BASED ON ACCREDITATION

Building accreditation is a prerequisite for rating sustainable commercial office buildings. In the UK, they include BREEAM, Environmental Performance Certificate and Passivhaus.

3.1.3.1 BREEAM

BREEAM (Building Research Establishment Environmental Assessment Methodology) is the world's longest established and most widely used method of assessing, rating and certifying the sustainability of buildings. More than 250,000 buildings have been BREEAM certified and over a million are registered for certification, many in the UK and others in more than fifty countries around the world (BREEAM, 2013).

Using independent, licensed assessors, BREEAM assesses scientifically based criteria covering a range of issues in categories that evaluate energy and water use, health and wellbeing, pollution, transport, materials, waste, ecology and management processes. Sustainable commercial office buildings are rated and certified on a scale of 'Unclassified', 'Acceptable', Pass', 'Good', 'Very Good', 'Excellent' and 'Outstanding'.

By setting sustainability benchmarks and targets that continue to stay ahead of regulatory requirements and by encouraging the use of innovative means of achieving these targets, BREEAM drives greater sustainability and innovation in the built environment.

3.1.3.2 ENERGY PERFORMANCE CERTIFICATE

An Energy Performance Certificate (EPC) is required for every commercial building when it is constructed, sold or let. This certificate gives information about the energy efficiency of the building to owners, prospective buyers and tenants. An Energy Performance Certificate (EPC) sets out the energy efficiency grade of a commercial building. Energy Performance Certificates (EPCs) are required when a commercial building over $50m^2$ is built, sold or rented. The EPC has two parts namely a graphic rating and a recommendations report.

The rating is calculated on the performance of the building and its building services (such as heating, lighting and air conditioning) rather than the appliances within it. This is known as an asset rating, that is, how energy efficient the building has been designed and modified. The certificate also gives an indicator of the potential rating of the building if all the cost-effective measures suggested in the recommendations are carried out. A building's rating will vary depending on the age, location, size and condition of the building.

3.1.3.3 PASSIVHAUS

Passivhaus buildings provide a high level or occupant comfort while using very little energy for heating and cooling. They build with meticulous attention to detail and rigorous design and construction according to principles developed by the Passivhaus Institute in Germany and is certified through an exacting quality assurance process. These processes include the Passivehaus Planning Package (PHPP) which is used to inform the design process and to access or verify compliance with the Passiv standard; a certification for designers and a certification process for Passivhaus buildings. It thus gives a robust method to help the industry achieve the 80% carbon reductions that are set as a legislative target for the UK.

3.2 APPLICATION OF LIFE CYCLE COSTING IN SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

It has long been acknowledged that it is unacceptable to appraise the costs of projects only on the basis of their initial costs. LCC is an estimation method that takes cognisance of all costs that arise all through the life cycle of a development, such as initial investment costs, subsequent operating and maintenance costs, salvage and resale value (Kishk and Al-Hajj, 1999). The method is mostly applied to enable effective selection among project options. It is best carried out during the initial feasibility, practicability and conceptual design where most, if not all, choices are subject to deliberation. According to Norman (1990), the several areas of application of LCC can be identified:

(i) The commissioning of new buildings to meet a perceived market demand.

(ii) Investment in new capital equipment to achieve specific cost reduction targets.

(iii) Modification of design to improve reliability and performance.

(iv) Decisions on the optimal time to replace ageing facilities.

Akhlaghi (1987) also applied LCC analysis and decision-making tool to buildings in four different contexts:

• In trading-off exercises between capital and revenue expenditures - often as a useful tool for presenting a case for higher capital expenditure and relaxation of cost limits in favour of better gains in terms of revenue, in organisations where such an initiative is politically and financially plausible.

• In comparisons between different design solutions that might provide equivalent baseline performance according to conventional criteria.

• In presenting a possibility for investigation into the inter-relationship between the performance of a building and its running costs or cost-in-use specification. Costs-in-use is not concerned with forecasting, it is a way of defining and quantifying required performance which can then be estimated.

Haworth (1975) summarises the benefits of LCC into four simple ideologies:

1. LCC must be used at all decision stages during the design process.

2. LCC must comprise of the operation costs within a building.

3. The logical procedure must encompass all decision-related factors.

Typically, LCC can be applied throughout the following main phases of the life cycle of any facility:

a) Preconstruction which involves project investment and planning.

b) Design and construction at practical, system and comprehensive component stage.

c) During occupation (cost-in-use) and post-construction.

d) Disposal (end-of-life).

In sum, LCC is a very adaptable management tool as it enables both short-term monitoring and long-term planning of costs to be carried out. LCC tends to change depending on the context it is applied. It may integrate several cost elements, assemble these elements in diverse paths, or even ignore specific cost elements that are considered needless for the specific examination. The other advantages of LCC are tabulated in Table 3.1.

Table 3.1: Applications of LCC in sustainable commercial office buildings

Author	**Applications of LCC**
Barringer and Weber (1996)	Affordability studies: Calculates the effect of a building's LCC on long-term budget estimates and maintenance outcomes.
Barringer and Weber (1996)	Design trade-offs: Affects design characteristics of buildings that directly influence LCC.
Barringer and Weber (1996)	Source selection studies: Compare projected LCC among rival systems.
Barringer and Weber (1996)	Supplier's sales strategies: Can combine precise equipment grades with overall operating knowledge and end-user let-down rates using LCC to sell for greatest benefits instead of just selling on the characteristics of low initial cost.
Barringer and Weber (1996)	Repair level analysis: Measure maintenance costs instead of using rules of thumb such as "maintenance costs ought to be less than a certain percentage of the capital cost of the equipment."
Horngren et al., (2003)	To deliver cost visibility at distinct product level in upstream and downstream sections. Usually, upstream and downstream cost information is provided in a combined manner as a result of financial accounting conventions.
Horngren et al., (2003)	Business risks are spotted early on as LCC indicates the cost occurrence of products therefore providing a yardstick for easier cost and revenue forecasts.
Griffin, (1993)	It also indicates cost category. It achieves this by ensuring that downstream and upstream cost information is stated in episodic and combined amounts.

Gluch and Baumann, (2004).	The continuous support of management decision making from the initial acquisition to disposal of the asset.
Gluch and Baumann, (2004).	LCC identifies the cost drivers. These drivers influence LCC thus permitting adequate management.

Source: Barringer and Weber (1996), Horngren, Foster and Datar (2003), Griffin (1993) and Gluch and Baumann (2004).

As recognised by NATO (2009), there is extensive consciousness on the subject of LCC, there are however no actual solutions yet to be recognised. This invariably reflects the difficulty and significance of these issues with regards to the global strategy making. Also, Woodward (2005) said that earlier uses of the LCC model have approached the task of computation as a sheer extension of 'conventional' discounted cash flow.

Therefore, while efforts have been made to classify all pertinent variables over the whole lifecycle of projected capital investments, and then assign estimations to them, analyses have nonetheless remained very much within the qualitative field. While the use of LCC methods is not in itself sufficient to guarantee optimal investment selection, a major advantage of using LCC is that the decision maker is forced to consider the relationship between the important variables, the organisation's objectives and its environment.

LCC allows the decision maker to concentrate on important matters, to explore and describe the issues that affect the decision variables and get a deeper understanding of the issues which will affect the final choice. By examining these factors early in the design process, when effective corrective action can be taken, important trade-offs between capital and running costs can be made.

The LCC approach can also have important benefits during the whole lifetime of the asset as a management tool which can identify short-term running costs of buildings or building components, ascertain ways in which cost savings can be achieved and feedback this information for use in subsequent LCC studies. Similarly, other applications of LCC in sustainable commercial office buildings are discussed in Table 3.2.

LCC model can be used to forecast the costs of all the life cycle phases for individual scheme and allow researchers to choose the most viable development on the basis of total performance (Arja et al., 2009). The quality of both the design and construction of the building have a substantial effect on the costs. Constructions where the design team exclusively emphasise on plummeting capital costs can result in a structure which is expensive to manage, operate, inhabit and ultimately dispose of.

Table 3.2: Applications of LCC in sustainable commercial office buildings (SCOB)

LCC identifies whole costs	LCC methods enable researchers to recognize the whole costs emanating from SCOB throughout its operational life without looking at only the initial capital costs.
LCC acts as a decision making tool	LCC helps in decision making and leads to functioning and monetary investment strategies
LCC acts as a management tool	LCC allows researchers to select the best resolution and also allows for good control of the asset during its operation
LCC acts as a maintenance guide	LCC provides diverse maintenance systems to be adopted, as well as maintenance cycles and their occurrences and to make repairs/replacement decisions, improvements, refurbishment decisions and also to agree on the maintenance budget.

LCC thus reduces costs and so knowledgeable investment choices might be arrived at dependent on the least likely use of funds. Waak (2004) identified situations in which operating and maintenance costs could be lowered by up to fifty percent, and concurring with Masiello (2002), the LCC method makes it conceivable to recognise the utmost important cost generators and hence attains the suitable blend of resources employed. Ferrin and Plank (2002) concluded that LCC-based assessment delivers a more long-term assessment and consequently enables a more well-grounded calculation of procurements.

3.3 LIMITATIONS OF LIFE CYCLE COSTING IN SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

Boussabaine and Kirkham (2008) claim that the attainment of LCC information and expertise within research and use is still in its embryonic stage, with a substantial disparity between theory and practice. This is still the situation now.

Specific models go further than the traditional deterministic methods to embrace explicit attention to uncertainty, risk tolerance of decision makers and other social issues that make the results more thoughtful of the aims of decision-making in practice (Jepsen et al., 2014).

Another limitation of LCC is the industry's relative lack of interest in its implications (Dhillon, 2013; Cuéllar-Franca and Azapagic, 2014). Other problems are discussed in the subsequent paragraphs:

a) The divorce between capital cost and running cost: The practice of accepting the cheapest tender and then the subsequent handover without any interest in its future beyond the defects liability period. The lack of clear definition of the responsibilities of the buyer and seller are thought to be the reason for this (Liapis, et al., 2014).

b) Professionals can be inclined not to care too much about LCC and in particular, cost optimisation as their fees is almost always calculated as a percentage of the entire contract price (Noor and Aizuddin, 2013).

c) Clients are ill informed about the benefits of a life cycle approach which can lead to subjective decision-making (Memon, 2013).

d) The concept of the "future cannot be forecast" shrouds life cycle costing concepts. This particularly applies to maintenance and upkeep of the interior. The amount spent on these is purely determined by the consideration given to it by the building occupier. It is extremely difficult to forecast this unless prior discussions have taken place between the client and the design team.

e) Main expenditure on maintenance is normally triggered by failure of listing, defective material or unskilled workmanship instead of complete ageing. This is very difficult to estimate. A well-constructed and maintained case of low-priced sustainable commercial office building may well last much longer than its hypothetical life, although certain exclusive work could need early renewal because of weather damage, vandalism etc.

f) The trouble of getting the correct level of information to calculate LCC. This is as a result of the absence of suitable, applicable and consistent historical figures and statistics (Kishk, et al., 2003). This is because although life cycle costing (LCC) plays an increasingly significant aspect in assessing the procurement of constructions, the absence of consistent and reliable data for precise LCC examination remains a grave apprehension as noted by Bouachera, et al., (2007) and Pelzeter, (2007).

The costs of data gathering are huge (Ferry and Flanagan, 1991). With regards to the restricted obtainability of 'hard data', idiosyncratic evaluations for the probable variables of unpredictable values need to be obtained from suitable professionals (Clemen and Winkler, 1999). Even if historic data are accessible, it is widespread to alter historic-based evaluations with independent views (Sobanjo, 1999).

This appears to be unavoidable in LCC studies because historic data would under no circumstances offer an exact answer and high quality decision will continually be needed (Ashworth, 1996). The lack of data prohibits the expansion of LCC as a tool in cost planning coupled with complicated equations that require significant amounts of data and user expertise provides evidence of how such models will find difficulty in practical implementation.

Also, costs of data gathering are huge (Gluch and Baumann, 2004). Similarly, the time required for data gathering and the examination process may leave insufficient time for the vital discussion with the users and the re-run of substitute decisions (Ammar et al., 2012).

g) The overabundance of cost models related to LCC has been noteworthy in generating an "air of misperception" over the topic. Lowe et al., (2006) considered the difficulty of simulation arrangement and the failure to associate models on a similar basis.

h) There is also the requirement to be able to estimate the future occurrences, numerous elements such as future operating and maintenance costs, life cycles and discount rates. The improbability encompassing the values utilised in any LCC method ought to be jettisoned to increase the precision of the approximation.

i) Furthermore, it is important to deal with intangible (non-monetary) data because in some instances they have a pivotal role to play (Stoy et al., 2008).

Also, the singular awareness of the life cycle methods raises numerous apprehensions. In 1983, two renowned academicians in LCC, Roger Flanagan and George Norman developed a methodology for gathering data which could subsequently be used to develop the LCC of a facility. This is widely held as the definitive work on the subject up to press.

However, since publication, LCC has not taken off in the way one would have expected. Keoleian et al., (2005) highlight how LCC has become a significant part of the total cost representation for some time but has not utilised in the decision-making process to a similar degree. This affirms the heated discussion in Hunter et al., (2005), that in some instances, LCC has continued to be an academic instead of a practical tool and that currently; the financial liability of applying an LCC method overshadows its anticipated benefits.

For instance, LCC has been extensively used in the procurement of Australian defence contracts and United States for some time now (Australian National Audit Office 2001; U.S. Department of Defence, 2001). The sheer cost involved in these kinds of projects stresses the necessity for LCC, that is the likelihood that substantial capital expenditure ought to be vindicated by the longer term gains. In the UK, a government report released by the Building

Research Establishment (Clift & Bourke, 1998) on LCC recognised numerous issues that currently serve as limitations to using LCC:

• The absence of acceptable approaches and universal frameworks for calculating LCC.

• The trouble in incorporating the operating and maintenance approaches at the design stage

• The volume of the data gathering exercise and data discrepancies.

• The obligation for an independently maintained database on performance and cost of building components.

Kshirsagar et al., (2010) note that LCC outcomes are not suitable budgeting methods. This opinion is established on the uncertainty that is discovered in most LCC submissions and this imprecision usually results in the time operational budgeting apprehensions. Table 3.3 further highlights the other limitations of LCC. Although modelling for improbability has been mentioned in the LCC literature for some decades now, most formats do not mention them, not to talk of the assertion that such improbability takes place. It must be specified that this is a matter within the broader LCC literature, with numerous professionals still refusing to modify their modelling.

Hardly were topics such as risk, improbability and related convincing suppositions recognised other than by ephemeral remarks. Taking into account that there are several circumstances that can influence the discount rate, a suitable level of regulation or structure for the definite value choice was a prominent absence from the literature reviewed. As indicated above, the setback of the existing literature to outline a universal technique for choosing the discount rate is an aspect of LCC which at the moment needs some extra effort.

Table 3.3: Limitations of LCC

Market conditions	The prevalent market conditions have momentous influence on LCC. The future is unknown, but LCC encompasses a countless deal of forecasts and assumptions of the future. These include the maintenance and operating costs, rate of interests, inflation, material and component prices. But in truth, these factors tend to change when applied to different interest rates and different scales.
Life of building, components of materials	The projected life has a bearing on the LCC. This is mainly dependent on the maintenance culture and standard of the user of the building.
Accuracy of data	The accuracy of LCC models depends on the exactness of various available historic databases available for examination purposes. Unfortunately, the structure of the components of LCC is in such a way that no appropriate record keeping mechanism is obtainable.
Constraints on investment	The lack of capital and the high financial costs and existing interest rates can limit the investor on advanced investment expending to cut the operating costs.
Type of investor/user	Most developers are concerned with the initial costs. Where the investment and maintenance are carried out by different organisations. Most of these decisions however may be affected by investors whose emphasis alone would be on the capital cost.
Maintenance policy and management	The economic obsolescence of buildings is another pertinent issue as it occurs as a result of inappropriate maintenance policies and maintenance management

These obstacles could be directly associated with the lack of sufficient understanding of LCC procedures and tools. There might similarly be a lack of readiness from practitioners to establish suitable methods to resolve these issues. These and other issues need to be adequately tackled before a higher level of application of LCC can be established.

3.4 OVERVIEW OF EXISTING LCC MODELS

There exists plethora of LCC models in calculating the whole life costs of sustainable commercial office buildings. A simple life cycle cost model for a building could be represented by:

$$LCC = Ic + Oc + Mc + Rc \quad (3.1)$$

Where Ic= initial capital costs

Oc= operational costs

Mc= maintenance costs

Rc= residual value

Naturally, this is LCC in its simplified form but the general model can be transformed to accommodate the nature of the building and its usage. Although this model looks very simple, the component parts would require a great deal of complex data collection and organisation. In essence, this equation would be very difficult to use without access to a fully comprehensive database. The time spent on the collection of this data can prove to be costly and ultimately prohibitive. Boussbaine (2013) also published a variation to this equation

$$LCC = Cc + Rc - Sc + Ac + Mc + Ec \quad (3.2)$$

Where: Cc= capital investment costs

Rc= the capital replacement costs

Sc= the resale value at the end of study period

Ac=the annually recurring costs of operating, maintaining and repairing the building

Mc= the non-annual recurring costs

Ec= the energy cost

The complexity of this LCC model is in dealing with and identifying as many specific terms as possible and individual activities as practicable. Although this lends an element of increased accuracy to the output of the model, its applicability to those in practice is debatable.

Regression analysis has been extensively used for investigating the relationship between LCC variables, forecasting maintenance and operating costs as seen in Wanous, (2000) and Makridakis et al., (1993). The core drawback of this method is that it cannot calculate non-linearity that could occur in the association among the dependent and independent values. Nonlinear regression is an effort to correct this anomaly, but then again it can easily be influenced by users.

Although the use of statistical measures in LCC is still widespread and widely held as a valuable prediction tool, Artificial Intelligence is now becoming a more widely accepted complementary tool for LCC analysis. Making available with precise predicting methods for users would allow them to make informed and consistent approximations about probable running costs in the future (Boussabaine et al., 1999). Research by Boussabaine (2013) has provided alternatives to the traditional techniques.

Neural computing is principally used for decision-making, forecasting and optimisation. Recent developments in the use of Neuro-networks within the building life cycle have identified the system to be reliable and be of value to professionals who require systems, which enable them to make informal decisions on the allocation and management of construction and operational costs. The system tends to generally work better with large data sets whereas ANN can work with smaller samples as well.

An artificial neural network (ANN) is an information processing system that has certain performance characteristics in common with biological neural networks which best suits the cost forecasting domain. Artificial neural networks, henceforth referred to as neural networks (NN) with artificial implied, retain two features of the biological neural network: the ability to learn from experience and make generalisations based on this acquired knowledge (Haykin, 1994).

Neural networks are particularly suited for complex, hard to learn problems where no formal underlying theories or classical mathematical and traditional procedures exist (Adeli, 2001). ANNs are fundamentally different from algorithmic computing and statistical methods in one way- they learn inductively by examples and then are able to generalise solutions. Modelling techniques including case-based reasoning and fuzzy logic analysis find it difficult dealing with problems such as imprecision, incomplete and uncertainty of data and other variables affecting costs and implicit combinatorial effects and inter-relationships of cost variables (Flood and Kartam, 1994), areas where NN is often at its best.

3.4.1 APPLICATIONS OF NEURAL NETWORKS

Neural network has been used successfully in flight and robot controls (Nepak, 2013) and loan applicant assessment (Malhotra et al., 2003). Earliest construction industry application of neural networks can be traced back to 1989 by Adeli and Yeh (1989) on engineering design and machine learning.

It has since been applied in building related disciplines for estimating the cost of highway projects (Pewdum et al., 2009); risk quantification (McKim, 1993); and tender price forecast (Boussabaine et al., 1999). Neural Network application bibliographies have been provided by Adeli (2001) for Civil Engineering and Moselhi et al., (1991) for construction management research. Several researchers in the construction industry have addressed potential applications of artificial neural networks. Boussabaine et al,, (1999) developed a neural network model for water pipeline projects. Hegazy and Moselhi (1994) used a back-propagation neural network for bidding strategy appraisal and mark-up estimation whilst Boussabaine (2001) compared the modelling of the cost of energy in sport facilities using artificial intelligence methods and Elhag and Boussabaine (1998) used ANN for cost estimation of school buildings. Although a substantial amount of research presently exists in ANN forecasting, none explicitly emphasise on sustainable commercial office buildings.

3.5 SUMMARY OF CHAPTER

As opposed to the use of relating forthcoming developments for procurement and decision making, the application of LCC during the life cycle of sustainable commercial office buildings give the impression it is rather limited and embryonic. The studies revealed that while most advocates of LCC acknowledge its addition in the basic framework, little consideration was given as to its use. It is essential that life cycle costing be implemented early in the project planning process. Only then will the decision- maker be able to exert any really strong influence either on the performance to be achieved from a given LCC or on the life cycle cost expenditures necessary to achieve the desired level of performance.

However, the application of risk and uncertainty appraisal tools is very restricted, and this makes obtaining maximum advantages from usage of LCC models in sustainable commercial office buildings very difficult. The lack of sufficiently progressive guidelines and measures, coupled with imperfect external appraisal of estimates would hinder the ideal performance of risk and uncertainty examination.

The most challenging matter in any LCC use is what discount rate to utilise. It is pertinent to mention that the discount rate employed in an LCC use can have a rather huge influence on the examination and the ultimate inferences that it attains. Hence, constructive strides should be made towards the determination of appropriate discount rates for use in LCC.

One of the most essential paradigm modifications necessary in LCC is the recognition by users of the inconsistency (risk and uncertainty) in almost all model inputs. Taking into account the improvements in computing capabilities and examination expertise, the use of arithmetical approaches to LCC is no more problematic than deterministic modelling techniques.

Despite the fact that the Building Management Cost Information Service (BMCIS) went some way in tackling the application difficulties of life-cycle costing, it however failed to produce a comprehensible methodology in which to deal most efficiently with this information. This historical data is also treated with scepticism and uncertainty as by explanation; it is deeply entrenched with the past while computer-generated data denotes the yet to come. The contention being that for maintenance and operating costs, data recorded in the past might be a weak benchmark for the future, more advanced asset management methods and higher quality products and consistency is needed.

Finally, LCC models like ANN can be used to forecast and quantify risk analysis. Neural networks do exact their own demands however. NN are data-hungry, and performance is largely dependent on plenteous, representative and reliable data. Another major criticism of the ANN approach to data modelling is that it offers little explanation on the relationships between the variables it is modelling The technique is still disregarded by some researchers, referring to it as a ‘black-box’ technique because the network parameters do not offer casual explanations, making it difficult to elucidate what is learnt from the neural network model. To these criticisms, it is argued that it might be preferable to focus on how well a neural network model produces its results, rather than how it produces it.

CHAPTER FOUR

DRIVERS AND BARRIERS IN LCC APPLICATIONS ON SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

4.0 INTRODUCTION

LCC is about understanding and application of costs to sustainable commercial office buildings by ensuring that non-renewable and rare resources are utilised to best advantage, achieving a balanced expenditure between the various building elements and ensuring that clients receive the best value for money for these buildings. Hence the need to investigate the suitability of LCC for calculating the whole life cost of sustainable commercial office buildings with particular emphasis on the barriers (technological and non-technological) and drivers (economic and social) of these buildings

The chapter explores the interrelationship between LCC and sustainable commercial office buildings and discusses the barriers (technological and non-technological) and drivers (economic and social) of these buildings. In a forward looking approach, recommendations that should facilitate the development of more sustainable commercial office buildings are suggested.

4.1 THE INTERRELATIONSHIP BETWEEN LIFE CYCLE COSTING AND SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

The increased pace in society in general has resulted in clients being less likely to tolerate delays in redesigning sustainable commercial office buildings when tenders are too high. Thus, a more effective system of control is desirable from inception up to completion which brings LCC into the picture as it considers all costs that arise all through the life cycle of the building, such as initial capital costs, consequent maintenance and operating costs and end of life costs (Sacks et al., 2012).

Similarly, the clients of the construction industry often represent large organisations and financial institutions. This often results in takeovers, mergers, acquisitions and some public ownership. There has thus been an increased emphasis on accountability as the efficiency of these organisations at construction work is only as good as the methodologies applied. LCC has proved it can sufficiently account for all the monetary value of sustainable commercial office buildings through the application of discounting, economic performance measures and key performance indicators.

Furthermore, there has been a trend towards modern designs and new techniques as seen in these green buildings and methods of construction. Hence, the need to choose from a wider range of products and this has produced a variety in construction. The traditional methods of estimation are unable to cope in these circumstances to achieve value for money unlike LCC which aids selection among project options and is best carried out during the initial viability, feasibility and conceptual design where most, if not all, alternatives are subject to deliberation (Dhillion, 2013).

In addition, several major construction projects in the UK and abroad have received adverse criticism on estimated costs. This is further necessitated by the desire to improve methods of forecasting and control of costs. The importance of counting the cost before clients build was recognised at least 2,000 years ago in St Luke’s Gospel (14:28): ‘’Suppose that one of you wants to build a tower. Will he not first sit down and estimate the cost to see if he has enough money to complete it?’’. This underscores the need for forecasting which incidentally is an integral part of LCC.

Also, the contractors’ profit margins have in real terms been reduced considerably during the past decade. This has resulted in their greater cost-consciousness in an attempt to redress possible losses. LCC secures cost-effectiveness and evaluates the probable economic outcome of the proposed sustainable commercial office building. It can thus be deduced that LCC methods can calculate the whole costs of buildings if the appropriate methods are applied. There is a need to ascertain if the current LCC methodologies are suitable for calculating these costs (see sections 6.3and 6.9)

4.2 ECONOMIC AND SOCIAL DRIVERS OF SUSTAINABLE COMMERCIAL OFICE BUILDINGS

As the world becomes more urbanised, the need for a more environmentally sustainable form of life increases. People become increasingly aware of the fact that the built environment severely contributes to raw material and energy use, emissions and waste generation. There is a growing consciousness that many environmental issues are directly or indirectly caused by the exploitation of land, they basically share many grounds, both literally and figuratively (Ozer, 2014). As a result, an enormous potential exists to make the built environment more sustainable, which also makes attempts to do so worthwhile (Passer et al., 2014).

The challenges the society goes through are momentous. These challenges consist of inadequate food, energy, natural resources; incessant war and persistent political instability, and disease; dipping quality of infrastructure and development of slums and ghettos; alarming levels of homelessness and poverty to mention a few. Similarly, present world population is about seven billion and is expected to reach eleven billion by 2100 (Kohler, 2012).The continuous population growth quickens the pressure on energy and natural resources (Osmani and O'Reilly, 2009). It is generally acknowledged that a more ecologically responsible method to building design and construction, application and disposal and recycling is essential. Such apprehensions are, nevertheless, not novel.

Richard Neutra (1954) stated that humans were becoming too separated from the natural habitat (cited in Morse, 2013). In 1962, Rachel Carson published Silent Spring, which is generally recognised as the facilitator to the global ecological drive and improved public consciousness of environmental matters (cited in Dunn, 2012).

Hence, if man disturbs the environment by toxic waste, for instance, it will disrupt the balance (e.g. ecological balance, varying weather conditions), an occurrence that is only too obvious now. Therefore, it is necessary to understand that it is impossible to distinguish between the forces that disturb nature from everyday decision making methods of the builders and occupiers of buildings.

For all building stakeholders, it means undertaking things differently from the conventional methods, breaking prevailing practices and taking time to deliberate on the implications of their choices. In particular, the construction industry has a key influence on the surroundings (Axon et al., 2012). Commercial properties in particular contribute as much as 14% of carbon emissions (Dixon et al., 2014).

In the wider building and running of structures, facilities contribute as much as 40 percent of solid landfill waste, fifty per cent of carbon dioxide emissions, forty percent of energy requirements, 71 percent of electricity consumption, 16 percent of water usage and 50 percent of raw materials (Pivo and Fisher, 2010; Wilkinson and Reed, 2011; Ozer, 2014).

Hence, the implementation of an environmentally friendly method to building construction tailored towards sustainable buildings. Subsequently, an array of demonstration schemes has been constructed over the years; however, their application on a larger scale has, to date, been sluggish. It is evident that there is a need to discuss the economic and social drivers of sustainable commercial office buildings. The enthusiasm and motives for applying sustainable buildings are numerous but can be summarised into basically protecting the earth's resources.

Many more reasons have been proffered as potentially requiring the need for building green especially by developers and builders who are leading the movement towards green building. Past works of Robinson (2005), CoreNet (2008), Thatcher and Milner (2014) and Lützkendorf et al., (2014) all documented a number of potential benefits that green buildings confer on the occupants and the environment.

4.2.1 ECONOMIC DRIVERS

An important feature of the rising interest in green buildings can be credited to the understanding on the part of users that there are evident economic benefits from sustainable buildings. It is obvious that profit-making is a main goal of investing in property construction for investors (Zhai et al., 2014). Lately, there have been a number of studies which have emphasised the economic benefits in building "green" to convince property developers of these professed economic profits (Eichholtz et al., 2013; Kats, 2003).

Industry professionals recognise the importance of sustainability matters for commercial real estate. A large number of the respondents also stated that they would pay up to 5 percent more for a sustainable building and a further 25 per cent said they would pay 5 to10 percent more (Buttimer and Ott, 2010; Salama and Hana, 2010). There are other economic drivers as discussed in subsequent subheadings:

4.2.1.1 RETURN ON INVESTMENT

Recent research by Langdon (2007) and Kibert (2012) assert that sustainable buildings produce a return higher than 10% on investment. It also advocated that effects on the construction market from carbon emission decline programmes would make this return even more eye-catching. Tenants choose green buildings because floor space in these buildings is in greater demand than less sustainable options.

4.2.1.2 INCENTIVES

Several reasons instigate the construction of sustainable buildings. These buildings improve and increase demand of services to customers, improve market value and employees' satisfaction. It also develops buildings for prospects in manufacturing and commercial activities

The switch to the sustainable building design is getting higher and it has been stated that it generates 65,000 jobs in the building industry (Roufechaei et al., 2014). It is collaborated with

Falkner et al., (2010) which claims that low carbon business generates as much as £106 billion a year in the UK and also employs over 800,000 people.

It is believed to also open up an extensive market for the supply chain in recognising the environmental market prospects (Khan and Burnes, 2007). Therefore, the supply chain is able expand businesses and at the same time benefit from the market division (Verbruggen, et al., 2011).

4.2.1.3 INCREASED RENTAL RATES

A 2008 Costar Group study established that green buildings outclass their non-green rivals in crucial areas such as sale price, tenancy, and rental rates usually by wide margins. According to the research, green facilities have a rent premium of $11.33 per square foot over their rivals and also have 4.1 percent higher occupancy (Osmani and O'Reilly, 2009). Similar research by Miller et al (2008); Fuerst and McAllister (2011) also deduced that green buildings command higher rents and can be transformed into an improvement of building value.

4.2.1.4. FILLING AESTHETIC INTEGRITY

There is substantial business for design experts who can apply the ideologies of sustainable building design and deliver this to the anxious clientele (Ortiz et al., 2009). This is because there is a growing demand for sustainable engineering and mounting rivalry to deliver these services. This struggle is not just offered by building services, but from other professions (Hojem, et al., 2014).

4.2.1.5 COST EFFECTIVENESS

Construction industry and its users usually tend to emphasise on immediate benefits instead of long-term investment prospects, the view that sustainable facilities require higher initial construction costs, substantial cost premium and maintenance costs is a key hindrance (Flynn, 2003; Myers et al., 2008).

However, green buildings generally enjoy lower operating costs (Kibert, 2012). This result from the use of renewable resources, sustainable products, natural resources, energy is sourced from sunlight for cooling, heating and other services. This results in lower cost of energy. Water consumption cost is also reduced as main dependence is on natural resources. With the adoption of green buildings, operating costs of businesses are drastically reduced with its attendant effects on increased productivity (Mansfield, 2009; Mills, 2005 Baird and Penwell, 2012; Swan, 2013).

Another study by Wilhelm (2012) contributes to the most conclusive empirical cost-benefit analysis in green building thus far, with the results favouring green buildings. Nalewaik et al., (2009) compared 33 green buildings with regard to aggregate costs and compared these to the total costs of conventional designs for those buildings.

The resulting figures indicate that a two percent increase in initial investment in green building is compensated by a twenty percent life cycle savings of total construction costs. The increase in initial investment is primarily due to extra architectural and engineering design time for green building projects and decreases linearly with the adoption time of green building in the design process (Warren-Myers, 2012).

4.2.1.6 REDUCED LIABILITY

Legislation is now an important deliberation as environmental organisations show increased readiness to introduce and apply the legislation to avert poor environmental practice (Lützkendorf and Lorenz, 2005).

4.2.1.7 EASE IN LEASING

Green buildings are more readily leased. That is because the design, features and all components of green buildings are environmentally friendly and attracts high demand for it (Yang and Yang, 2014). This results easily in high preference for green buildings relative to the traditional buildings. Introducing green buildings will enhance property liquidity and prevent loss of income to investors, some of who utilise borrowed fund for investment (Sparkling, 2012).

4.2.1.8 MITIGATE RISK

Green building certification can offer some degree of defence against imminent lawsuits through third-party confirmation of processes installed to protect indoor air quality, further than merely meeting obligatory requirements. Another risk management advantage of green facilities is the rapid leasing and sales of these buildings.

The application of green schemes offers quality guarantee and improves the rating of the builder's professional profile (De Jong and Arkesteijn, 2014). In this regard, it certainly helps to avert flaws during operation period, dipping builder's liability and lawsuit involvement (Kibert, 2012). Also, Mills (2005) states that any scheme that is able to acclimatise with climate change will cut the requirement of risk management in building.

4.2.2 SOCIAL DRIVERS

These drivers appraise the benefits of sustainability from the human perspective. These include increased productivity, high tenants' retention rate, attracting tenants and clients requirements as discussed in subsequent subheadings. Table 4.1 summarises the economic and social benefits of investing in sustainable commercial office buildings.

4.2.2.1 INCREASED PRODUCTIVITY

The subject of productivity and sustainable buildings is fascinating. While the initial drive of sustainable buildings emphasised primarily around greenhouse reduction and related energy cost savings, lately the connection between the interior building surroundings and output has attracted consideration (Halim, 2013).

While energy efficacies can be estimated reasonably accurately, productivity linked to building quality is less assured (Capital, 2003). There is however a robust band of case-study substantiation to propose that enhanced building surroundings lead to amplified productivity

(Carsrud and Brännback, 2010). A major motive for sustainable design is the acknowledgment of increased productivity from a facility that is comfortable, enjoyable and offers healthy internal conditions (Swan, 2013). Comfortable inhabitants are less distracted, able to concentrate better on their responsibilities and appreciate the physiological benefits green design delivers.

The renovation of the Reno Post Office in Nevada was carried out with the aim of lowering energy costs, it however also signalled a six percent rise in worker's productivity (Smith, 1999). The Pennsylvania Power and Light Company introduced task lighting for their recruiting staff. The result was to decrease energy bills by seventy-three percent which in itself led to a return on investment of about 24%. Then, faster drawing production times, attached with augmented quality and precision of work and enhanced worker self-esteem, joined to generate a profit on investment of over 1000% (Smith, 1999).

These results are mostly unswerving with other research on this subject, which clearly exhibits the very actual and constructive influence of green buildings with regards improved productivity for both owners and occupiers (De Jong and Arkesteijn, 2014).

4.2.2.2 HIGH TENANTS RETENTION RATE

Sustainable commercial office buildings have higher tenants retention rates. This is because tenants are often convinced of the need to continue in the occupation of a building where they have sustained level of productivity. The productivity benefits are estimated to be as much as ten times the energy savings from sustainable building (Breton and Miller, 2006).

These gains come in the manner of lower absence, fewer headaches at work, better retail sales and simpler reconfiguration of space leading to lower costs. The implication is that tenants are willing to continue in occupation for as long as profitability is sustained; a benefit offered by green buildings. Sustainability can therefore transform into an improvement of building value and sales prices (Carsrud and Brännback, 2010).

4.2.2.3 CLIENTS REQUIREMENTS

Clients more than ever before need builders to offer information on sustainability. Several companies now have sustainability obligations in the form of 'Corporate Social Responsibility' reports. These reports usually contain goals and objectives involving quantifiable environmental performance, and development goals for issues such as: energy/CO2 emissions, water and waste (Mickaityte et al., 2008). The most successful schemes integrating sustainable design are ones with devoted and active owners who are willing to scrutinise the whole range of ownership from design to construction to long-term operation and subsequent disposal of their facilities (Chuck and Kim, 2011).

These owners comprehend that sustainable buildings need more preparation and better implementation demanding a steady assurance to altering how building schemes are planned, built, operated and sustained to attain a lower total life cycle cost and lower long-term environmental effects.

4.2.2.4 TENANTS ATTRACTION

Today's tenants comprehend and are searching for the remunerations that green building spaces have to offer. These tenants use their sustainable offices as extra bullet point to encourage how they are sustainable; it is a built-in advertising platform for them.

Table 4.1: Economic and social benefits of sustainable commercial office buildings

Economic Benefits	**Social Benefits**
Reduce operating costs	Improve overall quality of life
Generate, develop and structure markets for sustainable goods	Reduce pressure on local facilities and amenities
Enhance occupant productivity	Heighten aesthetic qualities
Enhance life-cycle economic implementation	Improve occupier well-being and health

Source: Hoffman and Henn (2008).

Summarily, the perceived advantages first of all include an increase in productivity of staff in green offices. Second, a raised ethos of the green building's neighbourhood and an enhanced company image is expected, accumulated by a raised image of the developer or architect of the project.

Third, lower utility bills due to energy savings and a lower exposure to rising energy costs are achieved. An important fourth advantage is the fact that a green building has lower exposure to changing environmental legislation since it belongs to the upper part of the real estate market with regard to environmental compliance.

This is relevant for both lessee and lessor of a green building. Hidden benefits include the attraction and retention of committed staff and a reduction of stress through the more natural environment they are working in. Moreover, daylight improves the concentration and creativity of the employees. Simultaneously, the company itself actually sends a message of environmental care to the neighbourhood and other parties, which also improves the marketing of the company.

4.3 BARRIERS TO SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

Over the years, the UK government has sought ways to deliver sustainable buildings (DETR 2000a, 2000b; Häkkinen and Belloni, 2011). In this regard, it has embarked on a couple of measures aimed at ensuring that green building materials and techniques are utilised to reduce energy consumption in buildings (Winston, 2010; Sustainable Buildings Task Group, 2004).

Still recent research in the UK suggests that only few buildings are sustainable both in design and actual performance (Williams and Lindsay, 2007). One then begins to imagine what is hindering these sustainable developments despite the robust policy drive by the government.

These concerns have been emphasised in numerous reports including Sir Michael Latham's 1994 publication "Constructing the Team" and Rethinking Construction (Egan, 1998). This section looks at the technical and non-technical barriers affecting sustainable commercial office buildings.

4.3.1 TECHNOLOGICAL BARRIERS

This focuses on five aspects namely the low demand for sustainable materials and products, the lack of LCC, lack of readily accessible and reliable information and guidance, lack of appropriate UK certification and the lack of knowledge/experience and understanding about energy efficient buildings.

4.3.1.1 LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS

The lack of demand for green building products such as advanced glazing systems, cavity wall ties over 100mm in length in the UK produces no inducement and motivation for local building suppliers and component producers to store or utilise products capable of the performance required by these projects (Allwood et al., 2012).

Property developers need to develop and implement local procurement policies, and be prepared to work with local suppliers and manufacturers to share the short-term risks and long-term benefits of developing a local supply chain.

4.3.1.2 LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE

A lack of appropriate guidance appears to exist for designers in the areas of passive ventilation strategies, passive solar design and achieving air-tightness in buildings. It is important that information for these areas of design is made available to design professionals in an appropriate format, and to the contractors ultimately responsible for implementing the design (Shiers et al., 2006). Access to such information at an affordable rate is important to prevent mistakes made on some of the projects.

Of particular mention is the use of bespoke systems in some projects as it creates problems when the original designer of the system is no longer available to provide advice on maintenance. The use of non-standardised components or systems will often create problems during the lifetime of the project if detailed knowledge of the system is not kept in-house. It is essential that a comprehensive manual be created that outlines, in detail, all the systems employed in the office buildings. Future occupants will be able to use this to maintain the systems that they have inherited.

4.3.1.3 LACK OF LCC

There is a need to use LCC to appraise sustainable commercial office buildings as it has the ability to accurately predict post-occupancy costs of these buildings as there is a lack of awareness of the long-term economic benefits of green construction (Stephan et al., 2011).

4.3.1.4 LACK OF KNOWLEDGE/EXPERIENCE/AWARENESS AND UNDERSTANDING ABOUT ENERGY-EFFICIENT BUILDINGS

Most developers and contractors are not aware of energy design strategies and demonstrate an inability to identify opportunities for the inclusion of renewable energy technology. The general approach exhibited by these developers and consultants is that they attempt to trade the inclusion of sustainability features against other features, such as quality to offset the perceived additional cost.

Initial building cost estimates were considerably lower (up to 100 percent) than the final tender amounts submitted (Townsend, 2005). This is often due to developers not being made aware of the real cost implications of sustainable building features and adhering to an exaggerated perception of the additional costs of 'green' design and additional risks. The lack of any real data that demonstrates otherwise reinforces this position and leads developers to build a significant contingency amount into their tendered quotes.

In some instances, additional product training is provided in several cases for contractors who were working with 'novel' products or systems. This meant that the project incurred additional time and financial costs that had to be borne by these contractors who would ultimately drop the idea because their aim is to make profit. Hence, there is a lot of ignorance among builders on green construction methods and products. This is because there is an overall absence of skilled labour within the construction industry, and the opposition that occurs in embracing novel construction practices.

4.3.1.5 LACK OF APPROPRIATE UK CERTIFICATION

There exists several environmental certifications for evaluating the sustainability of commercial office buildings. However, the most recognised is the BREEAM which stands for the BRE Environmental Assessment Method. BREEAM achieves certification by integrating global, local and indoor impacts (Rohracher, 2001; Choi, 2009).

Currently, BREEAM is used in over 30% of new and old office buildings in the UK (Holmes and Hudson, 2003). However, there is an argument that BREAM is not an appropriate tool for quantifying the environment as different energy rating methods produce different energy performance results (Schweber, 2013). It also considers a lot of parameters for evaluating energy performance. Work therefore needs to be done on standardising green certification schemes for products and materials.

4.3.2 NON-TECHNOLOGICAL BARRIERS

This includes the learning period, no perceived consumer demand for sustainable commercial office buildings, the status Quo in rules and regulations, financial barriers and the fact that sustainability measures are not considered by the government.

4.3.2.1 FINANCIAL BARRIERS

Opponents often emphasise the major costs involved in green building. According to Häkkinen and Belloni (2011), several real and perceived disadvantages are involved in green building due to the uncertainty about the more innovative technology used and the performance of the building itself: is it reliable? Moreover, extra design and developing risks and costs are expected. Bordass (2000) also points towards the extra time and efforts that are needed for green construction: how ‘buildable’ is the green building?

Besides, it is more difficult to find and build a good relationship with contractors since there are more prerequisites demanded for green projects, i.e. the contractors need to build green. Also the tenants must take their responsibility and adhere properly to suitable guidelines. Lastly, many people simply fear the unfamiliarity of building green and therefore deter this concept.

However, many are sceptical about these arguments since the possible higher start-up costs are expected to be earned back later and outweighed by the premium returns that green buildings offer. The additional financial cost of providing the measures to improve the sustainability of housing was cited by consultants as being a major barrier to the realisation of their schemes.

The perceived long-term benefits are usually not expressed in terms of financial return in many of these cases, but focused instead on the environmental and social benefits that the developer believed the technology or methodology could deliver. The cost/price of sustainable buildings is considered as prohibitive. The widely held belief is that everyone would be investing in sustainable buildings if is inexpensive and lucrative.

Hence, it would be fair to state that this novelty draws from risk, cost and adequate planning. These extra parameters to a large extent stop concerted efforts of even the most unswerving and knowledgeable sustainability proponents. Some researchers however believe there is a misconception about the cost and efficacy of green building and sustainable development (Hunter and Kelly, 2009).

4.3.2.2 NO PECEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

The reason behind the lack of perceived consumer demand is the existing market trend. In the first instance, clients do not ask for sustainable buildings because they do not see it as a profitable investment (Abidin et al., 2013). Also, a lack of good, exemplar ‘demonstration projects' across the country that could be visited, presented and interpreted by knowledgeable staff, and which could help shape the demands of house buyers.

As a result of this, many developers are not eager to go the extra-mile especially when it comes to moving from their comfort zone (conservative way of construction) and undertaking innovative technologies. Hence, more developers will join in producing sustainable buildings if buyers demand them.

4.3.2.3 LEARNING PERIOD

Only recently did environmental issues become a matter of significance in the society and subsequently in school curriculum. It is therefore still difficult to disentangle from the standards in practice. Although, the coming age group are knowledgeable on sustainable construction, they however have no practical experience. Hence, the need to commence the application of sustainable ideologies in projects (Rohracher, 2001).

There are a small number of firms that have begun to employ a few of the sustainable principles in their developments or design for sustainable rating system (Sterling, 2001). They would have to hang on for two to three years to evaluate the gains they derive from this practice. Once they are content with it, then more developments will ensue. Learning from practice would take time.

4.3.2.4 STATUS QUO IN RULES AND REGULATIONS

For most developers, they would conform to prevailing laws as expected by law and only few companies would have the interest and competence to exceed the required benchmark. Lacking these improved guidelines, the circumstances are bound to be the same as there is a wide held belief that 'eco-development' is in some way 'optional'; a choice that you can make but is not binding (Abidin, 2010).

4.3.2.5 SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNEMENT

It is believed that sustainability objective is mainly not deliberated upon by the stakeholders involved. The lack of political will and strong leadership at the top levels of government is a major problem as the benefits of green certification are not clearly understood by many of the country's decision makers.

There is also the absence of governmental authority responsible for implementing the adoption of green buildings because of the lack of conceptual understanding among leaders about sustainability and its long-term, systemic benefits to the residents and the economic vitality of the country (Choi, 2009; Williams and Dair, 2007). Table 4.2 highlights the barriers to achieving sustainability and the incidence of occurrence of these barriers.

Table 4.2: Barriers to achieving sustainability

Obstacles to acting sustainably	**Incidence of barrier**
1 Sustainability activities were not well thought-out by individuals	Undoubtedly the most frequently documented obstacle
2 Sustainability activities was not needed by client (includes buyers and occupants)	Frequently documented
3 Participants had no ability to impose or ask for sustainable activities (in certain instances it was the duty of the end user or the builder)	Frequently documented
4 One sustainability activity was sacrificed in order to realize another (alternative forgone)	Frequently documented
5 Sustainable activities was limited, or not permitted, by regulators	Frequently documented
6 The sustainability activities are very expensive (in some instances the financiers failed to invest in)	Frequently documented
7 Existing site conditions mitigated against the application of a sustainable activity	Frequently documented
8 Ineffective, unproven or undependable sustainable materials (integrating long term administration difficulties)	Frequently documented
9 Sustainable activities was not accessible	Frequently documented
10 An unsustainable activity was permitted by the government (hence, no motivation for a green	Rarely documented

substitute to be utilised)	
11 Stakeholder was not incorporated, or was built-in too late, in the planning process to execute sustainability activities	Rarely documented
12 Stakeholder did not have sufficient information, ignorance or know-how to attain sustainable activities.	Rarely documented

Source: Williams (2007).

The construction sector is not only to deliver buildings and infrastructures, but to look beyond on opportunities that can reduce the usage of resources and energy, reduce waste, effluents and pollution and improve economic competence. It is time industry players think differently, rather than just on construction costs and immediate profit. There is also a need to realise that 'business as usual' is not sustainable and therefore simply cannot continue indefinitely, and that there could be real benefits to those enterprises who take it on-board at an early stage, rather than adopting a strategy of 'minimal compliance'.

Although the government and other stakeholders have introduced several initiatives for sustainable commercial office buildings; however the recognition of sustainability perception is not industry-wide. Several challenges that are impeding a faster progress on sustainability agenda have been identified.

The following set of recommendations is therefore made:

• Government needs to implement a range of fiscal incentives that favour more sustainable forms of construction.

• Government should endorse a range of national and international accreditation schemes that actively promote sustainable construction. This may take the form of developing a 'kite mark' that promotes sustainable building materials or technologies, or endorsement and promotion of existing schemes.

• An increase in the level of investment in training provision is essential if UK construction professionals are to meet the challenges of developing more sustainable forms of commercial office buildings. Government needs to increase the levy currently placed on the construction industry to make the level of investment in training in the UK comparable to that of countries like Germany and Denmark.

• A review should be undertaken of the guidance that is available to building design teams, developers, building contractors and local authority staff involved in the building stages to help them with the process of sustainable designs and constructions.

• It is essential that occupants are educated in 'getting the best' from the resource conservation technologies incorporated into their dwellings, and that they understand the implications of their choices and actions both on their fuel bills, and on the environment. It is essential to link this training to immediate and direct benefits for the occupants. Pilot or 'flagship' schemes should qualify for sufficient funding to carry out post-occupancy evaluation of the resource efficient technologies, using hard data (from built-in monitors) and the occupants own assessment. Above all, the precise combination of appropriate government directives, higher use of energy saving technologies and social change would significantly move the construction industry towards sustainable commercial office buildings.

4.4 SUMMARY OF THE CHAPTER

The suitability of LCC in the calculation of sustainable commercial office buildings is visible in achieving maximum profitability of the building, minimising construction costs within the criteria set for design, quality and space, maximising any social benefit, minimising risk and uncertainty and maximising safety, quality and public image.

There are a number of reasons for sustainable commercial office buildings, including the social, environmental and economic benefits. Still, modern sustainability inventiveness calls for a unified strategy to all forms of construction. While the skills utilised in sustainable facilities are continuously changing and might vary from area to area, there are essential ideologies that continue from which the technique is initiated. The reason for sustainable facilities is an optimisation of one or a collection of these ideologies. Similarly, with the appropriate all-inclusive policy, different sustainable facility skills might work collectively to create a better collective result.

Hence, no government or investor should attempt to leave sustainable structures out of its strategic design if it desires to conserve energy and cut greenhouse gas emission. Energy efficiency and the reduction of greenhouse gas emissions must be the basis of every international climatic change policy and fused into all development plans with those relating to asset's strategy.

CHAPTER FIVE

RESEARCH METHODOLOGY

5.0 INTRODUCTION

This chapter discusses the research framework after a detailed review of the extant literature in chapter two to four. The approaches to empirical data collection and the methods of data analysis were also described, followed by the formulation of the research model for the study.

5.1 THE RESEARCH PROCESS

The research has passed through a number of processes in order to achieve the objectives as stated in chapter one.

5.1.1 LITERATURE REVIEW

A review of the literature covered the need for a conceptual and standardised framework for LCC of sustainable commercial office buildings. The review provided an overview of the wide range of the elements and models of LCC (see chapter two) and subsequently investigated the impacts (barriers and limitations) of life cycle costing on sustainable commercial office buildings (see chapter three). Finally, it explored the suitability of LCC for calculating the whole life costs of sustainable commercial office buildings and focused on the barriers (technological and non-technological) and drivers (economic and social) of sustainable commercial buildings (see chapter four).

5.1.2 METHODS OF DATA COLLECTION

For the purpose of this research, primary sources of data included questionnaires and building cost data directly from a sustainable commercial office building while secondary source of data was gathered from the Building Cost Information Service (BCIS).

5.1.2.1 PILOT STUDY FOR QUESTIONNAIRE

Lewis and Saunders (2012) were of the opinion that a pilot study is essential in providing a focus mechanism to establish the research direction more clearly. As contended by numerous researchers like Munn and Drever (1990), such test run surveys are crucial to reveal the methodological thoroughness and precision of a survey. The sample employed in this survey was obtained mainly from the member directory of the Royal Institution of Chartered Surveyors (RICS) in the East Midlands. On the whole, 40 firms were randomly mailed questionnaires to complete this survey, taking into consideration the size, project type, annual turnover and age of organization.

Of the 40 pilot questionnaires sent out to the selected sample, 30 were sent back indicating a response rate of 75%. This compares positively with the 20% response rate realised in the pilot survey stated in Xiao (2002). As a result of the analysis of the pilot survey, the questionnaire was put through an activity of amendments and modifications to ensure it is more appropriate for the main questionnaire survey. Having fulfilled the necessity to pre-test the questionnaire and having finalised the modification of the questionnaire, it was all set for distribution and use in the main survey.

5.1.2.2 QUESTIONNAIRE SURVEY

A questionnaire was utilised as it is proficient and valuable in gathering information from a large population over a wide geographical area. Also, it is a relatively inexpensive data collection and processing method as suggested by McQueen and Knussen (2002). These advantages outweigh the use of interviews which is expensive, time consuming and has a high potential for bias (Yin, 2003).

Specifically, a cross-sectional questionnaire survey of construction professionals was embraced with the questionnaire prepared to:

- Investigate the level of application of LCC components, cost structure, uncertainty and risk analysis, economic performance measures, key performance indicators and forecasting tools such as Artificial Neural Networks.

• Investigate the suitability of the current LCC methods in calculating the whole cost of sustainable commercial office buildings and rank the drivers and barriers of sustainable commercial office buildings.

• Evaluate the applications and limitations of LCC on sustainable commercial office building.

5.1.2.3 PRIMARY DATA FROM INTERSERVE CONSTRUCTION LIMITED, LEICESTER

Primary data was also gathered from Interserve Construction, Limited located at Number 3, Rayns Way, Syston, Leicester, LE7 1PF (figure 5.1). The reason for selecting this building was because it is the first certified Passivhaus Carbon Negative commercial office to be built in the UK.

Figure 5.1: Side view of Interserve Construction, Limited, Leicester

Source: interserve.co.uk (content removed for copyright reasons)

Located at Watermead Business Park near Leicester, the new building was constructed by Interserve in partnership with park developer Raynsway Properties. The two-storey 6,000 square feet office houses approximately 60 staff in a modern, fresh, working environment, running at a mere 10 per cent of the energy usage of such a building constructed conventionally. Super insulation, triple glazing and high levels of air tightness (0.44 air changes per hour) have all reduced the requirements for space heating and cooling, thereby providing high-level comfort with very low energy consumption

A superior air-tight construction avoids heat loss through the external envelope. Reinforced concrete walls have been built using Durisol 80 per cent recycled wood blocks, which were delivered to site already insulated thermally and acoustically, with in- built fire protection (figure 5.2).

Figure 5.2: Durosil blocks with built in thermal and acoustical insulation made from the waste timber shavings

Source: interserve.co.uk (content removed for copyright reasons)

With triple glazing and insulated foundations, the building is able to hold warmth during the winter and stay cool in summer, whilst the south-facing windows make the most of solar heat during the winter. The ventilation air passes into the building from an earth tube system, making the most of ground warmth in the winter and cooler ground temperatures in the summer. Efficient lighting has been installed to optimise daylight use by using automatic dimming controls. The building has an efficient recovery ventilation plant which recovers 80 to 85 percent of the heat from the stale air and adding to the cooler incoming air (figure 5.3).

Figure 5.3: The heat recovery ventilation plant

Source: interserve.co.uk (content removed for copyright reasons)

The building offers super ventilation to the buildings with ''U'' values typically three times better than current building regulations. It also introduces earth tube technology whch lowers the intake of air by around 6 degrees celcius in summer and likewise introduces warmer air in the winter. It fits intelligent external window blinds to the south elevation preventing unwanted heat entering the building in the summer months. Similarly, it controlled opening of windows in summer when external emperature are cooler than outside (figure 5.4). The BMS indicates when it is appropraite to open windows on wall mounted teltales.

Figure 5.4: Screens located around the office as part of the BMS

Source: interserve.co.uk (content removed for copyright reasons)

Furthermore, the building introduces intelligent lightning, localised control of lux levels and automatic movement sensor switching, uses low energy lightning, low energy IT equipment and network printers replaced individual printers (figure 5.5).

Figure 5.5: Intelligent lightning and large area of glazing

Source: interserve.co.uk (content removed for copyright reasons)

With the Leicester site demonstrating perfectly Interserve's capabilities in building to Passivhaus standards, the company has now undertaken a number of other Passivhaus projects around the country, including a circa £10 million primary school new build in Leeds, which is set to be one of the most energy efficient schools in the world. The initial, operating and maintenance costs of this building were gathered on the 5^{th} of June, 2014 while on visit to the facility with my Director of Studies.

5.1.2.4 SECONDARY DATA FROM THE BUIDING COST INFORMATION SERVICE (BCIS)

Historical cost data was gathered from the BCIS for a sustainable commercial office building case study. Data from the BCIS was chosen because it gives early cost advice to budget and benchmark projects and to prepare life cycle cost plans. Similarly, BCIS data is used by consultants, clients and contractors to produce specific estimates for option appraisals, early cost advice, cost planning, reinstatement costs, benchmarking, whole life costing, facilities and maintenance budgeting.

Case studies have previously been adopted as a relevant and adequate research methodology in planning, design and construction, economic and political science (Yin, 2003). They allow an empirical inquiry into the real-life context of research work. For the purpose of this research, two environmentally accredited buildings (BREEAM and PASSIV) were used as case studies.

This is because these ratings are yardsticks for sustainable commercial office buildings in the UK.

The BCIS case study is a two storey office Block, Penllergaer Business Park, Swansea, West Glamorgan built on the 12th of November, 2008. It is a new build; steel framed with a floor area of 2,681m. It has a building cost of £3,007,373 and has an excellent BREEAM rating (figure 5.6).

Figure 5.6: Office Block, Penllergaer Business Park, Swansea, West Glamorgan

Source: interserve.co.uk (content removed for copyright reasons)

5.2 SAMPLE SIZE DETERMINATION FOR THE MAIN SURVEY

The sample size was calculated using the sample size method applied in Esan (1994). Responses from the pilot study bordering around the suitability of LCC for calculating the whole life costs of sustainable commercial office buildings were used to arrive at a suitable sample size determination for the main survey as depicted below. This method has been applied in similar research like Bragança et al., (2014), Holopainen, et al., (2014) and Shaikh et al., (2014).

$$n \geq N\left(1+\frac{d^2(N-1)}{4PQK^2_{\alpha/2}}\right)^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.1)}$$

Where,

n is the sample size

N is the population size

P is the proportion of pilot study respondents who say the current LCC techniques are suitable for calculating the whole costs of sustainable commercial office buildings

Q is the proportion of pilot study respondents who say the current LCC techniques are not suitable for calculating the whole costs of sustainable commercial office buildings

d is the width of the confidence interval

$K_{\alpha/2}$ is the value of z-distribution corresponding to 95% confidence interval

$N = 150$ $\quad K_{\alpha/2} = 1.96 \quad Q = 1 - P$

Where P is gotten from the pilot survey carried out

$$P = \frac{23}{30} = 0.77$$

Hence, $Q = 1 - 0.77 = 0.23$

$d = 0.15$

$$n \geq N\left[1 + \frac{d^2(N-1)}{4PQK_{\alpha/2}^2}\right]^{-1}$$

$$n \geq 150\left[1 + \frac{(0.15)^2(150-1)}{4(0.77)(0.23)(1.96)^2}\right]^{-1}$$

$$n \geq \frac{150}{2.23}$$

$n \geq 67.2 \approx 67.$

This implies that 67 or more questionnaires can be given out in this survey. Random sampling was utilised in the survey; this is where each member of a population has a known and non-zero probability of being involved in the sample. It was utilised because of the low cost involved, faster data collection and since data set is lesser, it is probable to guarantee similarity and to increase correctness and quality of data. Closed ended questionnaires were employed because they can be answered finitely by either “yes” or “no, in a few words or a specific short factual answer (see appendix one).

Collecting both historical data and questionnaire responses did pose a lot of challenges as companies did not respond to the questionnaire requesting information on primary data of sustainable buildings. I was eventually able to get a company after my Director of Studies intervened and contacted a company that released the much needed information. For the pilot and main survey, reminders were sent to respondents which eventually yielded results.

5.2.1 THE MAIN SURVEY

The sample employed in the survey was obtained from a databank of construction professionals listed in the UK Royal Institution of Chartered Surveyors (RICS). A total of one hundred and fifty questionnaires were mailed out to participants for purpose of this survey. The questionnaire was accompanied by a self-addressed stamped envelope and a statement of the objective of the research to inform the respondents on the possible input they could make to good practice.

For most of the questions, respondents were asked to specify the degree to which they concurred to a particular statement, on a five point scale: ‘strongly agree’, ‘agree’, ‘neutral’, ‘disagree’, and ‘strongly disagree’. For further questions, respondents were required to rank some specified issues. Three steps were followed in administering the survey to encourage a good response.

The first involved a mail-out of an advance-notice letter to all the members of the sample notifying them of the questionnaire they were to be receiving shortly and encouraging their participation. The second step was a mail-out of the actual questionnaire with an additional personalised, signed cover letter and a self-addressed stamped reply envelope (Babbie, 1990). This was undertaken on July 10, 2014, about one week after the advance-notice letter as recommended in Creswell (2003).

The final step involved a mail-out of another set of questionnaires to all non-respondents, again with an accompanying personalised, signed cover letter and a self-addressed stamped reply envelope. This was also undertaken, as recommended in Creswell (2003), about three weeks after the second step. Although the literature suggests two follow-up mail-outs to ensure high response rates (Babbie, 1990; Creswell, 2003), resource limitations meant that only one follow-up could be undertaken.

5.2.2 RESPONSE RATE

Of the one hundred and fifty questionnaires despatched to the chosen sample, 69 were returned, a response rate of 46%. The response rate of 46% is satisfactory and is in line with the views of Akintoye (2000), Dulami et al., (2003) and Takim et al., (2004).

They stated that the standard response rate in the construction industry for postal questionnaires is around 20-30 percent. Other sources that back this opinion include Ofori and Chan (2001) who obtained a 26 percent response rate, Vidogah and Ndekugri (1998) who got a 27 percent response rate, Black et al., (2000) who stated a response rate of 26.7% for a questionnaire survey conducted and Shash (1993) who got a 28.3 percent rate and also affirmed that response rates of this magnitude in construction industry surveys are not uncommon.

5.3 DATA ANALYSIS

Analysis of data is of paramount importance to turn raw data into useful information by statistical and quantitative methods so that conclusions can be drawn. Various statistical techniques were employed including descriptive statistics, correlation coefficient (mean ranking), regression analysis (anova), factor analysis, non-parametric analysis, correlation analysis, artificial neural network modelling and stochastic mathematical modelling based on the factors affecting operating and maintenance costs and the elements of LCC.

5.3.1 DESCRIPTIVE STATISTICS ANALYSIS

This involved the use of frequencies, percentages and means (see appendix five) for presenting descriptive findings of the survey. These techniques were employed for analysing data related to the characteristics of the respondents and their organisations. They were also used for the initial analysis of rating score data of the various research variables. Graphical techniques utilised for presenting the results from these analyses include bar chart and tables (see appendix nine).

5.3.2 FACTOR ANALYSIS

Factor analysis is a multivariate statistical technique for examining the underlying structure or the structure of interrelationships (or correlations) among a large number of variables (Hair et al., 1998). This analysis yields a set of factors or underlying dimensions which, when interpreted and understood, describe the data in a parsimonious but more meaningful number of concepts than the original individual variables (Glynn et al., 2009).

This analysis was performed with the assistance of SPSS Statistics v22. Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity were conducted to examine the sampling adequacy, ensuring that factor analysis was going to be appropriate for the research. Principal component analysis was then employed to extract group factors for the applications and limitations of LCC of sustainable commercial office buildings with eigenvalues greater than 1, suppressing all other factors with eigenvalues less than 1 based on Kaiser's criterion (Kim and Mueller, 1994; Field, 2000).

5.3.3 ANOVA

In statistics, one-way analysis of variance (abbreviated one-way ANOVA) is a technique used to compare means of three or more samples (using the F distribution), since the two-group case can be covered by a t-test. This statistical method was used to rank the technological and non-technological barriers of sustainable commercial office buildings. The t-value column provided the individual significance of each independent barrier of LCC application in the regression equation and told whether the barrier was making statistically significant contribution.

Spearman's rank correlation coefficient was used to rank the economic and social drivers of sustainable commercial office buildings. This is a non-parametric test used to measure the strength of association between two variables and accesses how well the relationship can be describe using a monotonic function.

5.3.4 THEORY OF WILCOXON SIGNED – RANK TEST

The Wilcoxon Signed-Rank test is a non-parametric statistical procedure for comparing two samples that are related or paired. It was used to ascertain whether key performance indicators and economic performance measures need to be incorporated into LCC and whether it is important to consider the initial, operating, maintenance and disposal costs of buildings when conducting LCC analysis.

The formula for computing the Wilcoxon Test statistic (T) for small samples is shown below. The signed ranks are the values that are used to compute the positive and negative values in the formula. The construction of the Wilcoxon test is described as:

First, the variables was ranked and the ranks were assigned the signs of the corresponding differences.

T = smaller of $\sum R_+$ and $\sum R_-$ Where $\sum R_+$ is the sum of the ranks with positive differences and $\sum R_-$ is the sum of the ranks with negative differences. After the T statistic is computed, it is examined for significance using a table of critical values and a large sample approximation. For such large samples, a z-score was computed and a table with normal distribution was used. The formula below (applied in Gibbons and Chakraborti, 2011) was used to find the z-score of a Wilcoxon signed ranks test for the samples.

$$E(T) = \frac{n(n+1}{4} \quad \ldots\ldots (5.2)$$

Where E (T) is the mean and n is the number of matched pairs included in the analysis

$$V(T) = \frac{n(n+1)(2n+1)}{24} \quad \ldots\ldots (5.3)$$

Where V (T) is the variance.

The normal approximation leads to the Z-statistic $Z = \frac{T-n(n+1)/4}{\sqrt{\left[\frac{n(n+1)(2n+1)}{24}\right]}} \sim N(0,1)$

5.3.5 ARTIFICIAL NEURAL NETWORK MODELLING

The ANN modelling technique was used to make precise, informed and consistent approximations about probable maintenance and operating costs In this research, a supervised learning paradigm was chosen with multi-layer feed-forward architecture. The back propagation was selected as the learning algorithm because it is based on a relatively simple concept and its principles are clear.

The fundamental mechanism of back-propagation is to propagate input operating and maintenance cost values in a feed-forward manner through hidden layers of a network to the output layer, and then propagate errors back from the output layer to the input layer.

It has a powerful and accurate association between input and output patterns. Each of these inputs had an assigned weight factor w. The neuron calculated the sum of weighted inputs and bias (or internal offsets) and produced an output n given the following equation (Haykin et al., 2009):

$$N= \sum(w_{ij} * x_j) - \Phi_i \qquad (5.4)$$

For all j=1,2,….,N. Where w_i is the weight from node j to node I, xj is the output value of node j, and Φ_i is the node threshold value (also called bias, or internal offset). This value n then form the output to a transfer function within the neurons which then produce an output to be processed by another layer of neurons or signalled as a final output.

$F(x)= (1+e-(\mu x))^{-1}$ where μ is a slope parameter

5.3.6 STOCHASTIC MODELLING FOR HISTORICAL COSTS

This historical data is treated with scepticism and uncertainty as by explanation; it is deeply entrenched with the past while computer-generated data denotes the yet to come. The contention being that for maintenance and operating costs, data recorded in the past might be a weak benchmark for the future, more advanced asset management methods and higher quality products and consistency would make available diverse cost structures.

Hence, the need to develop mathematical models to determine the operating and maintenance historical costs of buildings (see appendix four for full development of model). This was achieved with the following probability distribution functions of total operating and maintenance costs in Present Value (PV) of total ownership of a building given as:

$$g(PV) = \frac{g(k)}{1+g(d)} \quad \text{(5.5)}$$

Where, $g(k) = (t1 + t2 + t3 + t4 + t5 + t6)$

Thus, substituting for$g(k)$,

Hence;

$$g(PV) = \frac{t1}{1+g(d)} + \frac{t2}{1+g(d)} + \frac{t3}{1+g(d)} + \frac{t4}{1+g(d)} + \frac{t5}{1+g(d)} + \frac{t6}{1+g(d)}$$

$t1(\text{Engineering services}) = f1 + f2 + f3 + f4 + f5,$

Where,

f1= Design complexity/ Faulty design

f2= Unfamiliarity with local and site conditions

f3= Low concern for future maintenance

f4= Poor LCC techniques

f5= Unfamiliarity of maintenance methods

$t2(Labour) = w1 + w2 + w3$

Where,

w1= Unavailability of skilled labour

w2= Unavailability of the foreign labours to culture

w3= Defects and faulty workmanship in the initial construction

$$t3\ (Building\ materials)\ =\ v1 + v2 + v3 + v4,$$

Where,

v1= Usage of cheaper substandard materials

v2= Ignorance about the physical and chemical properties of usage of materials

v3= Material selection does not comply with client activities

v4= Fluctuation of prices

$$t4\ (Budget\ and\ finance)\ =\ y1 + y2,$$

Where,

y1= Poor financial support for maintenance work

y2= Poor financial control onsite

$$t5\ (Building\ user -\ behaviour)\ =\ n1 + n2,$$

Where,

n1= Misuse

n2= Intensity of use

$$t6\ (Management\ and\ administration) =\ s1 + s2 + s3 + s4.$$

Where,

s1= Lack of building management manuals

s2= Lack of communication between maintenance contractors and clients

s3= Unavailability of maintenance contractors

s4= Lack of local productivity standard and specification

Hence,

$$g(PV) = \frac{f1}{1+g(d)} + \frac{f2}{1+g(d)} + \frac{f3}{1+g(d)} + \frac{f4}{1+g(d)} + \frac{f5}{1+g(d)} + \frac{w1}{1+g(d)} + \frac{w2}{1+g(d)} + \frac{w3}{1+g(d)} + \frac{v1}{1+g(d)} + \frac{v2}{1+g(d)} + \frac{v3}{1+g(d)} + \frac{v4}{1+g(d)} + \frac{y1}{1+g(d)} + \frac{y2}{1+g(d)} + \frac{n1}{1+g(d)} + \frac{n2}{1+g(d)} + \frac{s1}{1+g(d)} + \frac{s2}{1+g(d)} + \frac{s3}{1+g(d)} + \frac{s4}{1+g(d)}$$

Similarly, the Probability distribution function of total operating and maintenance costs in Present Value (PV) of total ownership of a building for two years is assumed to be;

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2}$$

Thus, g (PV) is a linear function. Moreover, the g (PV) for nth year, i.e. when t=nth year;

$$\boxed{g(PV) = \sum_{t=1}^{n} \frac{g(\mathrm{k})}{(1+g(d))^t}}$$

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2} + \frac{g(k)}{(1+g(d))^3} + \cdots + \frac{g(k)}{(1+g(d))^n}$$

5.3.7 STOCHASTIC MODELLING FOR ECONOMIC PERFORMANCE MEASURES

A variety of economic performance measurement techniques and key performance indicators were used to draw inference from the resulting LCC present values. When using LCC analysis techniques in the cost analysis of existing buildings, it is simply inadequate to forecast a cost value without providing the analyst or manager with the ability to draw inference from the results.

In previous applications of LCC where the concept has been used solely as a competing options decision-making tool in construction projects, the results simply inform the analyst which project is more economically viable.

Using economic performance indicators in conjunction with LCC analysis helps to provide the information that is required, information on cost performance of a building over a specified time period. The cost to income ratio was used to develop stochastic simulations as seen below (see appendix three for full development of model). The Cost/Income Ratio (CIR) for one year at r interest is given by:

$$CIR = \frac{C}{W} + \frac{C}{W(1+r)} \qquad (5.6)$$

The normal of the above equation is given as;

$$CIR = \frac{C \times (W \times (1+r) + W)}{W \times (W \times (1+r))}$$

Where

W (income) = t1+t2+t3

C (cost) = m1+m2+m3+m4+m5+m6+m7+k1+K2+k3+k4+k5+k6

m1=Major replacement costs

m2= Subsequent refurbishment and adaptation costs

m3= Redecorations

m4= Minor replacement, repairs and maintenance costs

m5=Unscheduled replacement, repairs and maintenance

m6= Client definable costs

m7= Grounds maintenance

k1=Utilities costs

k2=Administrative costs

k3=Overhead costs

k4=Client definable costs

k5=Cleaning costs

k6=Taxes

t1= Non-construction costs

t2= Externalities

t3= Income

Substituting income (W) and Cost(C) into CIR;

$$CIR = \frac{(m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6) \times ((t1 + t2 + t3) \times (1 + r) + (t1 + t2 + t3))}{(t1 + t2 + t3) \times ((t1 + t2 + t3) \times (1 + r))}$$

$$CIR = \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{(t1 + t2 + t3)} + \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{(t1 + t2 + t3) \times (1 + r)}$$

Therefore, following the linear model trend, using the mathematical Programming language, MAPLE17 the CIR for y number of years for the rth interest will become;

$$CIR = \sum_{n=0}^{y} \left(\frac{C}{W \times (1 + r)^n} \right)$$

Since C and W are non-function of n then:

$$CIR = \frac{C}{W} \sum_{n=0}^{y} \left(\frac{1}{(1 + r)^n} \right)$$

5.3.8 TEST OF HYPOTHESIS

Hypothesis can be defined as a procedure that allows us to know whether or not possible relationship exist between two or more variables. A statistical hypothesis is an assertion or statement about a probability distribution or about population parameter(s).

The Hypotheses tested in this study are listed below.

To test if the level of agreement of respondents who say key performance indicators and economic performance measures need to be incorporated into LCC is equal to the level of respondents who disagree.

Let M be the Median of the population of respondents who agree.

H_0: $M_{AGREEMENT} = M_{DISAGREMENT}$

H_1: $M_{AGREEMENT} < M_{DISAGREMENT}$

To test if the proportion of respondents who said the current LCC techniques are suitable for calculating the whole cost of buildings are more than the proportion of respondents who decline.

Let P represent the proportion of respondents who said the current LCC techniques are suitable for calculating the whole cost of buildings

$$H_0 : P = 0.5$$
$$H_1 : P < 0.5$$

To test the level of agreement or disagreement of respondents who says it is important to consider the initial, operating, maintenance and disposal costs of building when conducting LCC analysis.

Let M be the Median of the population of respondents who agree.

H_0: $M_{AGREEMENT} = M_{DISAGREMENT}$

H_1: $M_{AGREEMENT} < M_{DISAGREMENT}$

To test if the proportion of respondents who said historical costs data are very accurate are more than the proportion of respondents with converse view.

Let P represent the proportion of respondents who said historical costs data is very accurate.

$$H_0 : P = 0.5$$
$$H_1 : P < 0.5$$

5.4 VALIDITY AND RELIABILITY OF THE QUESTIONNAIRE AND MATHEMATICAL MODELS

The responses received from participants contained some missing data. Indeed it is the exceptional study that has no missing data (LoPresti, 1998). Missing data can be problematic in analysis and occurs for many reasons. According to LoPresti (1998), in reputable studies, analysis of missing data is required to improve the validity of the study. Therefore to end up with a good data set and to be able to use all the data collected in the analysis, some time was spent investigating and resolving the missing data problem.

The SPSS v.22 Missing Values Analysis option was used to analyse the patterns of missing data. It was decided after Hair et al (1998) that where missing data levels were not excessively high (in the order of 50% or more) cases and variables would not be excluded from analysis. Where appropriate, the Replace Missing Values option was used to replace the missing values with the mean of all valid responses.

Whilst several different options exist for replacing missing values, substitution with the mean is one of the most widely used (Xiao, 2002). This is so because it is considered as the best single replacement value (Hair et al., 1998). Besides, it is easy to calculate, hence its use in this study. To check appropriateness of this approach, the regression method and the estimation maximization (EM) method were also used to estimate alternative replacement values.

The reliability of the data collected was carried out using Cronbach's alpha coefficient (see appendix six) and the skewness and kurtosis test (see table 6.2). The measurement reliability is essential to the validity of the results of the questionnaire survey. These methods were calculated to investigate the internal consistency among alternative items used to measure the same underlying construct.

Akintoye (2000) and Diallo and Thuillier (2004) also adopted the approach to test the reliability of the Likert-type scale. The larger the value, the better the reliability in each component. The technique was employed to examine the internal consistency among the responses of respondents. The mathematical and ANN models were validated using regression, performance test, error autocorrelation and mean squared error.

5.5 OBJECTIVITY TESTING OF RESEARCH FIELD

This process constituted the presentation of two peer reviewed papers at international conferences (Association of Researchers in Construction Management in Portsmouth, September, 2014 and CIBW in Lagos, Nigeria, January, 2014). The purpose of this exercise was to test the validity of the research topic and the theoretical framework adopted in this research. The aim of this approach was also to verify a research direction through a peer review process by experts. The responses from these conferences were positive and suggested comments were subsequently integrated in the research.

5.6 SUMMARY OF RESEARCH METHOD

This chapter has provided a framework of the research methodology implemented for carrying out this study. Combinations of approaches are implemented to allow a comprehensive research of the LCC and sustainable commercial office buildings, which assisted in accomplishing the study aim and objectives.

This included first, an in-depth literature review, then a pilot survey for adjusting the questionnaires for an ensuing postal survey to investigate knowledge and awareness of construction practitioners regarding the concept of LCC and sustainable commercial office buildings. The data gathered were investigated, with the aid of SPSS 22 and applying a selection of statistical approaches as well as descriptive statistics, factor analysis, descriptive statistics analysis, anova and factor analysis.

Information collected from literature review and the survey was employed to draw inferences and deductions in respect of the study objectives; and develop a model for LCC methodology for sustainable commercial office buildings. Secondary data from the BCIS and primary data from a carefully selected sustainable commercial office building were also used in developing the model.

CHAPTER SIX

PILOT AND MAIN SURVEY ANALYSIS

6.0 INTRODUCTION

This section discusses the results of the pilot and main survey analysis. The pilot survey was distributed to a random sample of forty individuals with thirty respondents returning the questionnaire. The pilot survey allowed for the easy detection of obstacles in the main questionnaire. The problems identified were that some of the germane questions were left unanswered and some of the respondents ticked more than one option in a question. As a result, some of the questions were restructured and it was clearly stated in the main survey questionnaire that only one option should be ticked.

The questions answered in the pilot survey bordered around the following:

i) Applications and limitations of LCC in sustainable commercial office buildings.

ii) Determining the level of awareness of key performance indicators, economic performance measures, risk assessment techniques and forecasting methods. It also ascertained whether key performance indicators and economic performance measures need to be incorporated into LCC, whether it is important to consider the initial, operating and maintenance costs of building when conducting LCC analysis, whether historical cost data is accurate and whether the current LCC techniques are suitable for calculating the whole costs of buildings

iii) Ranking of the technological and non-technological barriers of sustainable commercial office buildings.

6.1 APPLICATIONS AND LIMITATIONS OF LCC IN SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

The first objective of the pilot survey was to rank the applications and limitations of LCC. The summary statistics of the analysed variables are presented in Table 6.1. The t-value column provided the individual significance of each independent variable in the regression equation and indicated whether the variable was making statistically significant contribution. A variable must have a significant value of alpha less than 0.05 to make significantly unique contribution.

Table 6.1: Summary statistics of the analysed variables

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.333	58.872		.074	.953
	LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS	-.333	1.037	-.723	-.321	.802
	LCC ACTS AS A MAINTENANCE GUIDE	1.667	2.900	1.697	.575	.668
	LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL	.333	2.208	.525	.151	.905
	LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE	.333	1.773	.231	.188	.882
	BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS	-.167	1.126	-.195	-.148	.906
	LACK OF COMMON AND STANDARD METHODOLOGY	-3.000	7.531	-1.528	-.398	.759
	LACK OF RELIABLE DATA	.500	2.398	.509	.209	.869
	RISK AND UNCERTAINTY	.667	7.552	.463	.088	.944
	MARKET CONDITIONS AND ASSUMPTIONS	-.333	1.530	-.248	-.218	.863
	DEALING WITH INTANGIBLE FACTORS	4.498E-14	1.000	.000	.000	1.000
	TYPE OF INVESTOR/USER	.667	1.486	1.050	.449	.732
	TIME CONSUMING AND COST IMPLICATIONS	-.167	.799	-.231	-.209	.869
	LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	-.333	2.830	-.667	-.118	.925

a. Dependent Variable: THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS

The above table 6.1 presents the summary for the applications and limitations of LCC in sustainable commercial office buildings. All the applications and limitations do not made statistically unique contribution to sustainable commercial office buildings at 95% confidence level with R^2 = 0.861 (86.1%), F- Statistics = 0.477 (P > .000) and the overall significant value of 0.829 which is greater than 0.05 thus showing that all predictor variables are not significantly acceptable.

The box labelled 'model summary' (Table 6.2) gives the measure of how well the overall model fits, and how well the predictors are able to predict the dependent variable. The first measure in the table is called R. This is a measure of how well the predictors predict the outcome, but the square of R provides a more accurate measure. In this case, it is 0.861, so 86.1% of the variance in the dependent variable can be explained by the predictors. The final column gives the standard error of the estimate. This is a measure of how much R is predicted to vary from one sample to the next.

Table 6.2: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.928[a]	.861	-.944	.707

b. Dependent Variable: THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS

The Table 6.3 shows the ANOVA results. The F-value is the Mean Square Regression (0.238) divided by the Mean Square Residual (0.500), yielding F=477. The p-value associated with this F value is very small (0.0000). These values are used to answer the question "Do the independent variables reliably predict the dependent variable?" The p-value is compared to the alpha level (typically 0.05) and, if smaller, one can conclude the independent variables reliably predict the dependent variable. It is glaring that the group of (independent) variables can be used to reliably predict the dependent variable. The overall significant value (0.042) is less than the standardized significant value which reveals that the causes are generally acceptable

Table 6.3: Anova

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	3.100	13	.238	.477	.829[a]
	Residual	.500	1	.500		
	Total	3.600	14			

6.2 LCC AWARENESS

The results show that respondents were slightly aware of key performance indicators, economic performance measures and risk assessment techniques. Respondents were however somewhat aware of forecasting methods.

Respondents also strongly agreed that key performance indicators and economic performance measures need to be incorporated into LCC and that it is important to consider the initial, operating and maintenance costs of building when conducting LCC analysis.

Respondents however disagreed that the current LCC techniques are suitable for calculating the whole costs of buildings and were undecided on the accuracy of historical cost data (see appendix ten for frequency tables).

6.3 RANKING OF THE DRIVERS AND BARRIERS OF SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

The third objective of the pilot survey was to rank the drivers and barriers of sustainable commercial office buildings. The overall mean showed summary statistics of the analysed variables as presented in the Table 6.4. The overall column provided the individual significance of each independent variable.

6.4 MEASURE OF SKEWNESS AND KURTOSIS

A fundamental task in many statistical analyses is to characterise the location and variability of a data set. A further characterisation of the data includes skewness and kurtosis. Measure of Skewness and Kurtosis columns in figures 6.1 and 6.2 showed that all the data set in the pilot study look the same to the left and right of the centre point and the data has a distinct peak near the mean, decline rather rapidly with heavy tails thus validating the results of the pilot study (figure 6.1 and 6.2).

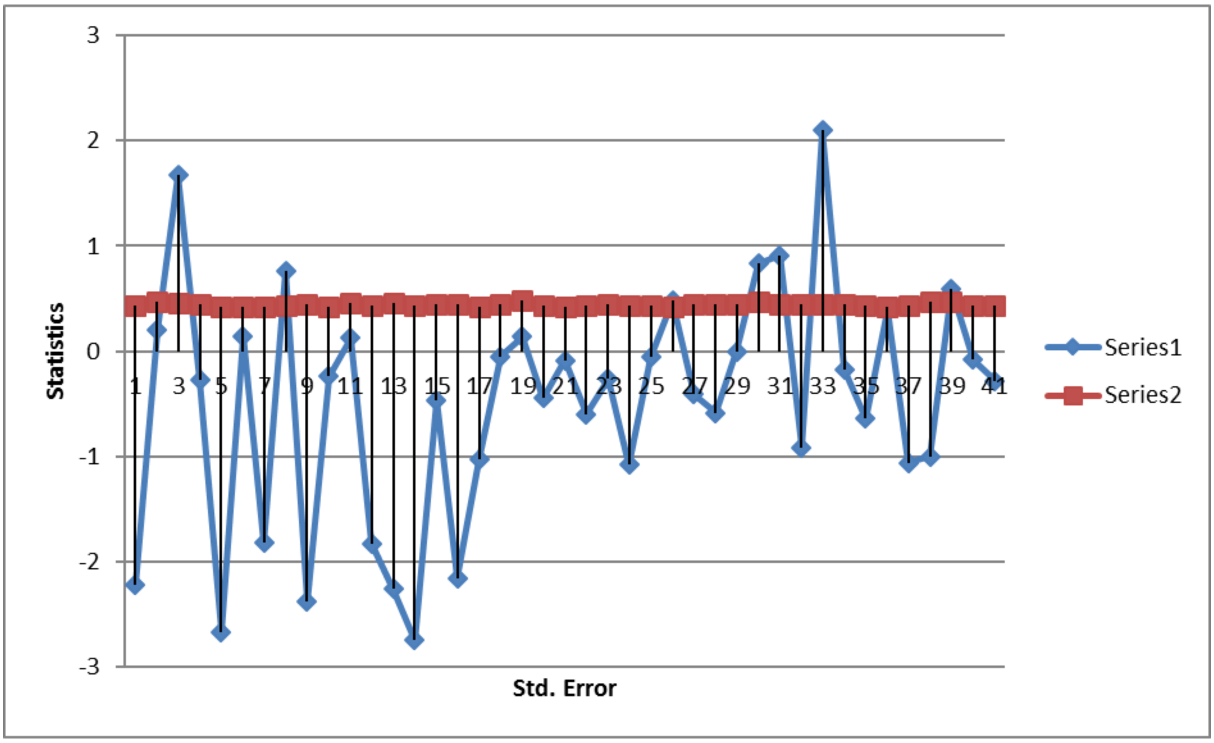


Figure 6.1: Measure of Skewness

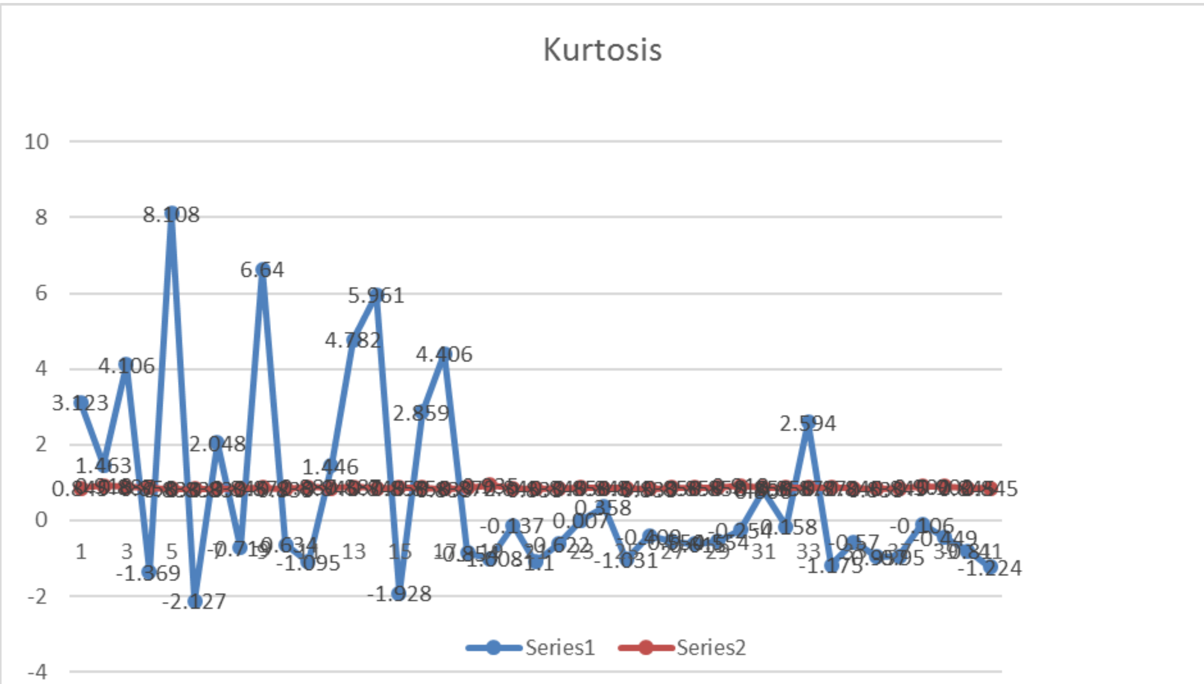


Figure 6.2: Measure of Kurtosis

The Table 6.4 shows the descriptive statistics of all the variables in the pilot survey. It also shows the measure of skewness and kurtosis as well as the overall ranking of each of the variables.

Table 6.4: Descriptive statistics of the analysed variables

Descriptive Statistics										
	N	Minimum	Maximum	Mean	Std. Dev.	Skewness		Kurtosis		Overall
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error	Mean
KEY PERFORMANCE INDICATORS	29	1	2	1.86	.351	-2.216	.434	3.123	.845	Slightly Aware
ECONOMIC PERFORMANCE MEASURE	24	1	3	2.08	.504	.196	.472	1.463	.918	Slightly Aware
RISK ASSESSMENT TECHNIQUES	26	1	5	1.81	.939	1.670	.456	4.106	.887	Slightly Aware
FORECASTING METHOD	28	1	5	3.04	1.503	-.277	.441	-1.369	.858	Somewhat Aware
KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES NEED TO BE INCORPORATED INTO LCC	30	1	5	4.57	.898	-2.666	.427	8.108	.833	Strongly Agree
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	30	1	2	1.47	.507	.141	.427	-2.127	.833	Strongly Disagree
IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING, MAINTENANCE AND DISPOSAL COSTS OF BUILDING WHEN CONDUCTING LCC ANALYSIS	30	3	5	4.67	.661	-1.820	.427	2.048	.833	Strongly Agree

HISTORICAL COSTS DATA IS VERY ACCURATE	29	1	5	2.31	1.391	.764	.434	-.719	.845	Neutral
LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS	27	1	5	4.48	.935	-2.380	.448	6.640	.872	Strongly Agree
LCC ACTS AS A MAINTENANCE GUIDE	30	3	5	4.20	.664	-.242	.427	-.634	.833	Agree
LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL	26	3	5	3.92	.744	.127	.456	-1.095	.887	Agree
LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE	29	4	5	4.83	.384	-1.831	.434	1.446	.845	Strongly Agree
BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS	26	3	5	4.77	.514	-2.260	.456	4.782	.887	Strongly Agree
LACK OF COMMON AND STANDARD METHODOLOGY	29	4	5	4.90	.310	-2.748	.434	5.961	.845	Very High
LACK OF RELIABLE DATA	28	4	5	4.61	.497	-.464	.441	-1.928	.858	Very High

RISK AND UNCERTAINTY	28	4	5	4.86	.356	-2.159	.441	2.859	.858	Very High
MARKET CONDITIONS AND ASSUMPTIONS	30	2	5	4.10	.607	-1.029	.427	4.406	.833	High
DEALING WITH INTANGIBLE FACTORS	27	3	5	4.04	.706	-.052	.448	-.854	.872	High
TYPE OF INVESTOR/USER	23	1	3	1.91	.733	.139	.481	-1.008	.935	Low
TIME CONSUMING AND COST IMPLICATIONS	29	2	5	4.00	.802	-.447	.434	-.137	.845	High
LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	30	1	4	2.60	1.037	-.087	.427	-1.100	.833	Neutral
ECONOMIC DRIVER: RETURN ON INVESTMENT	29	1	5	3.34	1.289	-.597	.434	-.622	.845	Neutral
ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES	28	2	5	3.57	.742	-.263	.441	.007	.858	Agree
ECONOMIC DRIVER: COST EFFECTIVENESS	29	1	5	3.72	1.251	-1.082	.434	.358	.845	Agree
ECONOMIC DRIVER: FILLING A DESIGN NEED	29	3	5	4.03	.731	-.054	.434	-1.031	.845	Agree
ECONOMIC DRIVER: EASE IN LEASING	30	1	5	2.83	1.177	.481	.427	-.409	.833	Neutral
SOCIAL DRIVER: INCREASED PRODUCTIVITY	28	3	5	4.36	.621	-.407	.441	-.554	.858	Agree
SOCIAL DRIVER: HIGH TENANTS RETENSION RATE	28	3	5	4.36	.678	-.586	.441	-.615	.858	Agree
SOCIAL DRIVER: CLIENTS REQUIREMENTS	28	3	5	4.00	.667	.000	.441	-.554	.858	Agree
SOCIAL DRIVER: ATTRACT TENANTS	24	3	5	3.54	.658	.833	.472	-.254	.918	Agree

SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES	28	2	5	3.25	.799	.908	.441	.806	.858	Neutral
TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS	28	2	5	3.71	.976	-.914	.441	-.158	.858	High
TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE	27	3	5	3.30	.724	2.099	.448	2.594	.872	Neutral
TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING(LCC)	27	1	5	3.19	1.388	-.171	.448	-1.175	.872	Neutral
TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARENESS/UNDERSTANDING AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS	29	3	5	4.38	.677	-.641	.434	-.570	.845	High
TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION	30	3	5	3.77	.728	.396	.427	-.957	.833	High
NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS	29	4	5	4.72	.455	-1.059	.434	-.950	.845	Very High
NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINDS	25	1	5	3.84	1.313	-1.002	.464	-.106	.902	High
NON-TECHNOLOGICAL BARRIER:	25	1	5	2.72	1.208	.590	.464	-.449	.902	Neutral

LEARNING PERIOD										
NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS	29	1	4	2.48	.949	-.082	.434	-.810	.845	Neutral
NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT	29	1	4	2.79	1.082	-.285	.434	-1.224	.845	Neutral
Valid N (listwise)	4									

Source: Analysis of pilot survey, 2014.

6.5 MAIN SURVEY RESULTS

The sample employed in the main survey was obtained from a databank of construction professionals listed in the UK Royal Institution of Chartered Surveyors (RICS). A total of one hundred and fifty questionnaires were mailed out to participants for purpose of this survey. This data was subjected to six different statistical tests with a view to guaranteeing the success of the test of the hypotheses namely t-test, Z-distribution, F-test, Dubin Watson and Wilcoxon signed rank test.

6.6 LCC AWARENESS AND RELATED ACTIONS

One of the objectives of the research was to determine the level of application and awareness of LCC in the construction industry. The responding construction professionals largely indicated that they were not aware of certain elements of LCC namely key performance indicators, forecasting methods, risk assessment techniques and economic performance measures. This is in line with other studies (Korpi and Ala-Risku, 2008; Olubodun et al., 2010; Oduyemi et al., 2014) who observe that the method that “persists to suffer in oblivion”. The following frequency tables 6.5 to 6.8 show the breakdown and subsequent discussions of the LCC elements.

Table 6.5: Key performance indicators.

KEY PERFORMANCE INDICATORS

		Frequency	Percentage	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	12	17.4	17.4	17.4
	SLIGHTLY AWARE	52	75.4	75.4	92.8
	SOMEWHAT AWARE	5	7.2	7.2	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

The result shows that 75.4% of the survey participants were slightly aware of key performance indicators and 17.4% were not aware at all. Similarly, 7.2% were somewhat aware of key performance indicators. None of the respondents were extremely aware of the method.

The relevance of KPIs' cannot be over emphasised as the figures made available by a KPI can be employed to ascertain how the running costs of managing of facilities equate with the existing standard, and consequently can develop a main element in a firm's step in the direction of best practice and value for money.

Surprisingly no research has sought to determine the level of application and awareness of key performance indicators in LCC. This research paints a gloomy picture as regards its application and awareness.

Table 6.6: Economic performance measures

ECONOMIC PERFORMANCE MEASURES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	13	18.8	18.8	18.8
	SLIGHTLY AWARE	47	68.1	68.1	87.0
	SOMEWHAT AWARE	8	11.6	11.6	98.6
	EXTREMELY AWARE	1	1.4	1.4	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

The result shows that 68.1% of the survey participants were slightly aware of economic performance measures and 18.8% were not aware at all. Similarly, 11.6% were somewhat aware of key performance measures while 1.4% were extremely aware of economic performance measures while none of the respondents was moderately aware of economic performance measures. It is merely insufficient to estimate a cost value devoid of offering the forecasters or users with the capacity to obtain conclusion from the outcomes. Using economic performance measures help to make available the information that is required for building performance.

Table 6.7: Risk assessment techniques

RISK ASSESSMENT TECHNIQUES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	28	40.6	40.6	40.6
	SLIGHTLY AWARE	28	40.6	40.6	81.2
	SOMEWHAT AWARE	10	14.5	14.5	95.7
	MODERATELY AWARE	1	1.4	1.4	97.1
	EXTREMELY AWARE	2	2.9	2.9	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

The result shows that 40.6 % of the survey participants were slightly aware of risk assessment techniques and 40.6% were not aware at all. Similarly, 14.5% were somewhat aware of risk assessment techniques while 1.4% were moderately aware of risk assessment techniques. 2.9% of respondents were extremely aware.

This shows a limited level of application of risk assessment techniques. The lack of risk and improbability assessment methods would result in grave restrictions to the use of the LCC methods, as cost computations would be inexact, with non- manageable values not being considered. Applying these procedures and steps would augment the accuracy of cost forecasts, accelerating the integration into the examination of unanticipated happenings all through the life cycle of the building.

Table 6.8: Forecasting methods

FORECASTING METHODS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	21	30.4	30.4	30.4
	SLIGHTLY AWARE	9	13.0	13.0	43.5
	SOMEWHAT AWARE	12	17.4	17.4	60.9
	MODERATELY AWARE	20	29.0	29.0	89.9
	EXTREMELY AWARE	7	10.1	10.1	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

The result shows that 13.0 % of the survey participants were slightly aware of forecasting methods and 30.4% were not aware at all. Similarly, 17.4% were somewhat aware of forecasting methods while 29.0% was moderately aware of forecasting methods. 10.1% of respondents were extremely aware. LCC always involves forecasting as it has to do with estimating and projecting values. Hence, it should be an integral part of LCC. The results however show a limited application of these methods.

6.7 HYPOTHETICAL STATEMENTS RELATING TO LCC

Certain hypothetical statements relating to LCC were stated, analysed and tabulated. The following statements were first ranked and then a test of hypothesis on the population proportion to the respondents' profiles was carried out.

6.7.1 KEY PERFORMANCE INDICATORS AND ECONOMIC PERFROMANCE MEASURES NEED TO BE INTEGRATED INTO LCC

The responding construction professionals indicated that there was a need to integrate and incorporate key performance indicators and economic performance measures into LCC as 81.2% and 13.0% of respondents strongly agreed and agreed respectively with this statement.

Therefore, key performance indicators and economic performance measures are especially imperative for users to appraise and distribute recognisable value from initial costs and maintenance costs to important shareholders in the life-cycle of an asset.

This will permit the concern of several shareholders' goals in the calculation of the LCC implementation and execution of an asset over a stated time period.

1.4% of respondents disagreed while 4.3% neither agreed nor disagreed with the statement (Table 6.9).

However, common conventional investment evaluation methods which emphasise on cash flows signified by the costs and anticipated proceeds of a development discounted to a general base period fail to reveal the entire value of capital outflow alternatives which consist of intangible and non-monetary remunerations along with decline of imminent costs and monetary incomes.

This research introduces a set of economic performance measures for the life cycle costing of sustainable commercial office buildings (see chapter seven).

Table 6.9: Key performance indicators and economic measures need to be incorporated into LCC

KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES NEED TO BE INCORPORATED INTO LCC

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	DISAGREE	1	1.4	1.4	1.4
	NEITHER AGREE NOR DISAGREE	3	4.3	4.3	5.8
	AGREE	9	13.0	13.0	18.8
	STRONGLY AGREE	56	81.2	81.2	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

6.7.2 THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE WHOLE COSTS OF BUILDING

The responding construction professionals strongly disagreed and disagreed that the current LCC techniques are suitable for calculating the costs of building as 50.7% and 37.7% of respondents strongly agreed and agreed respectively with this statement. 10.1% of respondents neither agreed nor disagreed while 1.4% agreed with the statement (Table 6.10).

Hence, the need for comprehensive frameworks with which to analyse the long-term cost of ownership for sustainable commercial office buildings as the costs of running and maintaining these buildings make up a significant portion of their entire outlay. This was achieved in the subsequent chapter of the thesis.

Table 6.10: The current LCC techniques are suitable for calculating the costs of buildings

THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	35	50.7	50.7	50.7
	DISAGREE	26	37.7	37.7	88.4
	NEITHER AGREE NOR DISAGREE	7	10.1	10.1	98.6
	AGREE	1	1.4	1.4	100.0
	Total	69	100.0	100.0	

6.7.3 IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING AND MAINTENACE COSTS OF BUILDINGS WHEN CONDUCTING LCC ANALYSIS

The responding construction professionals strongly agreed (94.2%) and disagreed (5.8%) that it is important to consider the initial, operating and maintenance costs of buildings when conducting LCC analysis respectively with this statement (Table 6.11).

Rather than considering just the initial cost, the significance of considering LCC is very clear considering running costs, such as energy, maintenance, security, and cleaning costs is also important. LCC allocation differs from building to building according to their types and functions. For example, the initial cost of an office building is considered as the largest single cost. It represents 42% of the LCC and 58% of the running or future costs; cleaning, 20%; other rates such as water, 16%; energy, 10%; annual maintenance, 7%; other maintenance, 5% (Flangan, 1989). From, the above discussion, one can deduce that it is indeed important to consider the initial, operating and maintenance costs of buildings when conducting LCC analysis.

Table 6.11: It is important to consider the initial, operating, maintenance and disposal costs of building when conducting LCC analysis

IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING, MAINTENANCE AND DISPOSAL COSTS OF BUILDING WHEN CONDUCTING LCC ANALYSIS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	AGREE	4	5.8	5.8	5.8
	STRONGLY AGREE	65	94.2	94.2	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

6.7.4 HISTORICAL COST DATA IS VERY ACCURATE

The responding construction professionals strongly disagreed and disagreed that historical costs data is very accurate as 43.5% and 33.3% of respondents strongly agreed and agreed respectively with this statement. 13.0% of respondents neither agreed nor disagreed while 15.8% agreed with the statement. Finally, 4.3% of respondents strongly agreed that historical costs data is accurate (Table 6.12).

Indeed, numerous researchers admit that the absence of readily obtainable and reliable LCC data constitutes a significant obstacle that hinders its effective practical application (Bouachera et al., 2007; Pelzeter, 2007; Bakis et al., 2003). Hence, the need to develop mathematical models to determine the operating and maintenance historical costs of sustainable commercial office buildings as done in the chapter seven of the thesis

Table 6.12: Historical cost data is very accurate

HISTORICAL COSTS DATA IS VERY ACCURATE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	30	43.5	43.5	43.5
	DISAGREE	23	33.3	33.3	76.8
	NEITHER AGREE NOR DISAGREE	9	13.0	13.0	89.9
	AGREE	4	5.8	5.8	95.7
	STRONGLY AGREE	3	4.3	4.3	100.0
	Total	69	100.0	100.0	

Source: Analysis of surveyed data, 2014.

6.8 TEST OF HYPOTHESIS FOR KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES

Key performance indicators and economic performance measures need to be incorporated into LCC * Respondent's view

Table 6.13: Wilcoxon Signed Test

Key performance indicators and economic performance measures need to be incorporated into LCC			
STRONGLY AGREE	56	AGREE	9
STRONGLY DIAGREE	0	DISAGREE	1

H_0: $M_{AGREEMENT} = M_{DISAGREEMENT}$

H_1: $M_{AGREEMENT} < M_{DISAGREEMENT}$

$d = X_{AGREEMENT} - X_{DISAGREEMENT}$	$\|d\|$	Rank of $\|d\|$	Signed – Rank of $\|d\|$
56	56	2	-2
8	8	1	-1

T = 2+1=3

E(t) = 1.5

V(t) = 1.25

$$Z = \frac{T - E(t)}{\sqrt{V(t)}} = \frac{3 - 1.5}{\sqrt{1.25}} = \frac{1.5}{1.118} = 1.34$$

For a 1− tailed test at 5% i.e. $\alpha = 0.05$ z – critical value = 1.65

DECISION: Since Z does not fall in the critical region, we Accept H_0: $M_{AGREEMENT} = M_{DISAGREEMENT}$ and Reject H_1: $M_{AGREEMENT} < M_{DISAGREEMENT}$.

Hence, the hypothesis that the median of the population of AGREEMENT reveals that key performance indicators and economic performance measures need to be incorporated into LCC.

6.9 TEST OF HYPOTHESIS FOR THE SUITABILITY OF LCC METHODS

H_0 : Proportion of respondents who said the current LCC techniques are suitable for calculating the whole cost of buildings is equal to 0.5

H_1 : Proportion of respondents who said the current LCC techniques are not suitable for calculating the whole cost of buildings is less than 0.5

$$H_0 : P = 0.5$$
$$H_1 : P < 0.5$$

P is the proportion of respondents who said the current LCC techniques are suitable for calculating the whole cost of buildings.

P is estimated by $\hat{P}$

where n' is the number of respondents who said the current LCC techniques are not suitable for calculating the whole cost of buildings

n is the total number of respondents sample

$$\hat{p} = \frac{8}{69} = 0.12$$
$$\hat{q} = 1 - \hat{p} = 1 - 0.12 = 0.88$$
$$\hat{V}(\hat{p}) = (1 - f)\frac{\hat{p}\hat{q}}{n-1}, \ f = \frac{n}{N}$$
$$\hat{V}(\hat{p}) = \left(1 - \frac{69}{250}\right)\frac{0.12 \times 0.88}{69 - 1}$$
$$\hat{V}(\hat{p}) = 0.0009$$
$$Z_0 = \frac{|p - p_0|}{\sqrt{\hat{V}(\hat{p})}} = \frac{|0.12 - 0.5|}{\sqrt{0.0009}} = 12.67$$

$Z_\alpha = Z_{0.05} = 1.64$ (Single tailed test)

Hence, $Z_o > Z_\alpha$. Thus H_0 is rejected and H_1 is accepted That is, the current LCC techniques are not suitable for calculating the whole costs of buildings

6.10 TEST OF HYPOTHESIS FOR THE ELEMENTS OF LCC

It is important to consider the initial, operating, maintenance and disposal costs of buildings when conducting LCC analysis *Respondent's view

Table 6.14: Wilcoxon Signed Test

It is important to consider the initial, operating, maintenance and disposal costs of buildings when conducting LCC analysis			
STRONGLY AGREE	65	AGREE	4
STRONGLY DIAGREE	0	DISAGREE	0

H_0: $M_{AGREEMENT} = M_{DISAGREEMENT}$

H_1: $M_{AGREEMENT} < M_{DISAGREEMENT}$

$d = X_{AGREEMENT} - X_{DISAGREEMENT}$	$\|d\|$	Rank of $\|d\|$	Signed – Rank of $\|d\|$
65	65	2	-2
4	4	1	-1

T = 2+1=3

E(t) = 1.5

V(t) = 1.25

$$Z = \frac{T - E(t)}{\sqrt{V(t)}} = \frac{3 - 1.5}{\sqrt{1.25}} = \frac{1.5}{1.118} = 1.34$$

For a 1− tailed test at 5% i.e $\alpha = 0.05$ z – critical value = 1.65

DECISION: Since Z does not fall in the critical region, H_0: $M_{AGREEMENT} = M_{DISAGREEMENT}$ is accepted and H_1 : $M_{AGREEMENT} < M_{DISAGREEMENT}$ is rejected.

Hence, the hypothesis that the median of the population of AGREEMENT affirm that it is important to consider the initial, operating, maintenance and disposal cost of buildings when conducting LCC analysis.

6.11 TEST OF HYPOTHESIS FOR THE ACCURACY OF HISTORICAL COSTS

H_0 : Proportion of respondents who said historical costs data is very accurate is equal to 0.5

H_1 : Proportion of respondents who said historical costs data is not very accurate is less than 0.5

$$H_0 : P = 0.5$$
$$H_1 : P < 0.5$$

P is the proportion of respondents who said historical costs data is very accurate.

P is estimated by $\hat{P}$

where n' is the number of respondents who said historical costs data is very accurate

n is the total number of respondents sample

$$\hat{p} = \frac{16}{69} = 0.23$$
$$\hat{q} = 1 - \hat{p} = 1 - 0.23 = 0.77$$
$$\hat{V}(\hat{p}) = (1 - f)\frac{\hat{p}\hat{q}}{n-1}, f = \frac{n}{N}$$
$$\hat{V}(\hat{p}) = \left(1 - \frac{69}{250}\right)\frac{0.23 \times 0.77}{69 - 1}$$
$$\hat{V}(\hat{p}) = 0.0019$$
$$Z_0 = \frac{|p - p_0|}{\sqrt{\hat{V}(\hat{p})}} = \frac{|0.23 - 0.5|}{\sqrt{0.0019}} = 6.19$$

$$Z_\alpha = Z_{0.05} = 1.64 \qquad \text{(Single tailed test)}$$

Hence , $Z_o > Z_\alpha$. H_0 is rejected. That is, the proportion of respondents who said historical costs data is very accurate is less than the proportion of respondents who said historical costs data is not very accurate.

6.12 APPLICATIONS OF LIFE CYCLE COSTING

The next objective of the thesis was to rank the applications of LCC. This was achieved using factor analysis. This analysis was executed with the help of SPSS Statistics v22. Bartlett's Test of Sphericity and Kaiser– Meyer–Olkin (KMO) measure were carried out to scrutinise the sampling capability confirming that factor analysis was going to be suitable for the study. Principal component analysis was then employed to extricate group factors with eigenvalues greater than 1, overwhelming all other factors with eigenvalues less than 1 based on Kaiser’s criterion (Kim and Mueller, 1994; Field, 2000).

Before the factor analysis, validity test for factors was conducted according to the method by Kaiser (1974). By Kaiser Method, a value called eigenvalue under 1 is perceived as being inadequate and therefore unacceptable for factor analysis.

Based on Kaiser’s eigenvalue rule, factor analysis is performed and the retained factor requires the eigenvalue to be larger than 1. After the primary factor analysis, oblique rotation method was used to look for a linear combination of the original factors, such that the variance of the loadings is maximised. The final factor analysis results are shown in Table 6.15.

Table 6.15: Factor Analysis

Correlation Matrix							
		(1)	(2)	(3)	(4)	(5)	(6)
Correlation	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	1.000	.114	-.019	-.348	.131	.156
	LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS (2)	.114	1.000	-.017	-.218	-.013	-.113
	LCC ACTS AS A MAINTENANCE GUIDE (3)	-.019	-.017	1.000	.133	-.114	-.249
	LCC ACTS AS A MANAGEMENT AND DECISION	-.348	-.218	.133	1.000	-.098	-.010

	MAKING TOOL (4)						
	LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE (5)	.131	-.013	-.114	-.098	1.000	.139
	BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS (6)	.156	-.113	-.249	-.010	.139	1.000
Sig. (1-tailed)	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)		.176	.439	.002	.142	.100
	LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS (2)	.176		.444	.036	.459	.177
	LCC ACTS AS A MAINTENANCE GUIDE (3)	.439	.444		.137	.175	.020
	LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL (4)	.002	.036	.137		.212	.467
	LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE (5)	.142	.459	.175	.212		.128
	BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS (6)	.100	.177	.020	.467	.128	

From the correlation above (table 6.15), it was deduced that all the applied factors were insignificant except for ‘’LCC acts as a management and decision making tool. This particular factor has a standardized significant value of (o.o5). However, it was observed that two factors (LCC indicates cost category and presents a possibility for investigation into the inter-relationship between performance of a building and its running costs and LCC acts as a maintenance guide) resulted with eigenvalues greater than 1, capturing 48.043% of total variance (see table 6.16).

Table 6.16: Total variance

Extraction Method: Principal Component Analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.596	26.600	26.600	1.596	26.600	26.600
2	1.287	21.443	48.043	1.287	21.443	48.043
3	.943	15.722	63.765			
4	.874	14.573	78.337			
5	.738	12.302	90.639			
6	.562	9.361	100.000			

.

The value of KMO is 0.533, which is above Kaiser's (1974) specification of 0.5. The factor scores were generated by using the Bartlett method, which calculated for each response, the 'weighted sum' of their standardized value for every variable multiplied by the corresponding factor loading of the variable in Table 6.17.

Table 6.17: KMO and Bartlett's test

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.533
Bartlett's Test of Sphericity	Approx. Chi-Square	23.049
	Df	15
	Sig.	.083

6.13 LIMITATIONS OF LIFE CYCLE COSTING

Factor analysis was also employed to analyse the structure of interrelationships among the variables. From the correlation in Table 6.18 it was deduced that all the limitations of LCC were above the standardised significant value of (o.o5) i.e. all the limitations hold.

Table 6.18: Factor Analysis

Correlation Matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Correlation	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	1.000	-.129	-.041	.177	-.068	-.150	.161	.044	-.136
	LACK OF COMMON AND STANDARD METHODOLOGY (2)	-.129	1.000	.197	-.043	.064	.327	-.446	-.110	-.054
	LACK OF RELIABLE	-.041	.197	1.000	-.069	-.170	-.033	-.189	-.268	.056

	DATA (3)									
	RISK AND UNCERTAINTY (4)	.177	-.043	-.069	1.000	.056	.008	.073	-.242	-.278
	MARKET CONDITIONS AND ASSUMPTIONS (5)	-.068	.064	-.170	.056	1.000	.162	-.072	.039	-.001
	DEALING WITH INTANGIBLE FACTORS (6)	-.150	.327	-.033	.008	.162	1.000	-.031	.139	-.175
	TYPE OF INVESTOR/USER (7)	.161	-.446	-.189	.073	-.072	-.031	1.000	.122	-.012
	TIME CONSUMING AND COST IMPLICATIONS (8)	.044	-.110	-.268	-.242	.039	.139	.122	1.000	.046
	LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS (9)	-.136	-.054	.056	-.278	-.001	-.175	-.012	.046	1.000
Sig. (1-tailed)	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)		.145	.368	.073	.290	.110	.093	.360	.132
	LACK OF COMMON AND STANDARD METHODOLOGY (2)	.145		.052	.362	.300	.003	.000	.185	.331
	LACK OF RELIABLE DATA (3)	.368	.052		.287	.081	.393	.060	.013	.323
	RISK AND UNCERTAINTY (4)	.073	.362	.287		.323	.473	.276	.022	.010
	MARKET CONDITIONS AND ASSUMPTIONS (5)	.290	.300	.081	.323		.092	.280	.377	.496
	DEALING WITH INTANGIBLE FACTORS (6)	.110	.003	.393	.473	.092		.401	.128	.076
	TYPE OF INVESTOR/USER (7)	.093	.000	.060	.276	.280	.401		.159	.460
	TIME CONSUMING AND COST IMPLICATIONS (8)	.360	.185	.013	.022	.377	.128	.159		.353
	LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS (9)	.132	.331	.323	.010	.496	.076	.460	.353	

It was observed that four factors (lack of common standard methodology, lack of reliable data, risk and uncertainty and market conditions and assumptions) resulted with eigenvalues greater than 1, capturing 63.487% of total variance (see table 6.19).

Table 6.19: Total variance

Extraction Method: Principal Component Analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.799	19.992	19.992	1.799	19.992	19.992	1.424	15.824	15.824
2	1.463	16.253	36.245	1.463	16.253	36.245	1.384	15.376	31.200
3	1.443	16.033	52.278	1.443	16.033	52.278	1.267	14.073	45.273
4	1.009	11.209	63.487	1.009	11.209	63.487	1.226	13.625	58.898
5	.881	9.784	73.271	.881	9.784	73.271	1.036	11.510	70.408
6	.758	8.419	81.690	.758	8.419	81.690	1.015	11.282	81.690
7	.660	7.329	89.018						
8	.559	6.206	95.224						
9	.430	4.776	100.000						

.

The value of KMO is 0.524, which is above Kaiser's (1974) specification of 0.5. Therefore, the results shown in Table 6.20 proved that all the factors presented an adequate reliability. The four factors (lack of common standard methodology, lack of reliable data, risk and uncertainty and market conditions and assumptions) however stood out as crucial and pertinent limitations of LCC application. The factor scores were generated by using the Bartlett method (table 6.20), which calculates for each response, the 'weighted sum' of their standardized value for every variable multiplied by the corresponding factor loading of the variable.

Table 6.20: KMO and Bartlett's test

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.524
Bartlett's Test of Sphericity	Approx. Chi-Square	58.038
	Df	36
	Sig.	.011

6.14 TECHNOLOGICAL AND NON-TECHNOLOGICAL BARRIERS OF SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

One of the objectives of the research is to rank the barriers of sustainable commercial office buildings. The summary statistics of the analysed variables are presented in the Table 6.21. The t-value column provided the individual significance of each independent variable in the regression equation and showed whether the variable was making statistically significant contribution (see appendix six for descriptive statistics of all the barriers and drivers).

Table 6.21: Technological and Non-technological barriers of sustainable commercial office buildings

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.270	1.393		3.065	.003
	TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS	.379	.210	.363	1.805	.076
	TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE	.051	.154	.058	.331	.742
	TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING(LCC)	-.068	.095	-.117	-.717	.476
	TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARENESS/UNDERSTANDING AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS	-.107	.193	-.095	-.556	.581
	TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION	-.033	.105	-.060	-.314	.755
	NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS	-.260	.128	-.359	-2.028	.047
	NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINDS	-.249	.096	-.376	-2.589	.012
	NON-TECHNOLOGICAL BARRIER: LEARNING PERIOD	.013	.109	.019	.115	.909
	NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS	-.116	.097	-.191	-1.199	.235
	NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT	-.296	.125	-.389	-2.376	.021

Source: Analysis of surveyed data, 2014.

a. Dependent Variable: THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS

Table 6.21 above presents the summary for the barriers of the sustainable commercial office buildings. Only three of the attributes of non-technological barriers made statistically unique contributions to sustainable commercial office building at 95% confidence level namely: financial barriers, no perceived consumer demand for sustainable commercial office building and sustainability measures are not considered by the government.

The perceived long-term benefits are usually not expressed in terms of financial return in many of these cases, but focused instead on the environmental and social benefits that developers believed the technology or methodology could deliver. The cost/price of sustainable buildings is perceived as prohibitive.

With regards to financial barriers, the widely held belief is that everyone would be investing in sustainable buildings if it was inexpensive and lucrative. These extra parameters to a large extent stop concerted efforts by even the most unswerving and knowledgeable sustainability proponents. Similarly, no perceived consumer demand for sustainable commercial office building is also rated highly among the barriers of sustainable commercial office buildings. This could be because clients do not ask for sustainable buildings because they do not see it as a priority (Zainul, 2010).

Also, a lack of good, exemplar 'demonstration projects' across the country that could be visited, presented and interpreted by knowledgeable staff, and which could help shape the demands of house buyers. Finally, sustainability measures are not considered by the government as the lack of political will and strong leadership at the top levels of government is a major problem as the benefits of green certification are not clearly understood by many of the Country's decision makers.

There is also the absence of governmental authority responsible for implementing the adoption of green buildings because of the lack of conceptual understanding among leaders about sustainability and its long-term, systemic benefits to the residents and the economic vitality of the Country as affirmed by Choi (2009).

This result is similar to results by Ahn et al., (2013) who state that the most significant barriers to sustainable design and construction were first cost premium of the project, long pay back periods from sustainable practices, tendency to maintain current practices, and limited knowledge and skills of subcontractors.

The box labelled ‘model summary’ (Table 6.22) gives the measure of how well the overall model fits, and how well the predictors is able to predict the dependent variable. The first measure in the table is called R. This is a measure of how well the predictors predict the outcome, but the square of R provides a more accurate measure. In this case it is 0.224, so 22.4% of the variance in the dependent variable can be explained by the predictors. The final column gives the standard error of the estimate. This is a measure of how much R is predicted to vary from one sample to the next.

Table 6.22: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.473[a]	.224	.090	.696	1.562

The Table 6.23 shows the ANOVA results. The F-value is the Mean Square Regression (0.810) divided by the Mean Square Residual (0.485), yielding F=1.670. The p-value associated with this F value is very small (0.0000). These values are used to answer the question "Do the independent variables reliably predict the dependent variable?” The p-value is compared to the alpha level (typically 0.05) and, if smaller, one can conclude the independent variables reliably predict the dependent variable. It is glaring that the group of (independent) variables can be used to reliably predict the dependent variable. The overall significant value (0. 110) is less than the standardized significant value which reveals that the causes are generally acceptable

Table 6.23: Anova

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	8.095	10	.810	1.670	.110[a]
	Residual	28.108	58	.485		
	Total	36.203	68			

In analysing the technological barriers of sustainable commercial office buildings, the standardized beta coefficients which provide the order of importance or relative contribution of the building attribute show that the low demand for sustainable material and products make the largest contribution, followed by the lack of readily accessibility and reliable information and guidance and then the learning period. The multiple regressions equation that relates sustainable commercial office building (SCOB) to the building attributes is given by the constant and the coefficients of the unstandardized beta as:

$$Scob = 4.270 + 0.37LD_{fsmap} + 0.05LO_{raari} - 0.068LO_{lcc} - 0.107LO_{kauae} - 0.033LO_{aukc} - 0.260FB - 0.249NP_{cdfscob} + 0.013LP - 0.116SQ_{irar} - 0.296SMAN_{cbtg} \text{ ----------------------------------- } (6.1)$$

The equation shows that the low demand for sustainable materials, lack of readily accessibility and reliable information and guidance are positively correlated to sustainable office commercial office buildings. Indeed, the lack of demand for green building products such as advanced glazing systems in the UK produces no inducement and motivation for local building suppliers and component producers to store or utilise products capable of the performance required by these projects (Allwood et al., 2012).

Products have to be imported from elsewhere in Europe in many cases, either directly by the project team or through a locally approved distributor. This eventually leads to a forfeiture of both income and know-how within the area and the UK in entirety.

A lack of appropriate guidance appears to exist for designers in the areas of passive ventilation strategies, passive solar design and achieving building air-tightness. It is important that information for these areas of design is made available to design professionals in an appropriate format, and to the contractors ultimately responsible for implementing the design (Shiers et al., 2006).

Access to such information at an affordable rate is important to prevent mistakes made on some of the projects. For the learning period, the time it takes to transit knowledge from teaching to practical reality takes a while. Hence, this transit period has dire consequences on the implementation of sustainable buildings as it takes a longer time for realisation.

6.15 ECONOMIC AND SOCIAL DRIVERS OF SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

Another objective of this research is to rank the economic and social drivers of sustainable commercial office buildings. This was achieved using spearman's rank correlation coefficient. This is a non-parametric test used to measure the strength of association between two variables and accesses how well the relationship can be describe using a monotonic function.

From the correlation Table 6.24, it is conspicuous under social drivers that high tenant retention rate, clients' requirements, attract tenants and improve overall quality of life and heighten aesthetic qualities are positively correlated in the current LCC while increased productivity is negatively correlated. More so, under economic drivers, it was deduced that return on investment, increase rental rates and incentives, cost effectiveness and filling a design need are negatively correlated to the current LCC while ease in leasing is positively correlated.

Table 6.24: Correlation tables for economic and social drivers of sustainable commercial office buildings

Correlations					
			(1)	(2)	(3)
Spearman's rho	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	Correlation Coefficient	1.000	-.088	-.056
		Sig. (2-tailed)	.	.470	.648
		N	69	69	69
	SOCIAL DRIVER: INCREASED PRODUCTIVITY (2)	Correlation Coefficient	-.088	1.000	.259*
		Sig. (2-tailed)	.470	.	.032
		N	69	69	69
	ECONOMIC DRIVER: RETURN ON INVESTMENT (3)	Correlation Coefficient	-.056	.259*	1.000
		Sig. (2-tailed)	.648	.032	.
		N	69	69	69
. *. Correlation is significant at the 0.05 level (2-tailed).					

Correlations					
			(1)	(2)	(3)
Spearman's rho	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	Correlation Coefficient	1.000	.117	-.142
		Sig. (2-tailed)	.	.338	.244
		N	69	69	69
	SOCIAL DRIVER: HIGH TENANTS RETENSION RATE (2)	Correlation Coefficient	.117	1.000	-.029
		Sig. (2-tailed)	.338	.	.814
		N	69	69	69
	ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES (3)	Correlation Coefficient	-.142	-.029	1.000
		Sig. (2-tailed)	.244	.814	.
		N	69	69	69

Correlations					
			(1)	(2)	(3)
Spearman's rho	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	Correlation Coefficient	1.000	-.009	.077
		Sig. (2-tailed)	.	.940	.528
		N	69	69	69
	ECONOMIC DRIVER: COST EFFECTIVENESS (2)	Correlation Coefficient	-.009	1.000	-.434**
		Sig. (2-tailed)	.940	.	.000
		N	69	69	69
	SOCIAL DRIVER: CLIENTS REQUIREMENTS (3)	Correlation Coefficient	.077	-.434**	1.000
		Sig. (2-tailed)	.528	.000	.
		N	69	69	69
. **. Correlation is significant at the 0.01 level (2-tailed).					

Correlations					
			(1)	(2)	(3)
Spearman's rho	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	Correlation Coefficient	1.000	.118	-.126
		Sig. (2-tailed)	.	.336	.301
		N	69	69	69
	SOCIAL DRIVER: ATTRACT TENANTS (2)	Correlation Coefficient	.118	1.000	.249*
		Sig. (2-tailed)	.336	.	.039
		N	69	69	69
	ECONOMIC DRIVER: FILLING A DESIGN NEED (3)	Correlation Coefficient	-.126	.249*	1.000
		Sig. (2-tailed)	.301	.039	.
		N	69	69	69
*. Correlation is significant at the 0.05 level (2-tailed).					

Correlations					
			(1)	(2)	(3)
Spearman's rho	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS (1)	Correlation Coefficient	1.000	.023	.111
		Sig. (2-tailed)	.	.851	.364
		N	69	69	69
	ECONOMIC DRIVER: EASE IN LEASING (2)	Correlation Coefficient	.023	1.000	-.351**
		Sig. (2-tailed)	.851	.	.003
		N	69	69	69
	SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES (3)	Correlation Coefficient	.111	-.351**	1.000
		Sig. (2-tailed)	.364	.003	.
		N	69	69	69
**. Correlation is significant at the 0.01 level (2-tailed).					

High tenant retention rate gains come in the manner of absenteeism, fewer headaches at work, better retail sales and simpler reconfiguration of space leading to lower costs. The implication is that tenants are willing to continue in occupation for as long as profitability is sustained; a benefit offered by green buildings.

With regards to clients' requirements, users more than ever before need developers to offer information on sustainability. Several companies now have sustainability obligations in the form of 'Corporate Social Responsibility' reports. These reports usually contain goals and objectives involving quantifiable environmental performance, and development goals for issues such as: energy/CO2 emissions, water and waste (Mickaityte et al., 2008). These features attract tenants to them and improve the overall quality of life while heightening aesthetic qualities of the buildings.

More so, under economic drivers, it was discovered that only the ease in leasing is positively correlated. Green buildings are more readily leased; That is, the fact that the design, features and all components of green buildings are environmentally friendly attracts high demand for it (Yang and Yang, 2014).

This results easily in high preference for green buildings relative to the traditional buildings. Introducing green buildings will enhance property liquidity and prevent loss of income to investors, some of who utilise borrowed fund for investment (Sparkling, 2012).

6.17 SUMMARY OF CHAPTER

This chapter has presented the results of a pilot and main questionnaire survey of construction professionals aimed at ascertaining current LCC application in sustainable construction; highlighting drivers and barriers of sustainable commercial office buildings and determining the level of application and the applications and limitations of LCC (see appendix five for the summary of the overall ranking correspondence of the mean approximated values)

Various statistical tests including frequencies, spearman's rank correlation, regression and factor analysis were used to analyse the survey data. There was a considerable corroboration between the study results and findings in the literature review.

The pilot survey showed that all the applications and limitations of life cycle costing did not make statistically unique contribution to sustainable commercial office building; that respondents were slightly aware of key performance indicators, economic performance measures and risk assessment techniques, that respondents were however somewhat aware of forecasting methods, that respondents strongly agreed that key performance indicators and economic performance measures need to be incorporated into LCC and that it is important to consider the initial, operating and maintenance costs of building when conducting LCC analysis, that respondents disagreed that the current LCC techniques are suitable for calculating the whole costs of buildings and were undecided on the accuracy of historical cost data. It also showed the ranking of the drivers and barriers of sustainable commercial office buildings.

A summary of the main survey findings of the survey are as follows:

a) The responding construction professionals largely indicated that they were not aware of certain elements of LCC namely key performance indicators, forecasting methods, risk assessment techniques and economic performance measures. Surprisingly, no research has sought to determine the level of application and awareness of key performance indicators and economic performance measures in LCC.

b) The responding construction professionals indicated that there was a need to integrate and incorporate key performance indicators and economic performance measures into LCC.

c) The responding construction professionals largely indicated that the current LCC techniques are not suitable for calculating the costs of building.

d) The responding construction professionals agreed that it is important to consider the initial, operating and maintenance costs of buildings when conducting LCC analysis.

e) It was discovered that historical costs data is not accurate. Hence, the need to introduce methodologies for modelling historical costs.

f) Only three of the attributes of non-technological barriers made statistically unique contributions to sustainable commercial office building at 95% confidence level namely: financial barriers, no perceived consumer demand for sustainable commercial office building and sustainability measures are not considered by the government.

g) In analysing the technological barriers of sustainable commercial office buildings, the standardized beta coefficients which provide the order of importance or relative contribution of the building attribute show that the low demand for sustainable material and products make the largest contribution, followed by the lack of readily accessibility and reliable information and guidance.

h) From the correlation tables, it is clear under social drivers that high tenant retention rate, clients' requirements, attract tenants and improve overall quality of life and heighten aesthetic qualities are positively correlated in the current LCC while increased productivity is negatively correlated.

i) It was deduced that return on investment, increase rental rates and incentives, cost effectiveness and filling a design need are negatively correlated to the current LCC while ease in leasing is positively correlated.

j) It was deduced that all the application of LCC factors were insignificant except for ''LCC acts as a management and decision making tool'' although two factors (LCC indicates cost category and presents a possibility for investigation into the inter-relationship between performance of a building and its running costs and LCC acts as a maintenance guide) resulted with eigenvalues greater than 1, capturing 48.043% of total variance.

k) It was observed that four factors (lack of common standard methodology, lack of reliable data, risk and uncertainty and market conditions and assumptions) resulted with eigenvalues greater than 1, capturing 63.487% of total variance. It can be seen that there is a need for a common methodology which is the aim of this research as well as integrate risk and uncertainty methods while accurately modelling for historical cost data (see chapter eight). The Cronbach alpha values of all the variables also showed that the values were all statistically significant at 0.084 (see appendix six).

CHAPTER SEVEN

DEVELOPING A CONCEPTUAL FRAMEWORK FOR LCC, HISTORICAL COSTS AND ECONOMIC PERFORMANCE MEASURES

7.0 INTRODUCTION

The results from the survey analysis revealed that the current LCC techniques are not suitable for calculating the whole life costs of sustainable commercial office buildings. It also indicated that there was a need to integrate and incorporate key performance indicators and economic performance measures into LCC. The result of the analysis also indicated that historical costs data is not accurate.

This chapter therefore looked at the development of three frameworks; firstly, the modelling of operating and maintenance historical costs and secondly, the introduction of economic performance measures in LCC and thirdly, the development of a robust and user-friendly framework for LCC. The two existing buildings discussed in the methodology chapter (the office Block, Penllergaer Business Park, Swansea, West Glamorgan and Interserve Construction Limited, Leicester) were used as comparative case studies.

7.1 DEVELOPMENT OF A CONCEPTUAL FRAMEWORK

The followings steps were followed in achieving this:

1.) Identify the objectives.

2.) Develop the cost breakdown structure

3.) Determine the length of the study period, discount and the inflation rate.

4.) Modelling of historical costs.

5.) The maintenance and operational historical costs data were forecasted using Artificial Neural Networks.

6.) These costs were discounted and summed up to the base period to establish the net present value. The result was added together with the initial capital cost to get the LCC results.

7.) The Artificial Neural Network was employed for quantitative risk analysis of the maintenance and operating costs

8.) A variety of economic performance measurement techniques and key performance indicators were used to draw inference from the resulting LCC present values.

7.2 CASE STUDY ONE: OFFICE BLOCK, PENLLERGAER BUSINESS PARK, SWANSEA, WEST GLAMORGAN

7.2.1 STEP ONE: IDENTIFY THE OBJECTIVES.

The LCC analysis aims to provide a user friendly framework by facilitating a more precise, reliable and dynamic utilisation of LCC appraisals thus generating a more efficient basis for LCC estimation. The application of this framework enables the analyst to forecast operational and maintenance costs mutually before integrating quantitative risk assessment and economic performance measures all through the building's life.

7.2.2 STEP TWO: DEVELOP THE COST BREAKDOWN STRUCTURE

The initial capital costs (Table 7.1) and operating and maintenance costs (Table 7.2) were gathered from the Building Cost Information Service (BCIS) and covered all the elemental costs of the building.

Table 7.1 and 7.2: Initial capital costs of the office block, Penllergaer Business Park, Swansea, West Glamorgan

Source: bcis.co.uk (contents removed for copyright reasons)

7.2.3 STEP THREE: DETERMINE THE LENGTH OF THE STUDY PERIOD, DISCOUNT AND THE INFLATION RATE

The study period began at year one till year five which is the period of availability of the historical cost data. The building was forecasted for a thirty year period. The inflation rate is used when forecasting a cash flow over time for the purposes of budgeting and cost planning while discounting is a method used to assess outflows and inflows that happen in diverse time frames. This was gotten from solicitations with industry practitioners as there is no precise rate for the construction industry. Hence, this was put at 1.5% and 30% as obtained from the Building Cost Information Service (BCIS, 2014) and HM Treasury (2011) respectively.

7.2.4 STEP FOUR: MODELLING OF HISTORICAL OPERATING AND MAINTENANCE COSTS (see appendix three for full model)

The Probability distribution functions of total operating and maintenance costs in Present Value (PV) of total ownership of a building for one year is given as

$$g(PV) = \frac{g(k)}{1+g(d)} \quad (7.1)$$

Where, $g(k) = (t1 + t2 + t3 + t4 + t5 + t6)$

Thus, substituting for$g(k)$,

Hence;

$$g(PV) = \frac{t1}{1+g(d)} + \frac{t2}{1+g(d)} + \frac{t3}{1+g(d)} + \frac{t4}{1+g(d)} + \frac{t5}{1+g(d)} + \frac{t6}{1+g(d)}$$

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2}$$

The above equation can be simplified to obtain;

$$g(PV) = \frac{\big(2+g(d)\big)g(k)}{1+2g(d)+g(d)^2}$$

$$g(k) = t1 + t2 + t3 + t4 + t5 + t6$$

Then,

$$g(PV) = \frac{(2+g(d))t1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t3}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t4}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t5}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t6}{1+2g(d)+g(d)^2}$$

The relationship between t=1 year and t=2 years of the prob distr..../, represents the linearity of the system. To ascertain this, when t=3,

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2} + \frac{g(k)}{(1+g(d))^3}$$

This can be simplified to obtain;

$$\frac{(g(d)^2 + 3g(d) + 3)g(k)}{1 + 3g(d) + 3g(d)^2 + g(d)^3}$$

Therefore, g(Pv) when t=3 is given by;

Thus, g (PV) is a linear function. Moreover, the g (PV) for nth year, i.e. when t=nth year;

$$\boxed{g(PV) = \sum_{t=1}^{n} \frac{g(\mathrm{k})}{(1+g(d))^t}}$$

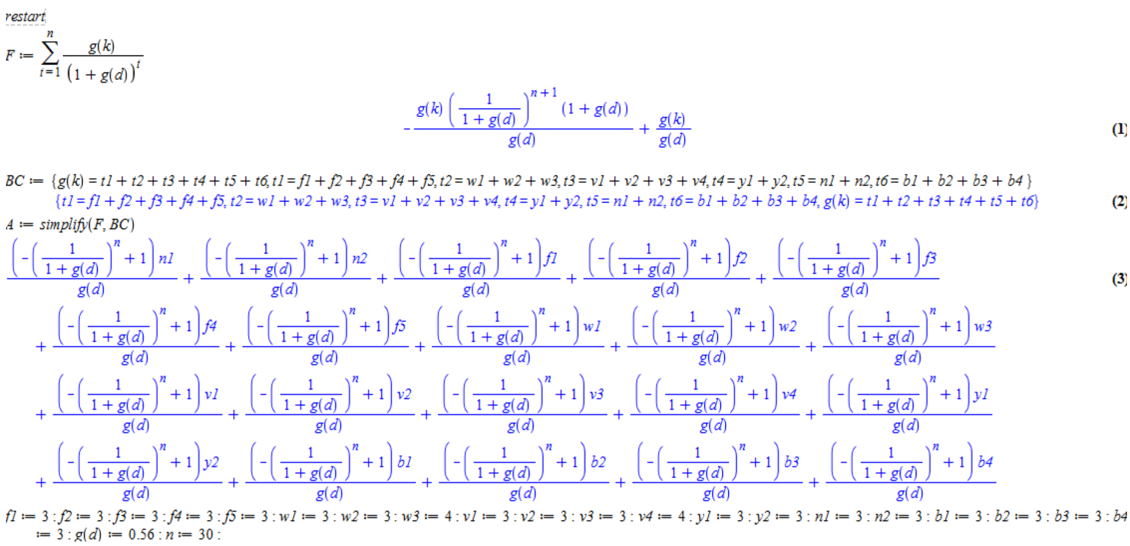


Figure 7.1: MAPLE probabilistic input simulations

Substituting the values in Table 7.2 into the equations, the newly generated historical operating and maintenance costs is shown in table 7.3

Table 7.3: Newly generated values for the historical cost breakdown structure of the operating and maintenance costs of the office block, Penllergaer Business Park, Swansea, Glamorgan

Costs (in £)	**2009**	**2010**	**2011**	**2012**	**2013**
Major replacement costs	13,000	12,750	12,500	15,830	14,000
Subsequent refurbishment and adaptation costs	4,000	3,500	3,260	4,380	3,000
Redecorations	2,400	2,750	2,630	3,000	2,200
Minor replacement, repairs and maintenance costs	1,200	1,100	2,200	2,400	2,280
Unscheduled replacement, repairs and maintenance	2,380	1,220	3,400	1,280	2,390
Client definable costs	N/A	N/A	N/A	N/A	N/A
Grounds maintenance	N/A	N/A	N/A	N/A	N/A
Utilities costs	49,000	51,000	53,360	55,200	57,420
Administrative costs	25,000	25,500	26,300	27,050	27,540
Cleaning costs	19,800	21,000	21,500	22,390	24,000
Taxes (if applicable)	8,900	9,100	9,700	10,000	10,000

Source: MAPLE simulation results.

7.2.5 STEP FIVE: FORECASTING WITH ARTIFICIAL NEURAL NETWORKS

The following steps were employed in the forecasting using ANN:

1. Data acquisition and analysis
2. Configuration of the network.
3. Training of the network.

7.2.5.1 DATA ACQUISITION AND ANALYSIS

This involves the data acquisition and analysis. To do this, open the Neural Network Start GUI with this command: nnstart. Data was subsequently inputted into the ANN fitting toolbox (figure 7.2)

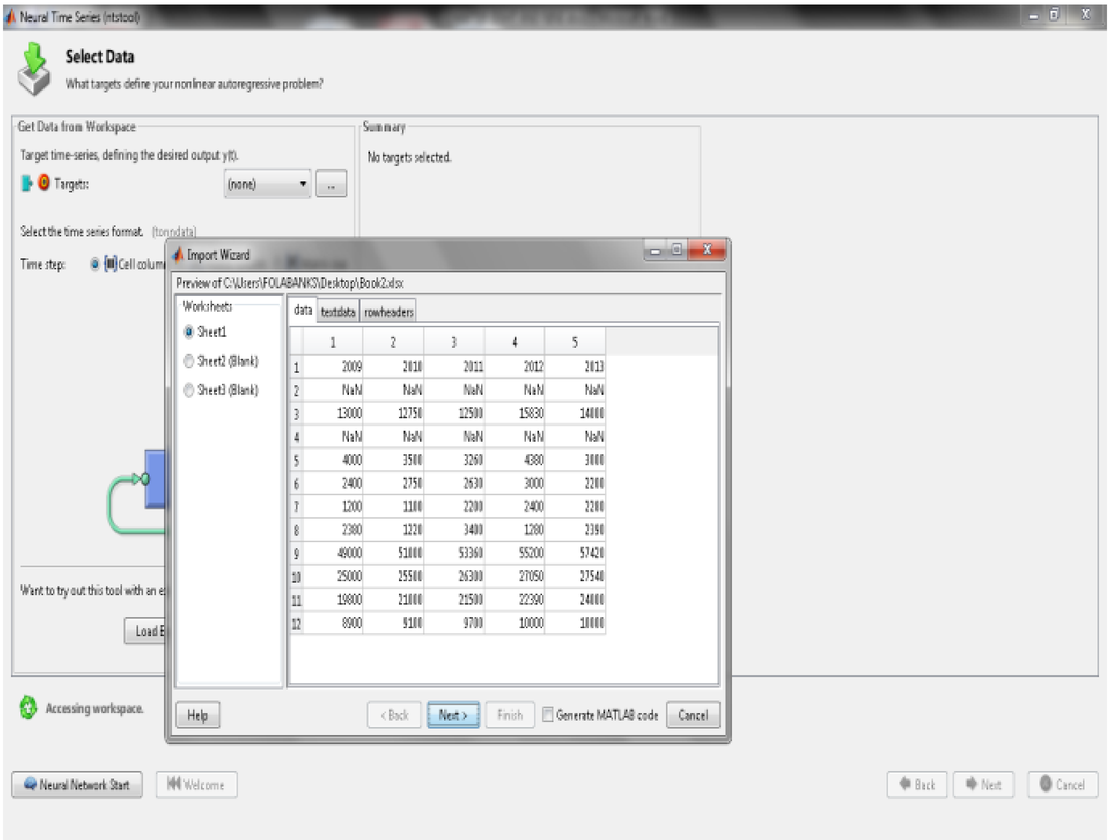


Figure 7.2: Data acquisition and analysis

7.2.5.2 CONFIGURATION OF THE NETWORK

This involves a learning process determination which initializes the weights and biases. A back-propagation neural network was utilised in this research to develop the cost estimation models. A training set of 42 values; a testing set of 9 values and a validation set of 9 were used for the thirty year forecasting period (data acquisition). Training was set arbitrarily at 70% while cross validation was at 15% and testing was also at 15% (figure 7.3)

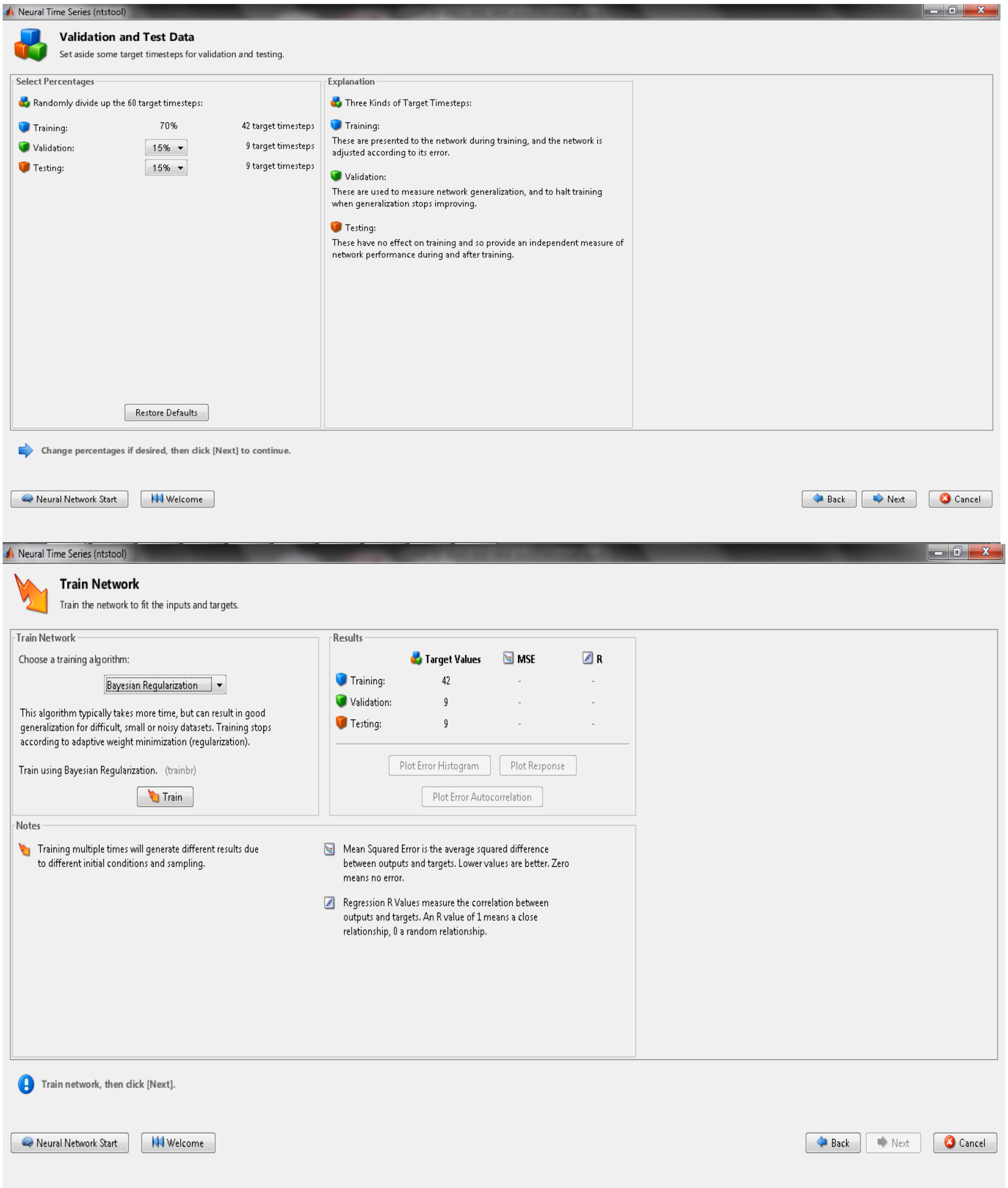


Figure 7.3: Collecting data in ANN

7.2.5.3 TRAINING OF THE NETWORK

• A training stage started by arbitrary selecting a set of connection weights for each layer. Each neuron calculated its summation function value and accordingly computes its transfer function value, which represented its output. This process was held in a feed-forward manner.

• A set of computed outputs was delivered in the output layer. For each processing element in the output layer, an error was calculated; each represents a deviation of the computed output from the desired output.

•Using a learning rule (generalized-delta rule and extended delta-bar-delta rule) the errors were back propagated through the hidden layer(s) and the connection weights adjusted and updated accordingly.

• A feed-forward process started all over again. New output values were computed and the above cycle continued until a desired set of requirements was achieved.

The objective of the training was to establish weights that minimise errors as the output neurons first provide variables that vary significantly from the precise outcomes. During training, both the inputs (representing problem parameters) and outputs (representing the solutions) were presented to the network normally for thousands of cycles (figure 7.4)

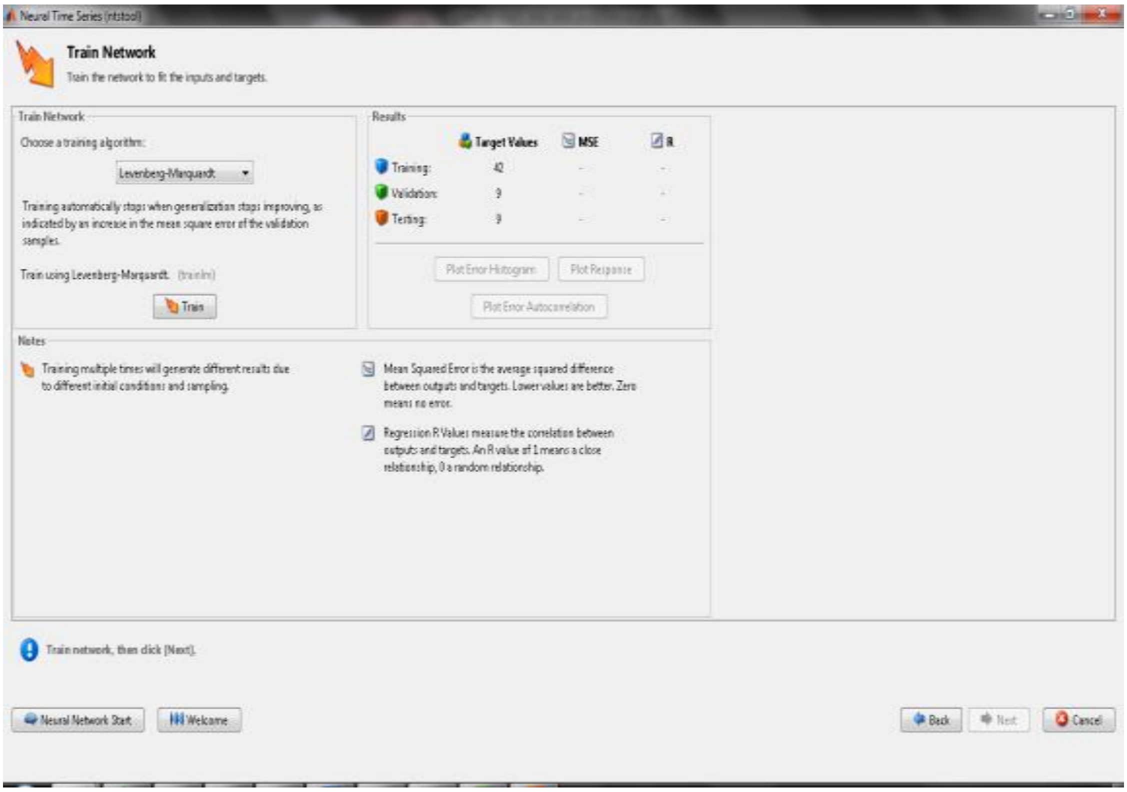


Figure 7.4 Training data in ANN

Table 7.4: Shows the forecasted values for thirty years extracted from ANN input simulations

2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
15407.66	15954.05	16180.54	16288.02	140593.11	16694.94	16858.09	17167.11	16694.94	17877.93	17334.10
3067.841	2542.56	2522.09	2257.854	2619.98	2667.32	2687.16	2963.55	2710.83	2737.70	2756.90
2870.78	2941.80	3130.54	3188.76	3154.85	3028.81	3147.82	3157.41	3223.95	3731.31	3257.22
2820.87	2934.76	3060.16	3186.20	3137.57	3140.13	3195.80	2756.90	3136.94	3223.95	3671.17
3131.82	2230.34	2270.65	2241.21	2422.28	2559.2	3035.851	3000.02	3131.18	2497.78	2229.70
34098.78	34213.94	34457.06	34538.32	33798.71	33803.19	34094.30	35178.12	34796.80	35120.54	35081.51
19053.88	20015.50	12773.41	20735.27	21032.14	21103.16	21007.8	21103.16	21104.44	21656.59	21683.46
18607.94	19664.25	19655.29	20301.49	19432.00	20392.98	20473.6	20879.87	20657.22	20944.49	21031.51
7805.56	7929.68	8790.21	7997.5	8499.10	8377.54	8852.91	9017.98	9586.12	9434.49	9597

2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
11989.85	12178.59	12510.64	12854.86	12884.29	13966.83	14321.28	14637.34	15190.77	23,740	13456.27	15826.09
1851.58	1979.54	2230.98	2548.96	2554.72	2350.63	2407.57	2542.57	2730.02	4,421	2930.28	3058.24
1541.28	1794.64	1529.12	1908.52	1914.92	1857.98	1979.54	2117.09	2245.05	3,904	2525.93	2584.15
1980.18	2547.68	2618.70	2245.06	2424.84	2232.90	2124.14	2810.00	2498.41	3,904	2619.98	2811.28
1477.30	2229.70	2103.02	1879.73	1816.39	1978.26	3147.82	2804.88	2676.92	4,923	4,637	2792.08
32560.07	32517.84	32244.64	32490.32	33206.90	31725.76	31929.86	32526.79	32308.62	52,938	33811.51	34043.11
17872.81	17745.49	18800.52	18920.16	19089.71	18449.91	18554.2	18643.77	18751.89	27,937	18509.41	19197.19
17322.59	17810.11	17833.15	17852.34	18102.50	18153.69	17334.74	18801.80	19043.00	29,872	19247.74	19752.54
7293.72	11,650	7223.34	7987.903	8250.22	8253.42	8291.81	7677.6	13499.78	11,990	7709.59	7767.17

Costs **(in £)**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Major replacement costs	9,084.63	9,373.07	9622.59	9552.21	10550.30	10598.29	10908.59	11708.34
Subsequent refurbishment and adaptation costs	1,857.34	1477.30	1813.19	1909.16	2520.81	2491.38	2396.69	2548.96
Redecorations	1,407.56	1429.95	1467.06	1490.73	2168.92	1537.440	1496.49	1595.02
Minor replacement, repairs and maintenance costs	1,343.58	1400.52	1413.32	1432.51	1477.30	1874.61	1598.22	1978.90
Unscheduled replacement, repairs and maintenance	932.19	837.50	1239.932	1090.22	1477.29	1502.89	2104.94	2103.02
Utilities costs	32,689.94	31954.81	31409.06	31850.52	31729.60	31978.48	32007.91	32880.60
Administrative costs	16,815.86	17264.36	17874.73	17334.10	17526.68	18067.31	18514.53	18509.41
Cleaning costs	15,025.70	15737.80	15772.35	14330.24	15936.14	16483.17	16623.28	17263.72
Taxes	6,206.06	6334.02	6398	6461.98	5630.24	7069.79	7225.90	7389.69

7.2.6 STEP SIX: DISCOUNTING USING NET PRESENT VALUE (NPV)

These costs were discounted and summed up to the base period to establish the NPV. The result was added together with the initial capital cost to get the LCC results. Table 7.5 shows the discounted values over a forecasted period of thirty years for the case study. This was carried out using Microsoft Excel spreadsheet (table 7.5).

Table 7.5: Shows the discounted values for thirty years extracted from ANN input simulations

2038	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**Discounted values**
25.421	26,094	26,349	26,832	26,094	27,943	27.093	561492.3
4,095	4,169	4,200	4,632	4,237	4,279	4,309	119,666
4,931	4,734	4,920	4,935	5,039	5,832	5,091	109,323
4,904	4,908	4,995	4,309	4,903	5,039	5,738	119,091
3.786	4,000	4.745	4.689	4,894	3,904	3,485	93,032
52,827	52,834	53,289	54,983	54,387	54,893	54,832	1,608,186
32,873	32,984	32,835	32,984	32,986	33,849	33,891	927,392
30,372	31,874	32,000	32,635	32,287	32,736	32,872	890,246
13,284	13,094	13,837	14,095	14,983	14,746	15,000	387,126

2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
20,138	21,830	22,384	22,878	23,743	23,740	21.032	24,736	24,082	24,936	25,290	25,458
3,993	3,674	3,763	3,974	4,267	4,421	4,580	4,780	4,795	3,974	3,942	3,529
2,993	2,904	3.094	3,309	3,509	3,904	3,948	4,039	4,487	4,598	4,893	4,984
3,790	3,490	3,320	4,392	3,905	3,904	4,095	4,394	4,409	4,587	4,783	4,980
2,839	3,092	4,920	4,384	4,184	4,923	4,637	4,364	4,895	3,486	3,549	3,503
51,902	49,587	49,906	50,839	50,498	52,938	52,847	53,209	53,296	53,476	53,856	53,983
29,837	28,837	29,000	29,140	29,309	27,937	28,930	30,005	29,781	31,284	32,094	32,409
28,294	28,374	27,094	29,387	29,764	29,872	30,084	30,873	29,084	30,735	30,721	31,731
12,895	12,900	12,960	12,000	21,100	11,990	12,050	12,140	12,200	12,394	13,739	12,500

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
14,200	14,650	15,040	14930	16,490	16,565	17.050	18,300	18.740	19,035	19,554	20,092
2,903	2,309	2,834	2,984	3,940	3,894	3,746	3,984	2,894	3,094	3,487	3,984
2,200	2,235	2,293	2,330	3,390	2,403	2,339	2,493	2,409	2,805	2,390	2,983
2,100	2,189	2,209	2,239	2,309	2,930	2,498	3,093	3,095	3,982	4,093	3,509
1,457	1,309	1,938	1.704	2,309	2,349	3,290	3,287	2,309	3,485	3,287	2,938
51,094	49,945	49,092	49,782	49,593	49,982	50,028	51,392	50,891	50,825	50,398	50,782
26,283	26,984	27,938	27,093	27,394	28,239	28,938	28,930	27,935	27,736	29,385	29,572
23,485	24,598	24,652	22,398	24,908	25,763	25,982	26,983	27,075	27,837	27,873	27,903
9,700	9,900	10,000	10,100	8,800	11,050	11,294	11,550	11,400	11,650	11,290	12,485

Costs (in £)	Major replacement costs	Subsequent refurbishment and adaptation costs	Redecorations	Minor replacement, repairs and maintenance costs	Unscheduled replacement, repairs and maintenance	Utilities costs	Administrative costs	Cleaning costs	Taxes

7.2.7 STEP SEVEN: The Artificial Neural Network was employed for quantitative risk analysis of the maintenance and operating costs. This is important because LCC decisions encompass a substantial degree of improbability which makes it very challenging to carry out simulations with a high degree of dependability. These include assumptions for expected physical life, expected economic life, discount rate and inflation which make LCC analysis very sensitive.

At the end of each cycle, or iteration, the network was used to evaluate the error between the desired output and actual output. This error was used to modify the connection weights according to the training algorithms used. The number of input data and output data used was 5 input neurons and 30 output neurons.

The network was found to stabilise with 27 hidden nodes after numerous trial and error. After training, the network provided adequate responses to situations even those not included in the training set. The resulting coefficients and parameters are given in table 7.6 along with the R squared value which indicates how close the relationship is between the dependent and independent variables. The results show a strong linear relationship between the variables. The accuracy of the costs is favourable but it is important to take cognisance of the fact that a larger amount of data will produce better forecasted values (table 7.6).

Table 7.6: Quantitative risk analysis from the ANN input simulations

Validation Stages	**Regression**	**Mean Squared Error**
Training	0.99264	1.29839
Validation	0.99259	1.83725
Testing	0.99224	1.49321

Regression Values measure the correlation between outputs and targets. An R value of 1 means a close relationship, 0 a random relationship. The smaller the value of the regression is, the smaller the change between the projected time series and the real one. The MSE is the average squared difference between outputs and targets. Lower values are better. Zero means no error. One can see that these values are close to zero thus exhibiting better performance results.

7.2.1.8 STEP EIGHT: A variety of economic performance measurement techniques and key performance indicators were used to draw inference from the resulting LCC present values.

The Income/Cost ratio was applied as an economic performance measure. To determine this, variables were assigned for the LCC, income, non-construction costs and externalities as seen in the resultant equations (see appendix four for full model).

The general model for Cost/Income ratio for the present year is given by:

$$CIR = \frac{C}{W} \quad \text{..} \quad (7.2)$$

The Cost/Income Ratio (CIR) for one year at r interest is given by

$$CIR = \frac{C}{W} + \frac{C}{W(1+r)}$$

The normal of the above equation is given as;

$$CIR = \frac{C \times (W \times (1+r) + W)}{W \times (W \times (1+r))}$$

Substituting income (W) and Cost(C) into CIR;

$$CIR = \frac{(m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6) \times ((t1 + t2 + t3) \times (1 + r) + (t1 + t2 + t3))}{(t1 + t2 + t3) \times ((t1 + t2 + t3) \times (1 + r))}$$

Also, Substituting for Income (W) and Cost(C): The normal of the above becomes;

$$\frac{(m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6) \left((t1 + t2 + t3 + (t1 + t2 + t3) \times (1 + r))((t1 + t2 + t3) \times (1 + r)^2\right) + (t1 + t2 + t3) \times (1 + r) \times (t1 + t2 + t3))}{(t1 + t2 + t3) \times \left((t1 + t2 + t3) \times (1 + r)\right) \times ((t1 + t2 + t3) \times (1 + r)^2)}$$

Therefore, following the linear model trend, using the mathematical Programming language, MAPLE17 the CIR for y number of years for the rth interest will become;

$$CIR = \sum_{n=0}^{y} \left(\frac{C}{W \times (1 + r)^n} \right)$$

Since C and W are non-function of n then:

$$CIR = \frac{C}{W} \sum_{n=0}^{y} \left(\frac{1}{(1 + r)^n} \right)$$

r= number of ***x*** *interest*

y= number of ***y*** *years*

Table 7.7 shows the variables for non-construction costs, externalities and income for case study one. The values for LCC were discounted in the Step Seven.

Table 7.7: Variables for non-construction costs

Costs **(in £)**	**2009**	**2010**	**2011**	**2012**	**2013**
Income	2,000,000	2,000,000	1,450,000	3,2000,000	3,500.000
Non-construction costs	N/A	N/A	N/A	N/A	N/A
Externalities	N/A	N/A	N/A	N/A	N/A
LCC discounted value is £4,815,554	N/A	N/A	N/A	N/A	N/A

These values are inputted in the MAPLE 17 software along with the discounted LCC values as seen in figure 7.6

restart

$$CIR := \sum_{n=0}^{y} \left(\frac{C}{W.(1+r)^{n}} \right) :$$

$W := t1 + t2 + t3 :$

$C := m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6 :$

$m1 := 5 : m2 := 6 : m3 := 4 : m4 := 9 : m5 := 6 : m6 := 4 : m7 := 1 : k1 := 2 : k2 := 3 : k3 := 2 : k4 := 4 : k5 := 6 : k6 := 6 : t1 := 2 : t2 := 7 : t3 := 10 :$

$y := 3 : r := 4 :$

CIR

$$\frac{9048}{2375}$$

$CIR.(100)$

$$\frac{36192}{95}$$

convert(CIR, float, 59)

$$3.8096842105263157894736842105263157894736842105263157894737$$

Figure 7.5: Probability input simulations

The cost to income ratio shows the efficiency of a firm in minimising costs while increasing profits. The lower the cost-to-income ratio, the more efficient the building is running. The higher the ratio, the less efficient management is at reducing costs. After several iterations the *CIR* was 0.602 as the value of income exceeded the costs in the long run. This further proves the importance of investing in sustainable buildings.

Table 7.8: Key performance indicators

KPI	***Operation***	***Maintenance***	***Capital***	***Results***
Ratio of Operation to Capital	3,812949.70	-	£3,007,373	1.27
Ratio of Maintenance to Capital	-	1,002,604.30	£3,007,373	0.33

The operating costs include utilities costs, cleaning costs, taxes, while the maintenance costs include major replacement costs, subsequent refurbishment and adaptation costs, redecorations, minor replacement, repairs and maintenance costs, unscheduled replacement, repairs and maintenance

These tools have been used to draw inference from the LCC results (i.e. to compare cost performance of the building). Validating this economic performance model was difficult as the use of benchmarks is outside the remit of this research. This section only aims to provide an awareness of the applicability of these techniques.

7.2.2 CASE STUDY TWO: INTERSERVE COSTRUCTION LIMITED, LEICESTER

7.2.2.1 STEP ONE: IDENTIFY THE OBJECTIVES.

The LCC analysis aims to provide a user friendly framework by facilitating a more precise, reliable and dynamic utilisation of LCC appraisals thus generating a more efficient basis for LCC estimation. The application of this framework enables the analyst to forecast operational and maintenance costs mutually before integrating quantitative risk assessment and economic performance measures all through the building's life

7.2.2.2 STEP TWO: DEVELOP THE COST BREAKDOWN STRUCTURE.

The initial capital costs (table 7.9) and operating and maintenance costs (table 7.10) were gathered directly from the staff in the company and cover all the elemental costs of the building.

Table 7.9 and 7.10: Initial capital costs of Interserve Construction Limited, Leicester

Source: interserve.co.uk (contents removed for copyright reasons)

7.2.2.3 STEP THREE: DETERMINE THE LENGTH OF THE STUDY PERIOD, DISCOUNT AND THE INFLATION RATE.

The study period began at year one till year three which is the period of availability of the historical cost data. The building was forecasted for a thirty year period. The inflation rate is used when forecasting a cash flow over time for the purposes of budgeting and cost planning while discounting is a method used to assess outflows and inflows that happen in diverse time frames. This was gotten from solicitations with industry practitioners as there is no precise rate for the construction industry. Hence, this was put at 1.5% and 30% as obtained from the Building Cost Information Service (BCIS, 2014) and HM Treasury (2011) respectively.

7.2.2.4 STEP FOUR: MODELLING OF HISTORICAL OPERATING AND MAINTENANCE COSTS (same procedure as the case study one and see appendix for full model)

$$\boxed{g(PV) = \sum_{t=1}^{n} \frac{g(\mathrm{k})}{(1+g(d))^t}} \text{........................ (7.3}$$

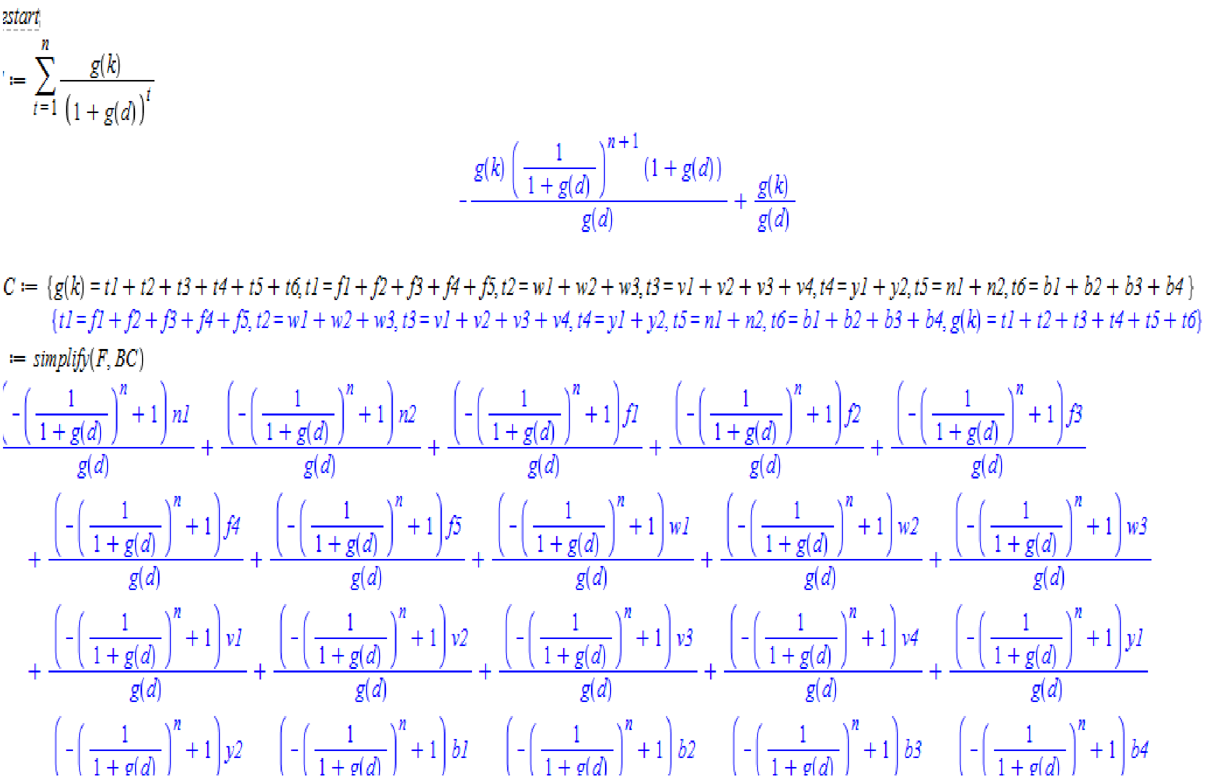


Figure 7.6: MAPLE probabilistic input simulations

Substituting the values in Table 7.10 into the equations, the newly generated historical operating and maintenance costs is seen in table 7.11

Table 7.11: Newly generated values for the historical cost breakdown structure of the operating and maintenance costs of Interserve Construction, Limited, Leicester

Costs (in £)	**2011**	**2012**	**2013**
Major replacement costs	9,800	11,100	8,250
Subsequent refurbishment and adaptation costs	2,102	1,902	1,823
Redecorations	2,170	1,928	2,129
Minor replacement, repairs and maintenance costs	2,283	2,172	2,091
Unscheduled replacement, repairs and maintenance	2,341	1,092	1,291
Client definable costs	N/A	N/A	N/A
Grounds maintenance	N/A	N/A	N/A
Utilities costs	21,025	21,502	22.934
Administrative costs	20,170	19,750	21,921
Cleaning costs	12,100	18,920	19,319
Taxes (if applicable)	4,284	5,281	6,813

Source: MAPLE simulation results

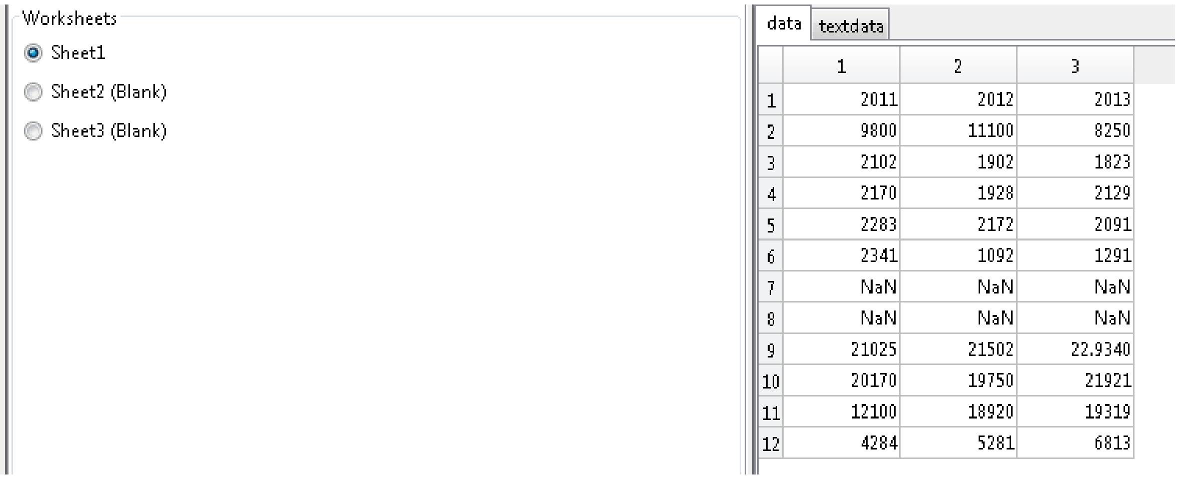
7.2.2.5 STEP FIVE: FORECASTING WITH ARTIFICIAL NEURAL NETWORKS

The following steps were employed in the forecasting using ANN:

1. Data acquisition and analysis
2. Configuration of the network.
3. Training of the network.

7.2.2.5.1 DATA ACQUISITION AND ANALYSIS

This involves the data acquisition and analysis. To do this, open the Neural Network Start GUI with this command: nnstart. Data was subsequently inputted into the ANN fitting toolbox (figure 7.7)



	1	2	3
1	2011	2012	2013
2	9800	11100	8250
3	2102	1902	1823
4	2170	1928	2129
5	2283	2172	2091
6	2341	1092	1291
7	NaN	NaN	NaN
8	NaN	NaN	NaN
9	21025	21502	22.9340
10	20170	19750	21921
11	12100	18920	19319
12	4284	5281	6813

Figure 7.7: Data acquisition and analysis

7.2.2.5.2 CONFIGURATION OF THE NETWORK

This involves a learning process determination which initializes the weights and biases. A back-propagation neural network was utilized in this research to develop the cost estimation models. A training set of 26 values; a testing set of 6 values and a validation set of 6 values were used for the thirty year forecasting period (data acquisition). Training was set at 70% while cross validation was at 15% and testing was also at 15% (figure 7.8)

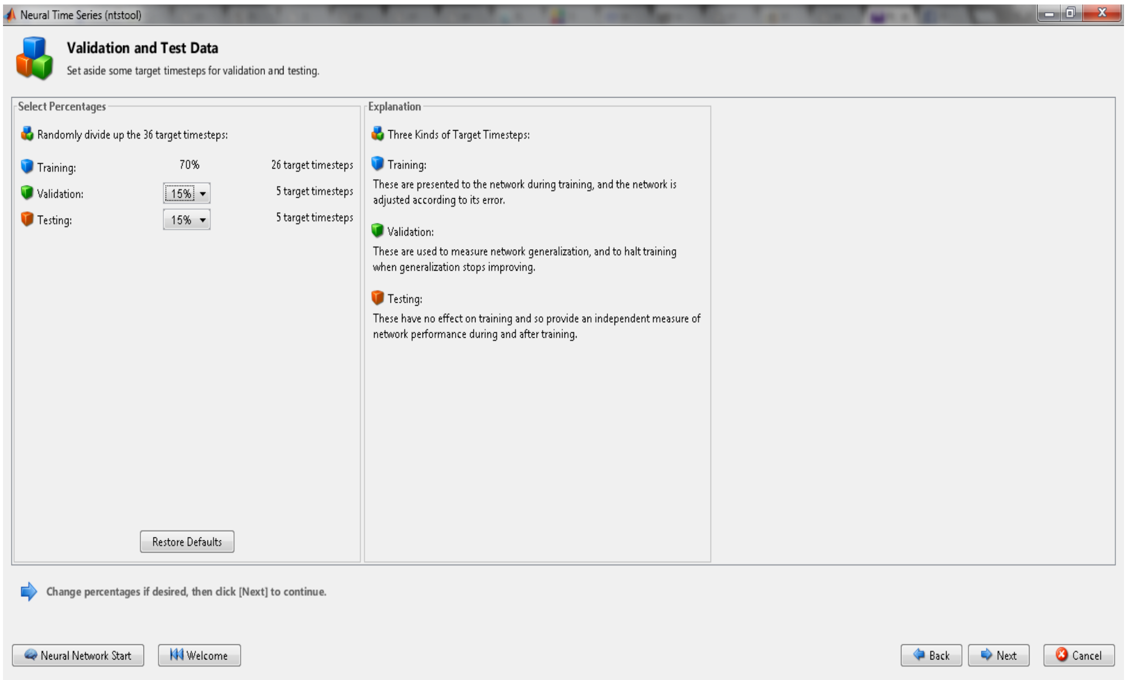


Figure 7.8: Collecting data in ANN

7.2.2.5.3 TRAINING OF THE NETWORK

• A training stage starts by arbitrary selecting a set of connection weights for each layer. Each neuron calculates its summation function value and accordingly computes its transfer function value, which represents its output. This process is held in a feed-forward manner.

• A set of computed outputs is delivered in the output layer. For each processing element in the output layer an error is calculated, each represents a deviation of the computed output from the desired output.

•Using a learning rule (generalized-delta rule and extended delta-bar-delta rule) the errors are back propagated through the hidden layer(s) and the connection weights adjusted and updated accordingly.

• A feed-forward process starts all over again. New output values computed and the above cycle continues until a desired set of requirements is achieved.

The objective of the training was to establish weights that minimise errors as the output neurons first provide variables that vary significantly from the precise outcomes During training, both the inputs (representing problem parameters) and outputs (representing the solutions) are presented to the network normally for thousands of cycles (figure 7.9)

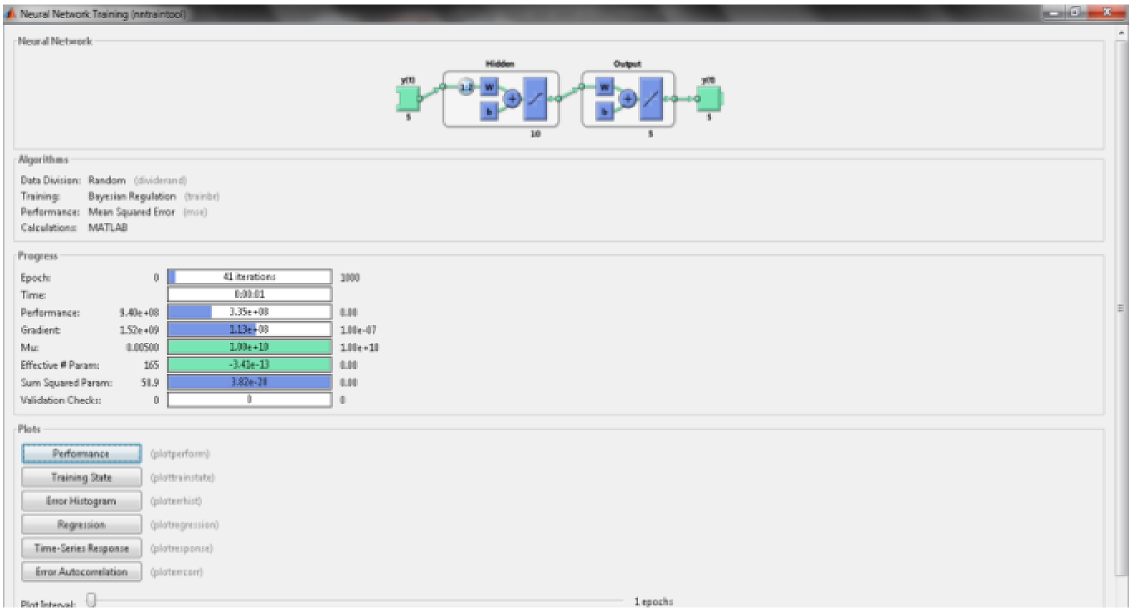


Figure 7.9 Training data in ANN

Table 7.12: Shows the forecasted values for thirty years extracted from ANN input simulations

2034	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**
13597.40	15954.05	13097.18	14,987.98	14,934.41	12,306.05	11,938.85	14,950.93	15,409.05	15,938.52	16,328.64
3032.41	2232.47	2252.06	2654.852	2518.64	2374.33	2267.15	2443.43	2240.43	2334.20	2254.56
2372.78	2646.80	3123.24	3123.76	3543.85	3012.81	3121.82	3017.41	3122.95	3332.31	3153.22
2310.87	2432.76	3031.16	3127.20	3122.57	2110.13	3025.80	241.90	3016.94	3122.95	3273.17
3532.82	2132.34	2121.65	2131.21	2321.28	2219.2	3021.51	3120.02	3021.18	2294.78	2129.70
32698.78	32253.94	32353.06	32528.32	33798.71	32103.19	32124.30	32078.12	32696.80	34140.54	34281.51
17353.88	20425.50	11343.41	16725.27	21242.14	21202.16	23007.8	20101.16	20004.44	23636.59	22613.46
16607.94	14634.25	19245.29	20211.49	12432.00	20242.98	19443.6	19829.87	22457.22	20333.49	20021.51
7325.56	7249.68	8324.21	6437.5	8239.10	8274.54	8224.91	9014.28	9482.12	9333.49	9327

2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
10,3951.94	11,237.21	10,305.25	9,954.28	12,492.10	11,302.39	12,039.43	10,394.46	13209.19	11,498.71	12,103.45	12,409.82
1801.98	191.83	2151.23	2320.54	2404.55	2210.30	2103.43	2542.21	2396.74	31,321	2236.17	2466.24
1221.28	1593.64	1423.12	1908.52	1723.92	1857.98	1773.24	2315.09	2146.05	3,895	2455.93	2485.15
1450.18	2446.68	2532.70	2245.06	2224.84	2232.90	2136.24	2320.00	2368.41	3,509	2316.98	2421.28
1257.30	2125.70	2202.02	1879.73	1314.39	1978.26	3244.22	2302.88	2536.92	4,923	4,323	2562.08
34520.07	31525.84	31124.64	32490.32	32216.90	31725.76	37919.86	31536.79	31208.62	51,648	31312.51	33026.11
15832.81	14735.49	15520.52	18920.16	16069.71	18449.91	15354.2	17622.77	17451.89	23,914	15439.41	16157.19
13222.59	14510.11	16823.15	17852.34	15101.50	18153.69	16324.74	17501.80	18042.00	25,432	16327.74	13742.54
6233.72	10,320	7431.34	7987.903	8240.22	8153.42	8141.81	7322.6	12489.75	10,750	7506.39	6737.17

Costs **(in £)**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Major replacement costs	8,032.13	7,405.21	9622.59	8,321.96	9,543.43	9,385.53	9,432.90	10,409.17
Subsequent refurbishment and adaptation costs	1,732.57	1,3294.47	1,659.83	1820.93	2104.52	2203.42	2493.02	2493.48
Redecorations	1,345.66	1328.95	1327.06	1292.73	2028.92	1233.440	1256.49	1325.02
Minor replacement, repairs and maintenance costs	1,654.67	134452	1343.32	1322.51	1272.30	1272.61	1438.22	1674.90
Unscheduled replacement, repairs and maintenance	854.39	75350	1533.932	1051.22	1372.29	1201.89	2001.94	2104.02
Utilities costs	20,438.94	32351.81	29202.06	11254.52	30129.60	32578.48	31007.91	25680.60
Administrative costs	13,345.86	13234.36	16771.73	16324.10	16516.68	17027.31	16514.53	14649.41
Cleaning costs	13,024.70	14654.80	14722.35	12320.24	12926.14	15413.17	13623.28	16233.72
Taxes	4,132.16	5765.02	6218	5462.98	5210.24	6029.79	7114.90	6334.69

7.2.2.6 STEP SIX: DISCOUNTING USING NET PRESENT VALUE (NPV)

These costs were discounted and summed up to the base period to establish the NPV. The result was added together with the initial capital cost to get the LCC results. Table 7.13 shows the discounted values over a forecasted period of thirty years for the case study. This was carried out using Microsoft Excel spreadsheet (table 7.13).

Table 7.13: Shows the discounted values for thirty years extracted from ANN input simulations

2038	2039	2040	2041	2042	2043	2044	Discounted values
25.421	26,094	26,349	26,832	25,094	25,943	25093	556492
4,095	2,169	3,200	4,632	3,237	4,279	3,309	105,666
4,931	4,734	3,920	4,935	4,039	4,832	4,091	98993
2,904	4,908	4,995	2,309	2,903	5,039	5,738	100161
1.786	2,000	4.745	4.689	4,894	3,904	3,485	73932
52,827	52,834	53,289	54,983	54,387	54,893	54,832	1,408,186
32,873	32,984	30,835	30,984	32,986	30,849	33,891	857392
30,372	31,874	32,000	32,635	32,287	32,736	32,872	820,246
13,284	13,094	13,837	10,095	14,983	14,746	15,000	356,626

2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
20,138	21,830	22,384	22,878	23,743	23,740	21.032	24,736	24,082	24,936	25,290	25,458
3,993	2,674	3,763	2,974	4,267	2,421	4,580	2780	2,795	3,974	2,942	2,529
1,993	2,904	3.094	3,309	3,509	3,904	2,948	4,039	3,487	4,598	4,893	4,984
3,790	3,490	3,320	2,392	3,905	1,904	4,095	4,394	2,409	4,587	2,783	4,980
2,839	3,092	2,920	2,384	2,184	4,923	2,637	2,364	4,895	3,486	3,549	1,503
41,902	39,587	39,906	40,839	40,498	42,938	42,847	43,209	43,296	53,476	53,856	43,983
29,837	28,837	29,000	29,140	29,309	20,937	28,930	30,005	20,781	31,284	32,094	32,409
20,294	28,374	20,094	29,387	29,764	29,872	30,084	30,873	29,084	30,735	30,721	31,731
12,895	12,900	10,960	12,000	21,100	11,990	12,050	10,140	10,200	12,394	13,739	12,500

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
14,200	14,650	15,040	14930	16,490	16,565	17.050	18,300	18.740	19,035	19,554	20,092
2,903	2,309	2,834	1984	3,940	2,894	3,746	3,984	2,894	2,094	3,487	2,984
2,200	2,235	21293	2100	3,390	2,403	2,339	2,493	2,409	2,805	1,390	2,983
1100	2,189	1,209	2,239	2,309	2,000	1,498	3,093	3,095	3,982	2,093	3,509
1,457	1,209	1,938	1.704	1309	2,349	3,290	2,287	1,309	2,485	2,287	2,938
31,094	49,945	29,092	49,782	29,593	49,982	20028	51,392	50,891	50,825	40,398	50,782
26,283	20984	20,938	20,093	27,394	28,239	28,938	20,930	20935	27,736	20385	29,572
20,485	20,598	20652	20,398	20,908	20,763	20,982	20,983	20,075	20,837	20,873	27,903
8,200	9,900	5,000	6,100	4800	11,050	10,294	11,550	10,400	10,650	10,290	10,485

Costs (in £)	Major replacement costs	Subsequent refurbishment and adaptation costs	Redecorations	Minor replacement, repairs and maintenance costs	Unscheduled replacement, repairs and maintenance	Utilities costs	Administrative costs	Cleaning costs	Taxes

7.2.2.7 STEP SEVEN: The Artificial Neural Networks were employed for quantitative risk analysis of the maintenance and operating costs. The number of input data and output data used was 3 input neurons and 30 output neurons.

The network was found to stabilise with 39 hidden nodes after numerous trial and error. After training, the network provided adequate responses to situations, even those not included in the training set. The resulting coefficients and parameters are given in table 7.14 along with the R squared value which indicates how close the relationship is between the dependent and independent variables. The results show a strong linear relationship between the variables although not as high as the first case study. This is because the first case study has a larger amount of data which thus produced better forecasted values.

Table 7.14: Quantitative risk analysis from the ANN input simulations

Validation Stages	**Regression**	**Mean Squared Error**
Training	0.91784	1.99832
Validation	0.9273	1.97234
Testing	0.93731	1.78392

Regression Values measure the correlation between outputs and targets. An R value of 1 means a close relationship, 0 a random relationship. The smaller the value of the regression is, the smaller the change between the projected time series and the real one. The MSE is the average squared difference between outputs and targets. Lower values are better. Zero means no error. It is glaring that these values are close to zero this exhibiting better performance results.

7.2.2.8 STEP EIGHT: A variety of economic performance measurement techniques and key performance indicators were used to draw inference from the resulting LCC present values.

$$CIR = \frac{C}{W} \sum_{n=0}^{y} \left(\frac{1}{(1+r)^n} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7.4)$$

Table 7.14 shows the variables for non-construction costs, externalities and income for the case study. The values for LCC have been discounted already in the Step Seven.

Table 7.15: Variables for non-construction costs

Costs **(in £)**	**2011**	**2012**	**2013**
Income	4,200,000	5,730,000	6,310.000
Non-construction costs	N/A	N/A	N/A
Externalities	N/A	N/A	N/A
LCC discounted values is £4,377,694	N/A	N/A	N/A

These values are inputted in the MAPLE 17 software along with the discounted LCC values as seen in figure 7.10

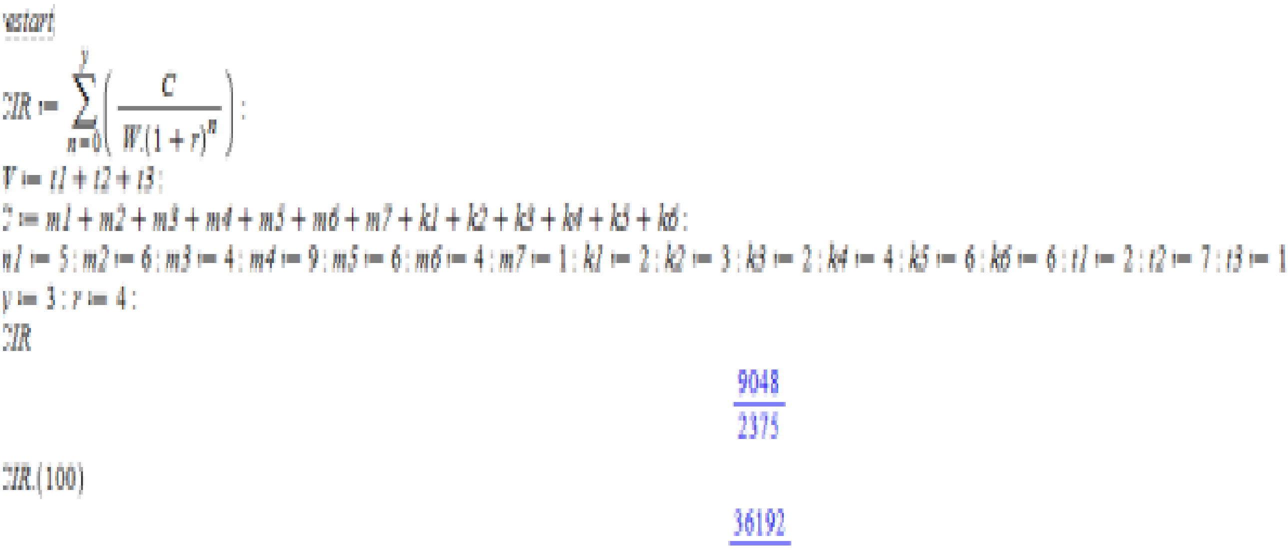


Figure 7.10: Probability input simulations

The cost to income ratio shows the efficiency of a firm in minimising costs while increasing profits. The lower the cost-to-income ratio, the more efficient the building is running. The higher the ratio, the less efficient management is at reducing costs. After several iterations the *CIR* was 0.270 as the value of income exceeded the costs in the long run. This further proves the importance of investing in sustainable buildings.

TABLE 7.16: Key performance indicators

KPI	***Operation***	***Maintenance***	***Capital***	***Results***
Ratio of Operation to capital	£3,159,756	-	£2,846,543	1.11
Ratio of Maintenance to capital	-	£1,217,938	£2,846,543	0.43

The operating costs include utilities costs, cleaning costs, taxes, while the maintenance costs include major replacement costs, subsequent refurbishment and adaptation costs, redecorations, minor replacement, repairs and maintenance costs, unscheduled replacement, repairs and maintenance. In this research specifically, benchmarks were not used *per se* as there is no existing benchmarks/standards for commercial office buildings.

Therefore, to benchmark these LCC costs would be wholly inaccurate and statistically impossible. However, future work resulting from the framework proposed in this research should be aimed at moving towards benchmark integrated LCC modelling.

7.3 COMPARATIVE ANALYSIS BETWEEN THE TWO CASE STUDIES

The buildings reviewed and compared as case studies have similarities such as both being new builds, both being two-storey buildings and both having environmental certifications. The table below shows the difference between the two case studies.

Table 7.17: COMPARATIVE ANALYSIS BETWEEN THE TWO CASE STUDIES

OFFICE BLOCK, PENLLERGAER BUSINESS PARK, SWANSEA, WEST GLAMORGAN	INTERSERVE COSTRUCTION LIMITED, LEICESTER
CERTIFICATION It has a BREEAM rating certification	**CERTIFICATION** It has a Passivhaus house certification
DATA COLLECTION Secondary data was gathered from the Building Cost Information Service (BCIS)	**DATA COLLECTION** Primary data was from a physical survey of the building
LOCATION CODE It is located in the Wales region	**LOCATION CODE** It is in the East midlands region
CONSTRUCTION CODE It is a steel framed building	**CONSTRUCTION CODE** It is a steel framed and brick construction
RISK ANALYSIS RESULTS It has an average regression of 0.99267. It also has better MSE results than the second case study	**RISK ANALYSIS RESULTS** It has an average regression of 0.92164. It has good MSE results but not as good as the first case study
ECONONOMIC PERFORMANCE MEASURES It has an income to cost ratio of 0.602 which shows that it has a higher cash inflow than expenditure.	**ECONONOMIC PERFORMANCE MEASURES** It has an income to cost ratio of 0.270 which is better than the first building and thus shows that this case study has a higher income than cost.
KEY PERFORMANCE INDICATORS Ratio of operation (ROC) to capital is 1.27 while the Ratio of maintenance (RMC) to capital is 0.33. The lower the values the better the productivity of the case study. Here, the RMC for this case study produces better results than the second case study. This means that this case study has a lower rate of maintenance compared to the second case study.	**KEY PERFORMANCE INDICATORS** Ratio of operation to capital is 1.11 while the ratio of maintenance to capital is 0.43. The ROC values in this case study are lower than the first case study. This implies that a lower amount of money is expended on operating costs for this building unlike when compared to the first case study

7.4 SUMMARY OF CHAPTER

This chapter introduced a novel framework (ANN and probabilistic simulations) for modelling of operating and maintenance historical costs; economic performance measures and LCC. The methodology consisted of eight steps and presented a novel approach to modelling the LCC of operating and maintenance costs of sustainable commercial office buildings.

For each of the LCC costs identified, a variety of mathematical techniques were used to model the overall LCC. A risk integrated ANN time series forecasting model was developed to predict the operating and maintenance costs, and stochastic modelling techniques are used to forecast the historical costs.

Finally, a set of performance measurement indicators were utilised to draw inference from these results. Two existing buildings were used as comparative case studies. The Office Block, Penllergaer Business Park, Swansea, West Glamorgan produced better and more accurate results because of the availability of more data unlike when compared to the second case study. The second case study, Interserve Construction Limited, Leicester had a higher income to cost ratio which implies that the property generates more income than expenditure.

Similarly, the ratio of operating costs to capital cost values in this case study is lower than the first case study. This implies that a lower amount of money is expended on operating costs for this building On the whole, the second case study proved to be a more viable option both economically and energy efficient wise.

CHAPTER EIGHT

MODEL VALIDATION AND DISCUSSION

8.0 INTRODUCTION

The principal objective of this research was to propose a new LCC methodology for sustainable commercial office buildings using applied risk techniques, forecasting methods and a novel approach to modelling historical input probability distributions as stochastic assumptions and economic performance measures.

Practitioners do not currently employ LCC techniques in the cost analysis of the sustainable commercial office buildings (the main driver behind this research) and thus a comparison of other types of models is not possible.

The validity of the processes used in the modelling of the cost assumptions in the LCC model is however an essential concept and this has been a constant theme of discussion throughout the thesis. Therefore, this section is devoted to the validation of the assumption modelling procedures. The validity and testing of each of these probability distributions was investigated using mean square error, regression, performance test and plot error autocorrelation.

8.1 ERROR AUTOCORRELATION TEST

The following figures show the error autocorrelation function. It defines how the forecast errors are interrelated in time. For a faultless prediction model, there must only be one non-zero value of the autocorrelation function, and it ought to occur at zero lag.

This implies that the forecast errors were entirely uncorrelated with each other. If there was substantial relationship in the forecast errors, then it would improve the forecast possibly by increasing the number of delays in the tapped delay lines. For the case study one, the correlations, but for the one at zero lag, fall roughly within the 95% confidence limits of zero, so the model is satisfactory.

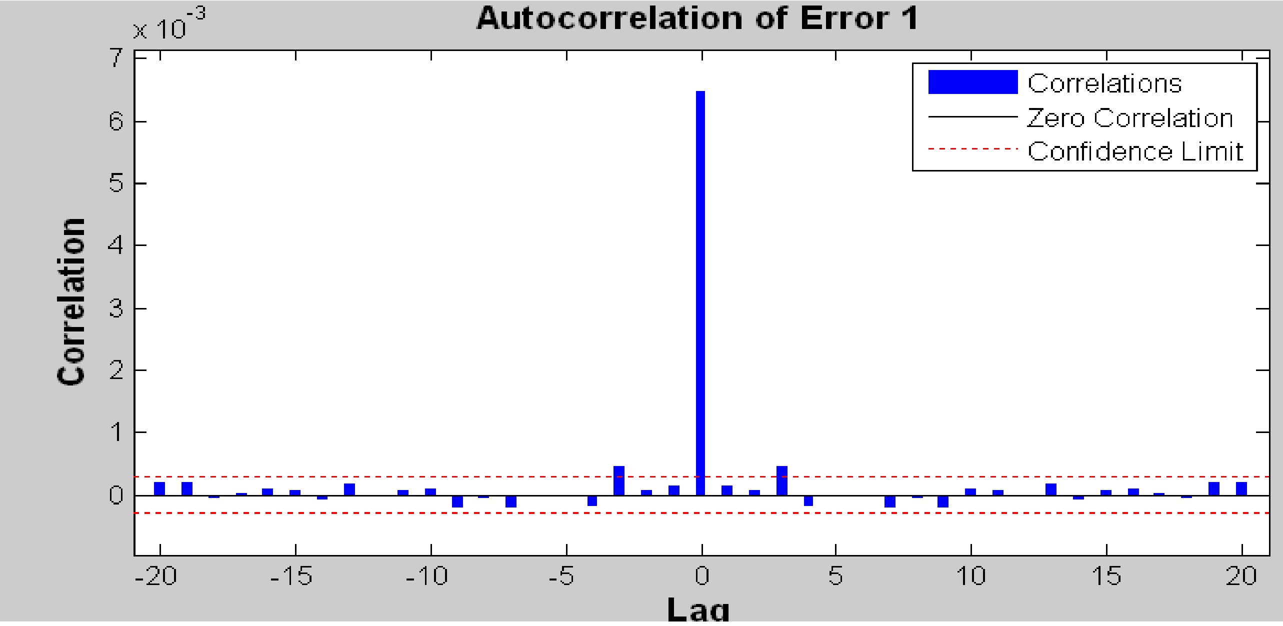


Figure 8.1: Case study one autocorrelation results

For the second case study, confidence limits are also at zero thus exhibiting a high level of accuracy. The autocorrelation function of the graph describes the general dependence of the values of the samples at one time on the values of the samples at another time. The two graphs depict a systematic relationship between the residuals measured at different points in time

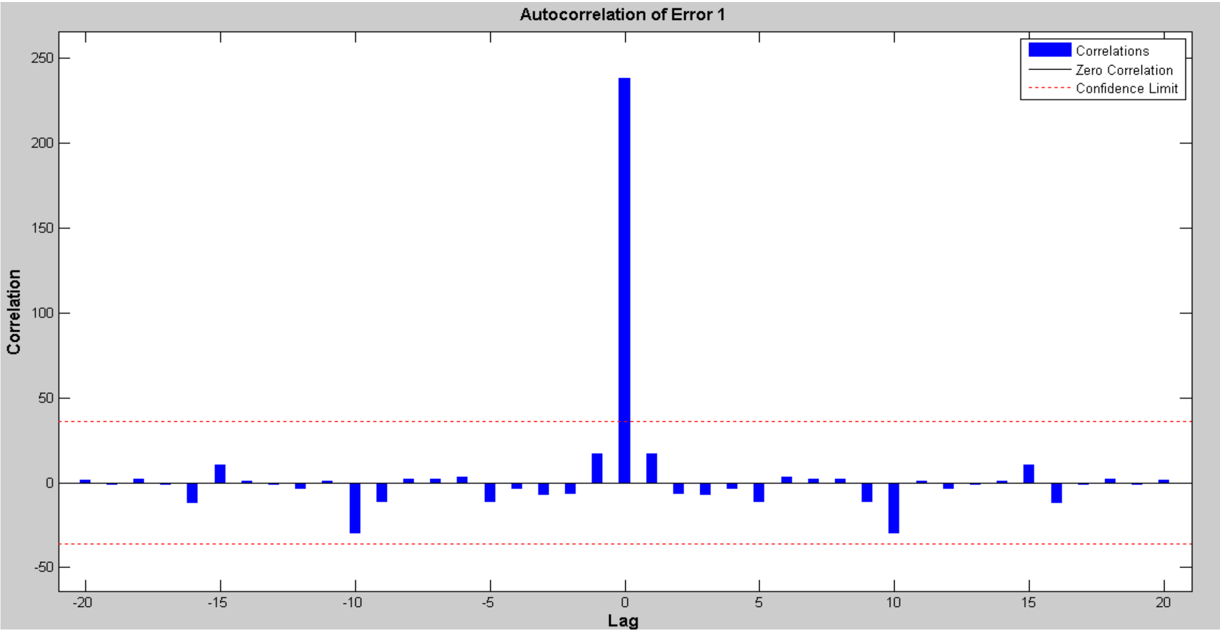


Figure 8.2: Case study two autocorrelation results

8.2 PERFORMANCE TEST

When the training in Train and Apply Multilayer Neural Networks was completed, the network performance was checked to determine if any changes needed to be made to the training process, the network architecture, or the data sets. First, the training record, tr, returned from the training function. Then the cost tr.best epoch indicated the iteration at which the validation performance reached a minimum.

The training for case study one continued for 6 more iterations before the training stopped. This result did not indicate any major problems with the training as seen in figure 8.3. Similarly, the validation and test curves are very similar. If the test curve had increased significantly before the validation curve increased, then it is possible that some over fitting might have occurred. This is however not the case in this model.

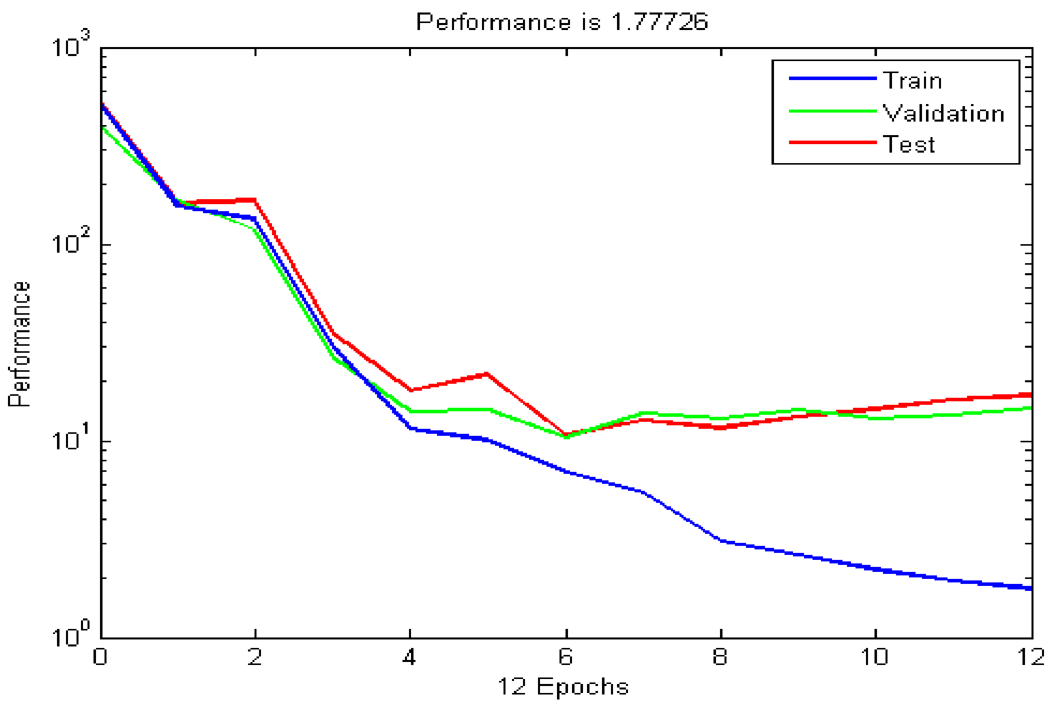


Figure 8.3: Performance test of case study one

The case study two performance test results continued for 9 more iterations before the training stopped. This result also did not indicate any major problems with the training as seen in figure 8.4. Similarly, the validation and test curves are very similar.

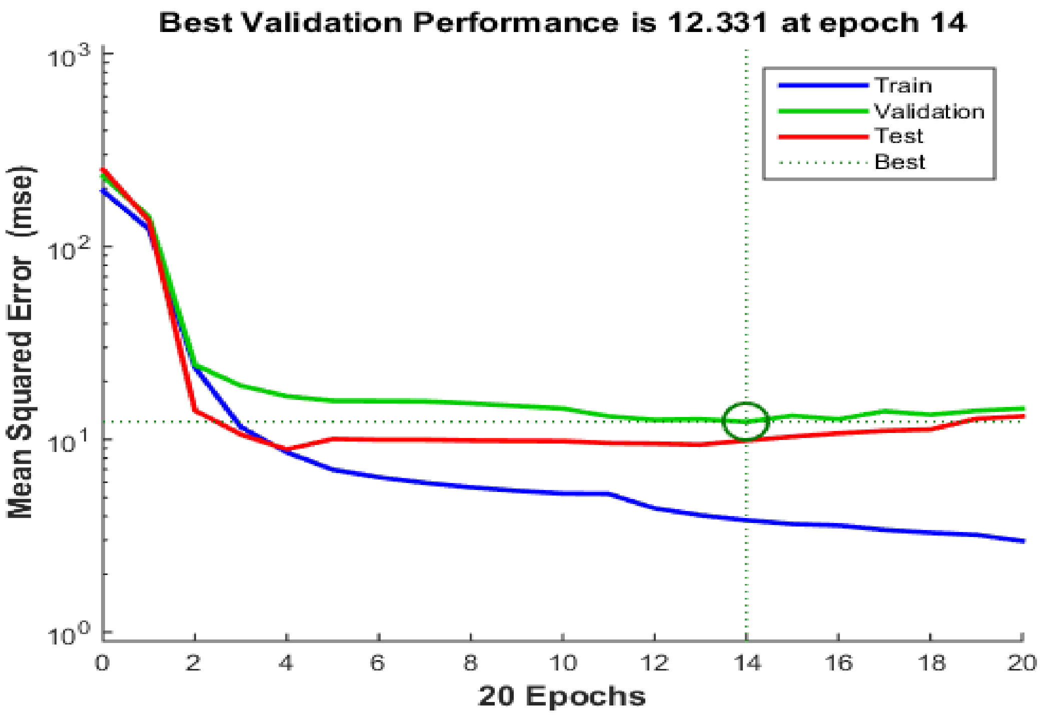


Figure 8.4: Performance test of case study two

8.3 REGRESSION AND MEAN SQUARED RESULTS

Regression values measure the correlation between outputs and targets. An R value of 1 implies that there is a close relationship, 0 means there is a random relationship. The smaller the value of the regression is, the smaller the difference between the predicted time series and the actual one. The mean squared error on the other hand is the average squared difference between outputs and targets. Lower values are better while zero means no error. The regression values were close to zero this exhibiting better performance results (see table 8.1 and table 8.2).

Table 8.1: Regression and mean squared results for case study one

Validation Stages	**Regression**	**Mean Squared Error**
Training	0.99264	1.29839
Validation	0.99259	1.83725
Testing	0.99224	1.49321

For the two case studies, the training data indicated a good fit. The validation and test results also show R values that greater than 0.9. The scatter plot is helpful in showing that certain data points have poor fits.

Table 8.2: Regression and mean squared results for case study two

Validation Stages	Regression	Mean Squared Error
Training	0.91784	1.99832
Validation	0.9273	1.97234
Testing	0.93731	1.78392

The next step in validating the network is to create a regression plot, which shows the relationship between the outputs of the network and the targets. If the training was perfect, the network outputs and the targets would be exactly equal, but the relationship is rarely perfect in practice. The following regression plots display the network outputs with respect to targets for training, validation, and test sets. For a perfect fit, the data should fall along a 45 degree line, where the network outputs are equal to the targets. For this problem, the fit is reasonably good for all data sets, with R values in each case of 0.93 or above.

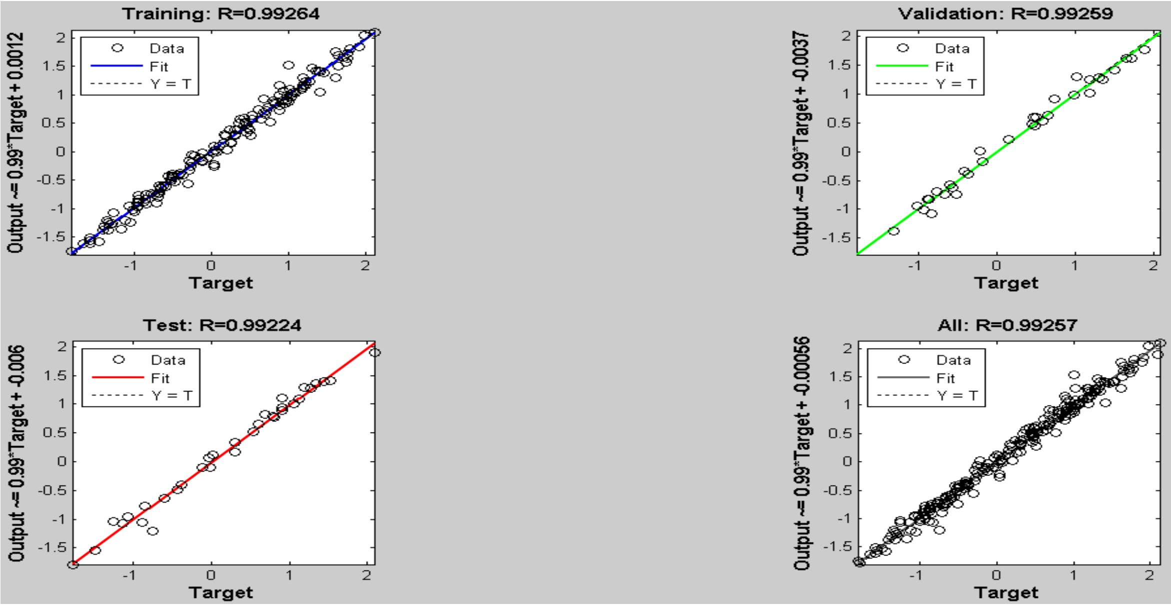


Figure 8.5: Case study one regression results

The above figure represents the training, validation, and testing data. The dashed line in each plot represents the perfect result – outputs = targets. The solid line represents the best fit linear regression line between outputs and targets. The R value is an indication of the relationship between the outputs and targets. If R = 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets.

In this instance, the training data indicates a good fit. The validation and test results also show R values that greater than 0.9. The scatter plot is helpful in showing that certain data points have poor fits.

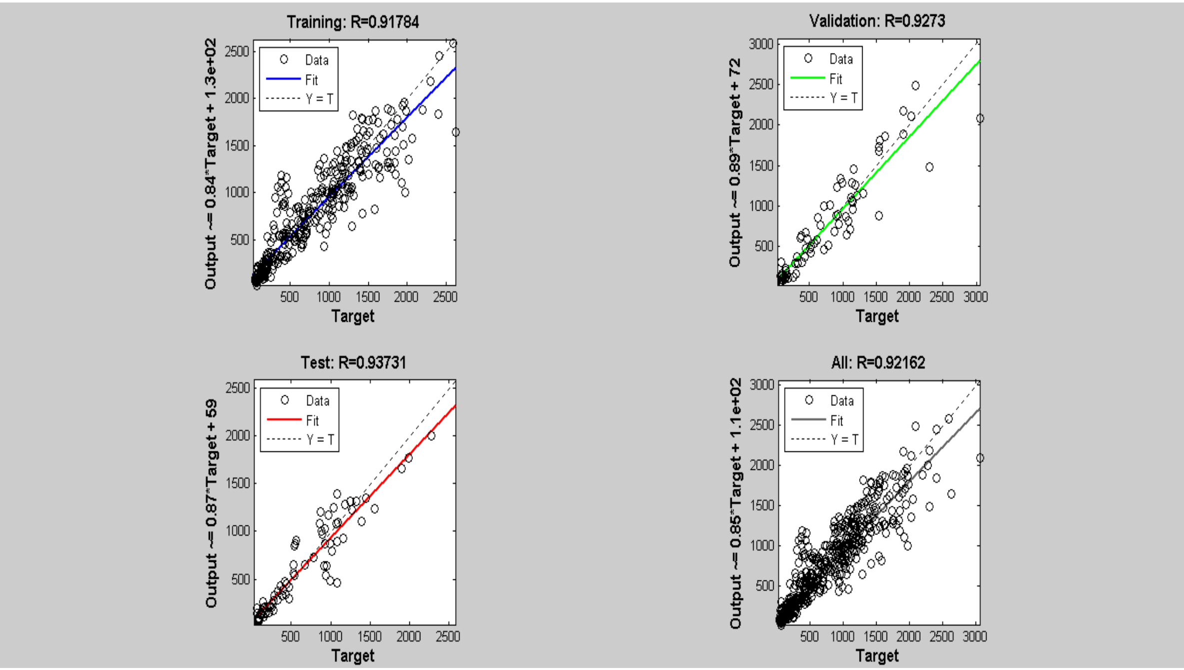


Figure 8.6: Case study two regression results

8.4 SUMMARY OF CHAPTER

The purpose of this chapter is to validate the models applied in the two sustainable commercial office buildings used as case studies. More specifically, the results of this research project reveal a high degree of accuracy and precision of the variables utilised in the LCC methodology.

Error autocorrelation, regression, mean squared error and performance test were used to test the results and they all proved to have a high degree of accuracy. The case study one however exhibited a higher degree of accuracy because of the larger data sets used. This goes to further prove that more the data sets used for modelling and simulations, the better and more precise the results would be.

CHAPTER NINE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

9.0 SUMMARY

Deterministic life cycle cost models were the earliest models developed for cost in use analysis of buildings. Although these models were mathematically quite simple, the failure to adequately assess and quantify the risk in the forecasts, assumptions based on unsound statistics or merely guesswork and failure to incorporate economic performance measures have made these models unsuitable for use by practitioners.

However, all LCC models that have been presented in the literature and in practice fail to consider uncertainty in the forecasts and in the assumptions. In chapter one, the concern of practitioners that the assumptions were based on inappropriate statistical methods and that the forecasts were produced of a high-risk nature were discussed.

Similarly, the application of LCC to existing buildings has not been investigated in recent research. It is seen principally as a capital investment decision-making tool at the tender stage, and not a management tool for long-term estate management. Therefore, the contribution that this research aimed to achieve was to develop a dynamic LCC framework for sustainable commercial office buildings, and by means of two existing buildings, demonstrate how assumption modelling can be utilised within a probabilistic environment.

In this research, the key themes of risk assessment, probabilistic assumption modelling and stochastic assessment of LCC has been addressed (see chapter two). Significant improvements in existing LCC models have been achieved in this research in an attempt to make the LCC model more accurate and meaningful to estate managers and high-level capital investment decision makers (see chapter seven).

A new approach to modelling historical costs and forecasting these costs in sustainable commercial office buildings is presented based upon a combination of ANN methods and stochastic modelling of the annual forecasted data. These models provide a far more accurate representation of long-term building costs as the inherent risk associated with the forecasts is easily quantifiable and the forecasts are based on a sounder approach to forecasting than what was previously used in the commercial sector.

A novel framework for modelling the facilities management costs in two sustainable commercial office buildings is also presented (see chapter seven). This is not only useful for modelling the LCC of existing commercial office buildings as presented here, but has wider implications for modelling LCC in competing option modelling in commercial office buildings. The processes of assumption modelling presented in this work can be modified easily to represent other types of commercial office buildings. Discussions with policy makers in the real estate industry revealed that concerns were held over how these building costs can be modelled given that available historical data represents wide spending and are not cost specific to commercial office buildings.

However, the use of LCC methods to current buildings has been hardly considered in the past, but the application of such methods has been promoted compellingly in this study. This model has made a number of significant improvements over previous models as detailed below.

9.1 A COMPARISM WITH OTHER MODELS

The summary of findings of the main survey is as follows:

a) The responding construction professionals largely indicated that they were not aware of certain elements of LCC namely key performance indicators, forecasting methods, risk assessment techniques and economic performance measures. Surprisingly no research has sought to address the level of application and awareness of key performance indicators and economic performance measures in LCC.

b) The responding construction professionals indicated that there was a need to integrate and incorporate key performance indicators and economic performance measures into LCC.

c) The responding construction professionals largely indicated that the current LCC techniques are not suitable for calculating the whole life costs of building.

d) The responding construction professionals agreed that it is important to consider the initial, operating and maintenance costs of buildings when conducting LCC analysis.

e) It was discovered that historical costs data may not be accurate enough for use in LCC.

f) Only three of the attributes of non-technological barriers made statistically unique contributions to sustainable commercial office building at 95% confidence level namely: financial barriers, no perceived consumer demand for sustainable commercial office building and sustainability measures are not considered by the government.

g) In analysing the technological barriers of sustainable commercial office buildings, the low demand for sustainable material and products ranked highest, followed by the lack of readily accessibility and reliable information and guidance.

h) From the correlation tables, it was conspicuous under social drivers that high tenant retention rate, clients' requirements, attract tenants and improve overall quality of life and heighten aesthetic qualities are positively correlated to the current LCC while increase productivity is negatively correlated.

i) It was deduced that return on investment, increase rental rates and incentives, cost effectiveness and filling a design need are negatively correlated to the current LCC while ease in leasing is positively correlated.

j) It was deduced that all the application of LCC factors were insignificant except for ''LCC acts as a management and decision making tool although two factors (LCC indicates cost category and presents a possibility for investigation into the inter-relationship between performance of a building and its running costs and LCC acts as a maintenance guide) capturing 48.043% of total variance.

k) It was observed that four factors (lack of common standard methodology, lack of reliable data, risk and uncertainty and market conditions and assumptions) captured 63.487% of total variance. It can be seen that there is a need for a common methodology which is the aim of this research as well as integrating risk and uncertainty methods while accurately modelling for historical cost data.

This study has presented a new approach to the concept of LCC and demonstrated how this technique could be applied in the context of two sustainable commercial office buildings. The original deterministic LCC model devised in Flanagan and Norman (1983) formed the basis for such models, but since that time, the problems of modelling uncertainty in the cost centre assumptions has not been addressed sufficiently until now.

The model for LCC of maintenance and running costs in al- Hajj and Homer (1998) identified the possibilities of using rules of cost significance to reduce the complexities of data collection, but this again offered no treatment of uncertainty. In this study, an approach to modelling cost centre assumptions as probabilistic values is presented.

In NIST (1995), consideration of uncertainty is addressed in LCC models, building on the risk management issues in LCC discussed in Perry and Hayes (1983), by reference to the use of deterministic methods, and the power of such a technique is utilised in this study. However, probabilistic modelling is discussed vaguely, and no rationale is presented for modelling assumptions in this fashion.

9.2 SPECIFIC CONTRIBUTION TO KNOWLEDGE

The principal contributions of the work presented in this study were discussed in section 9.2 and these were contrasted with the current models proposed in the literature. The presented model has made many advances over previous models, these include the following:

1.The model presented is a first attempt to harness the benefits and knowledge that can be generated from applying LCC techniques and utilising this in the cost appraisal of existing buildings, and more specifically in this case, for sustainable commercial office buildings.

2. This study utilises existing data collection mechanisms that record operational costs of these buildings to model probabilistically the maintenance, facilities management and financial costs of two sustainable commercial office buildings. The techniques used here were validated using regression, error autocorrelation, performance and mean squared error tests.

3. The model can constantly be updated every year to take into account new data trends and capital cost expenditure.

4. The LCC model is dynamic, not static like existing models so performance can be monitored over time.

5. Stochastic models were developed to suitably model historical costs as there is a strong belief that these costs are not correct. This was achieved by developing stochastic equations from the factors affecting operating and maintenance costs. Validations using this probability distribution functions showed a high level of accuracy (see chapter eight)

The model presented here can be applied to many other commercial buildings providing that the assumptions are re-sampled on new data that is representative of the building under consideration. Thus it can be concluded that the presented LCC model overcomes the principal disadvantages of existing models as it deals probabilistically with inputs and outputs, it can be used in the analysis of existing buildings

Chapter seven looked at the development of three frameworks; firstly, the modelling of operating and maintenance historical costs and secondly, the introduction of economic performance measures in LCC and thirdly, the development of a robust, and user-friendly framework for LCC. A variety of economic performance measurement techniques and key performance indicators were used to draw inference from the resulting LCC present values.

The LCC analysis aimed to provide a user friendly framework by facilitating a more precise, reliable and dynamic utilisation of LCC appraisals thus generating a more efficient basis for LCC estimation. The application of this framework enables the analyst to forecast operational and maintenance costs mutually before integrating quantitative risk assessment and economic performance measures all through the building's life.

9.3 LIMITATIONS OF THE RESEARCH

No model can claim to be perfect. As such, the final LCC cost model presented in this study has limitations, some of which are presented below:

1. The samples of data for the maintenance cost centre were not as large as would be desired for probabilistic modelling work.

2. The complexities involved in the modelling of assumptions is significant, therefore the model has failed to address the issue of reducing the complexities involved in modelling LCC. However, as this is a first attempt to model assumptions and associated risks in this fashion, it is contended that the probabilistic nature of these forecasts counter-balances the problems associated with complexity

3. The developed model is specific to commercial office buildings. However, the assumption modelling processes can be modified to adapt to different types of building in other LCC analyses.

4. Three or more similar commercial office buildings might have given a different result.

In this research specifically, benchmarks cannot be used *per se* for economic performance measures and key performance indicators as there is no existing benchmarks/standards for commercial office buildings. Therefore, to benchmark these LCC costs would be wholly inaccurate and statistically impossible. Further research is required to overcome the limitations discussed above. The following section explores some possible areas of further research and development.

9.4 RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis has identified a number of themes that would benefit from further research. The risk-integrated whole life cycle cost model developed in this work could be enhanced in several ways including some of the following:

1. There is a need for a service life forecasting interface for specifying the actual component remaining service life estimates that make up the overall value. However, this requires significant data collection in order to model this effectively.
2. The principal theme in terms of further research should be aimed towards the development of a generic web based LCC tool that can cope with all types of commercial office buildings. The user will be able to select the characteristics of the building under consideration and specify the most appropriate assumptions from a database of theoretical distributions modelled in the same fashion as that presented in this research.
3. The development of a methodology for determining the discount rate to be applied.
4. A validation procedure is required to assess the validity of the cost assumption forecasts and the time series model proposed for the energy cost centre in future years.

REFERENCES

Abidin, Z (2010) Sustainable Construction Concept by Malaysian Developers," *Habitat International*, vol. 34, no. 4, pp. 421 – 42

Abidin, Z; N. Yusof, A.A.E., Othman, (2013) "Enablers and Challenges of a Sustainable Housing Industry in Malaysia," *Construction Innovation: Information, Process and Management.* vol. 13, no. 1, pp. 10 – 25

Adeli, H. (2001) Neural networks in civil engineering: 1989-2000. *Computer-Aided Civil and Infrastructure Engineering*, 16(2), 126-142.

Adeli, H and Yeh, C. (1989) Perceptron learning in engineering design. *Computer-Aided Civil and Infrastructure Engineering*, 4(4), 247-256.

Akhlaghi,F. (1987) "Life cycle costing - a tool for decision making", *Facilities*, Vol. 5 Iss: 8 pp. 4 – 1

Akintoye, A. (2000) Analysis of factors influencing project cost estimating practice. *Construction Management and Economics*, 18: pp 77-89

Al-Hajj, A., and Horner, M.W. (1998). Modelling the running costs of buildings, *Journal of Construction Management and Economics*, 16(4), 459-470

Allwood, J. M., Cullen, J. M., Carruth, M. A., Cooper, D. R., McBrien, M., Milford, R. L. & Patel, A. C. (2012). *Sustainable materials: with both eyes open* (pp. 186-188). UIT Cambridge Limited.

Ammar, M., Zayed, T., & Moselhi, O. (2012). Fuzzy-based life-cycle cost model for decision making under subjectivity. *Journal of Construction Engineering and Management*, *139*(5), 556-563.

Aouad, G F, Bakis, N, Amaratunga, D, Osbaldiston, S, Sun, M, Kishk, M, Al-Hajj, A and Pollock, R (2001) An integrated life cycle costing database: a conceptual framework.In: Akintoye, A (Ed.), Proceedings 17th Annual ARCOM Conference, 5-7 September 2001, Salford, UK. *Association of Researchers in Construction Management*, Vol. 1, 421–31

Argenti, J. (1976). Whatever happened to management techniques? *Management Today*, April, 78-79.

Arja, M., Sauce, G., & Souyri, B. (2009). External uncertainty factors and LCC: a case study. *Building Research & Information*, *37*(3), 325-334.

Ashworth, A. (1993). How life cycle costing could have improved existing costing. *Life cycle costing for construction*, 119-134

Ashworth, A., (1996). Assessing The Life Expectancies Of Buildings For Life Cycle Costing, *Proceedings of COBRA'96*, RICS.

Ashworth, G., & Larkham, P. (Eds.). (2013). *Building A New Heritage*. Routledge.

Australian National Audit Office, (2001), ''Life Cycle Costing: Better Practice Guide'', Australian Government, Canberra.

Awosoga , O.A. (1996). Statistics for Sciences. 1st ed., JAS Publishers, Lagos.

Axon, C. J., Bright, S. J., Dixon, T. J., Janda, K. B., & Kolokotroni, M. (2012). Building communities: reducing energy use in tenanted commercial property. *Building Research & Information*, *40*(4), 461-472.

Babbie, E. R. (1990) Survey research methods, Belmont, California, Wadsworth Pub. Co.

Baccarini, D (2004) Estimating project cost contingency - a model and exploration of research questions. In: Khosrowshahi, F (Ed.), 20th Annual ARCOM Conference, 1-3 September 2004, Heriot Watt University. Association of Researchers in Construction Management, Vol. 1, 105-13.

Baker, W. and Reid, H. (2005) *Identifying and Managing Risk*, Frenchs Forest, N.S.W.: Pearson Education.

Bakis, N., Kagiouglou, M., Aouad, G., Amaratunga, D., Kishk, M. and Al-Hajj, A. (2003), An integrated environment for life cycle costing in construction‖, Proceedings of the CIB W78's 20th International Conference on Construction IT, Construction IT Bridging the Distance, CIB Report 284, Waiheke Island, 23-25 April.

Barlow, S., and Fiala, D. (2007). "Occupant comfort in UK offices - How adaptive comfort theories might influence future low energy office refurbishment strategies." *Energy and Buildings* (39): 837-846.

Barringer, P. and Weber, D. (1996). "Life cycle cost tutorial", paper presented at the 5th

International Conference on Process Plant Reliability, Houston, TX.

BCIS (2013) BIS Construction Price and Cost Indices. In, http://www.bcis.co.uk:Building Cost Information Services, UK

BCIS (2014) BIS Construction Price and Cost Indices. In, http://www.bcis.co.uk:Building Cost Information Services, UK

Black, C., Akintoye, A. and Fitzgerald, E. (2000) An analysis of success factors and benefits of partnering in construction, *International Journal of Project Management*, 18, 423-434.

Bordass, B. (2000). Cost and value: Fact and fiction. *Building Research and Information*, 28(5-6), 338-352.

Bouachera, T, Kishk, M and Power, L (2007) Towards A generic framework for whole life costing in the oil industry. In: Boyd, D (Ed.), "23rd Annual ARCOM Conference", 3-5

September 2007, University of Belfast. Association of Researchers in Construction Management, 863-871

Boussabaine, A. H. (2001). A comparative approach for modelling the cost of energy in sport facilities. *Facilities*, *19*(5/6), 194-203.

Boussabaine, A. (2013). Cost planning of PFI and PPP building projects. Routledge.

Boussabaine, A.H, Kirkham, R.J. Grew, R.J (1999),"Modelling total energy costs of sport centres", *Facilities*, Vol. 17 Iss: 12 pp. 452 – 461

Boussabaine, A. H., & Kirkham, R. J. (2006). Whole life cycle performance measurement re-engineering for the UK National Health Service estate. *Facilities*, *24*(9/10), 324-342.

Boussabaine A and Kirkham R (2008) Whole Life-cycle Costing: risk and risk responses, Blackwell, Oxford.

Bragança, L., Vieira, S. M., & Andrade, J. B. (2014). Early Stage Design Decisions: The Way to Achieve Sustainable Buildings at Lower Costs. *The Scientific World Journal*, *2014*.

Brandon, P. S. (Ed.) (1987). 'Building Cost Modelling and Computers'. E. & F. N. Spon,

London.

BREEAM, (2013). BREEAM - The world's leading design and assessment method for sustainable buildings [Online]. Available at: http://www.breeam.org. Accessed June 2013.

Breton-Miller, L., & Miller, D. (2006). Why Do Some Family Businesses Out-Compete? Governance, Long-Term Orientations, and Sustainable Capability. *Entrepreneurship Theory and Practice*, *30*(6), 731-746

Bryan, T., (2005). Construction Technology: Analysis and Choice. United Kingdom: Wiley-Blackwell.

Buttimer and Ott (2010), Valuation of Green Buildings, The Effect of Green on NOI, Green Valuation papers, Renomics Corporation.

Capital E, (2003). The Cost and Financial Benefits of Green Buildings – A report to California’s sustainable Building Task Force.

Carsrud, A., & Brännback, M. (2010). Fostering sustainability in family firms. *Sustainable Economy: Corporate, Social and Environmental Responsibility, Singapore: World Publications*, 53-70.

Choi, C. (2009). Removing market barriers to green development: principles and action projects to promote widespread adoption of green development practices. *The Journal of Sustainable Real Estate*, *1*(1), 107-138.

Choong, P.M., and Sharratt, P.N. (2002). A life-cycle framework to analyse business risk in process industry projects, *Journal of Cleaner Production*, *10* (5), 479-493

Chuck, W. F., & Kim, J. T. (2011). Building environmental assessment schemes for rating of IAQ in sustainable buildings. *Indoor and Built Environment*, *20*(1), 5-15.

Clemen, R. T.; and Winkler, R. L., (1999), Combining Probability Distributions From Experts ln Risk Analysis, ‘’Risk Analysis’’, 19(2), 187-203.

Clift, M. and Bourke, K. (1998), ‘’Study on Whole Life Cycle Costing for the Department of the Environment, Transport and the Regions (DETR)’’, (CR 336/98), Building Research Establishment, Watford.

CoreNet (2008), Global Trends in Sustainable Real Estate: An Occupier’s Perspective – February, Available from: www.nzgbc.org.nz/main/resources/documents/sustainableRealEstate (accessed 02/03/2014)

Creswell, J. W. (2003) Research design: qualitative, quantitative, and mixed method approaches, Thousand Oaks, Calif., Sage Publications.

Cuéllar-Franca, R. M., & Azapagic, A. (2014). Life cycle cost analysis of the UK housing stock. *The International Journal of Life Cycle Assessment*, *19*(1), 174-193

Denscombe, M. (2010) *The Good Research Guide for small scale social research projects*. 4th edition, Open press University Publications

De Jong, P., & Arkesteijn, M. (2014). Life cycle costs of Dutch school buildings. *Journal of Corporate Real Estate*, *16*(3).

Department of the Environment, Transport and the Regions (2000a). *Our Towns and Cities: the Future – Delivering the Urban Renaissance*. Stationery Office: London.

Department of the Environment, Transport and the Regions (2000b). *Building a Better Quality of Life*. HMSO: London.

Dhillon, B. (2013). Life cycle costing: techniques, models and applications. Routledge.

Diallo, A., & Thuillier, D. (2004). The success dimensions of international development projects: the perceptions of African project coordinators. *International Journal of Project Management*, *22*(1), 19-31.

Dikmen, I, Birgonul, M T and Arikan, A E (2004) A critical review of risk management support tools. *In:* Khosrowshahi, F (Ed.), *20th Annual ARCOM Conference*, 1-3 September 2004, Heriot Watt University. Association of Researchers in Construction Management, Vol. 2, 1145-54.

Dixon, P. T., & Mallaburn, P. S. B. A. D. P. (2014). Energy performance in commercial property: research and practice challenges. *Journal of Property Investment & Finance, 32*(4).

Doloi, H. (2011). Understanding stakeholders' perspective of cost estimation in project management, *International Journal of Project Management*, 29(5), 622-635

Dulami, M.F., Ling, F.Y.Y. and Bajracharya, A. (2003) Organisational motivation and inter-organisational interaction in construction innovation in Singapore. *Construction*

Management and Economics, 21: pp 307-318

Dunn, R. (2012). In retrospect: Silent Spring. *Nature*, *485*(7400), 578-579

Edwards S, Bartlett E and Dickie, I (2000) Whole life costing and life-cycle assessment for sustainable building design, BRE Digest 452, CRC, London

Egan, J. (1998) ‘’Rethinking Construction’’. The report of the Construction Task Force to the Deputy Prime Minister, on the scope for improving the quality and efficiency of UK construction. Department of Trade and Industry. The Stationery Office, London.

Eichholtz, P., Kok, N., & Quigley, J. M. (2013). The economics of green building. *Review of Economics and Statistics*, *95*(1), 50-63.

Elhag, T. & Boussabaine, A. H., (1999). Applying fuzzy techniques to cash flow analysis. *Construction Management & Economics*, *17*(6), 745-755.

El-Haram, M. A., Marenjak, S., & Horner, M. W. (2002). Development of a generic framework for collecting whole life cost data for the building industry. *Journal of Quality in Maintenance Engineering*, *8*(2), 144-151.

Energy Performance Certificate (2014). The history, Blackwell Publishers

Esan, E. O. (1994). An Introduction to Sampling Theory and Practice. JAS Publishers, Lagos,

Falkner, R., Stephan, H., & Vogler, J. (2010). International climate policy after Copenhagen: Towards a ‘building blocks’ approach. *Global Policy*, *1*(3), 252-262.

Ferrin, D, Plank, E (2002) ‘’Total cost of ownership models: an exploratory study’’, *J Supply Chain Manage*, 38, pp. 18–29

Ferry, D.J.O. and Flanagan, R. (1991), “Life cycle costing – a radical approach”, Construction Industry Research and Information Association Report No. 122, London.

Fields, A. (2000) Discovering statistics using SPSS for windows, Sage Publications, London (2000).

Flanagan, R. & Norman, G, (1983). Risk Management and Construction. . 1st ed. Oxford: Blackwell Science.

Flanagan, R., Norman, G., Meadows, J. and Robinson, G. (1989). 'Life Cycle Costing: theory and practice'. Basil Blackwell Scientific Publishing, Oxford.

Flanagan, R., Jewell, C., and Norman, G. (2005). Whole life appraisal for construction, Blackwell Science, Oxford.

Flood, I., and Kartam, N. (1994). Neural networks in civil engineering I: Principles and Understanding. *Journal of Computing in Civil Engineering*, 8(2), 131-148.

Flynn, L. (2003) Driven to be green. *Building Design & Construction*, Nov. 2003, Vol. 44, Issue 11, p.24

Fuerst, F., & McAllister, P. (2011). Green noise or green value? Measuring the effects of environmental certification on office values. *Real Estate Economics,39*(1),

Ghauri, P., Gronhaug, K., & Kristinslund, I. (2010). Research Methods in Business Studies. 4. painos. *Essex: Pearson Education Limited*.

Gibbons, J. D., & Chakraborti, S. (2011). *Nonparametric statistical inference* (pp. 977-979). Springer Berlin Heidelberg.

Glynn, S. M., Taasoobshirazi, G. and Brickman, P. (2009) Science Motivation Questionnaire: Construct validation with nonscience majors. *Journal of Research in Science Teaching*, 46: 127–146.

Gluch, P., & Baumann, H. (2004). The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and Environment*, *39*(5), 571-580.

Griffin, J. J. (1993), "Life Cycle Cost Analysis: A Decision Aid", In Bull, J. W. (Ed.), "Life Cycle Costing for Construction", Blackie Academic & Professional, Glasgow, UK.

Guinee, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R.,& Rydberg, T. (2010). Life cycle assessment: past, present, and future†. *Environmental science & technology*, *45*(1), 90-96.

Hair, J. F., Anderson, R. E., Tatham, R. L. and Black, W. C. (*1998)* Multivariate data analysis, Upper Saddle River, N.J., Prentice Hall.].

Häkkinen, T., & Belloni, K. (2011). Barriers and drivers for sustainable building. *Building Research & Information*, *39*(3), 239-255.

Halim, M. (2013). Economic issues on green office buildings in Malaysia.

Haworth, D. (1975). The Principles of Life Cycle Cosating. Industrial forum. Volume 6

Haykin, S., (1994). Neural Networks — A Comprehensive Foundation. MacMillan College, New York.

Haykin, S. S., Haykin, S. S., Haykin, S. S., & Haykin, S. S. (2009). *Neural networks and learning machines* (Vol. 3). Upper Saddle River: Pearson Education.

Hegazy, T., & Moselhi, O. (1994). Analogy-based solution to markup estimation problem. *Journal of Computing in Civil Engineering*, *8*(1), 72-87.

Hinge, A., Winston, D., Stigge, B., and Happold, B. (2006). Moving Toward Transparency and Disclosure in the Energy Performance of Green Buildings. American Council for an Energy Efficient Economy. Washington, DC.

HMSO (2000). The new Treasury Procurement Guidance Note – No. 7; "Whole Life Costs". The HM Treasury, HMSO, UK

Hoar, D.W. (1988). "An Overview of Life Cycle Costing Techniques", *Property Management*, Vol. 6 Iss: 2 pp. 98

Hoffman, A. J., & Henn, R. (2008). Overcoming the social and psychological barriers to green building. *Organization & Environment*, *21*(4), 390-419.

Hojem, T. S., Sørensen, K. H., & Lagesen, V. A. (2014). Designing a 'green' building: expanding ambitions through social learning. *Building Research & Information*, (ahead-of-print), 1-11.

Holmes, J., & Hudson, G. (2003). The application of BREEAM in corporate real estate: A case study in the design of a city centre office development. *Journal of Corporate Real Estate*, *5*(1), 66-77.

Horngren, C.T., Datar, S.M. and Foster, G. (2003). ''Cost Accounting - A Managerial Emphasis'', Pearson Education, Inc., New Jersey, Eleventh Edition

Holopainen, R., Tuomaala, P., Hernandez, P., Häkkinen, T., Piira, K., & Piippo, J. (2014). Comfort assessment in the context of sustainable buildings: Comparison of simplified and detailed human

Hunkeler, D., & Rebitzer, G. (2003). Life Cycle costing—paving the road to sustainable development? *The international journal of life cycle assessment*, *8*(2), 109-110.

Hunter, K; Hari, S; Kelly, J (2005) "A whole life costing input tool for surveyors in UK local government", *Structural Survey*, Vol. 23 Iss: 5, pp.346 – 358

Hunter, K and Kelly, J. (2009) ''Life Cycle Costing of Sustainable Design'', RICS Research Report

Hunter, K. and Trufil, G. (2006). "Whole Life Costing of Sustainable Design." Salford: in house publishing

Jepsen, L. B., Dell'Era, C., & Verganti, R. (2014). The contributions of interpreters to the development of radical innovations of meanings: the role of ‘Pioneering Projects’ in the sustainable buildings industry. *R&D Management*, *44* (1), 1-17.

Jones, O. (2000) Future opportunities, scope and impact. *Facilities*. 18(3/4): 133-137.

Kats, G. (2003). *Green building costs and financial benefits* (p. 1). Boston, MA: Massachusetts Technology Collaborative.

Kawauchi, Y. and Rausand, M., (1999), Life Cycle Cost (LCC) Analysis in Oil and Chemical Process Industries, RAMS Group, NTNU, Norway.

Keoleian, G. A., Kendall, A., Dettling, J. E., Smith, V. M., Chandler, R. F., Lepech, M. D., & Li, V. C. (2005). Life cycle modelling of concrete bridge design: Comparison of engineered cementitious composite link slabs and conventional steel expansion joints. *Journal of infrastructure systems*, *11*(1), 51-60

Khan, O., & Burnes, B. (2007). Risk and supply chain management: creating a research agenda. *International Journal of Logistics Management*, *18*(2), 197-216.

Kibert, C. J. (2012). *Sustainable construction: green building design and delivery*. Wiley.

Kim, J. and Mueller, C.W. (1994) Introduction to factor analysis: what it is and how to do it? In: M.S. Lewis-Beck, Editor, Factor analysis and related techniques. International handbooks of quantitative applications in the social sciences vol. 5, Sage Publications, London (1994).

Kirk, S.J. & Dell’Isola, A.J. (1995) Life-cycle costing for Design Professionals. McGraw-Hill, New York.

Kirkham, R. J., Boussabaine, A. H., & Awwad, B. H. (2002). Probability distributions of facilities management costs for whole life cycle costing in acute care NHS hospital buildings. *Construction Management & Economics*, *20*(3), 251-261.

.

Kirkham, R J, Alisa, M, Silva, A P d, Grindley, T and Brondsted, J (2004) Rethinking whole life cycle cost based design decision-making. In: Khosrowshahi, F (Ed.), 20th Annual ARCOM Conference, 1-3 September 2004, Heriot Watt University. Association of Researchers in Construction Management, Vol. 1, 91-103.

Kirkham, R. J. (2005). Re-engineering the whole life cycle costing process. *Construction Manageme* Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N., & Sun, M. (2003). Whole life costing in construction-A state of the art review. *RICS Foundation Research Papers*, *4*(18), 1-39.

Kishk, M, and Al-Hajj, A., (1999), "An Integrated Framework for Life Cycle Costing in

Buildings", Proceedings of the COBRA 1999 RICS Construction and Building Research Conference, September 1 - 2, 1999, Vol. 2, pp. 92-101. *Economics*, *23*(1), 9-14.

Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N., & Sun, M. (2003). Whole life costing in construction-A state of the art review. *RICS Foundation Research Papers*, *4*(18), 1-39.

Kohler, H. P. (2012). Copenhagen Consensus 2012: Challenge Paper on" Population Growth".

Korpi, E., & Ala-Risku, T. (2008). Life cycle costing: a review of published case studies. *Managerial Auditing Journal*, *23*(3), 240-261.

Kozlowski, D. (2003), Green gains: Where sustainable design stands now, *Building Operating Management,* Vol. 50, No. 7, pp. 26-32

Kshirsagar, A. S., El-Gafy, M. A., & Abdelhamid, T. S. (2010). Suitability of life cycle cost analysis (LCCA) as asset management tools for institutional buildings. *Journal of Facilities Management*, *8*(3), 162-178.

Kumaran, D. S., Ong, S. K., Tan, R. B., & Nee, A. Y. C. (2001). Environmental life cycle cost analysis of products. *Environmental Management and Health*, *12*(3), 260-276.

Lair, J. and Chevalier (2002) Failure Mode Effect And Criticality Analysis For Risk Analysis (Design) and Maintenance Planning (Exploitation), Proceedings of 9th International Conference on Durability of Building Materials and Components, CSIRO, Brisbane, Australia

Langridge, A. (2010).''Uncertainty. In: SCAF workshop on defence indecision, Bristol, UK; 2010.

Langdon Davis Management (2007) "Life Cycle Costing as a contribution to sustainable design: a common methodology – Final report", Retrieved on September 3 from http://ec.europa.eu/enterprise/sectors/construction/!les/compet/life_cycle_costing

Latham, M. (1994) Constructing the Team. Final report of the government/industry review of procurement and contractual arrangements in the UK construction industry

Leicester University (1999) *Whole Life Costing Model for Purchase Supply*, University of Leicester Purchasing Department

Lewis, P., & Saunders, M. (2012). Doing research in business and management: An essential guide to planning your project. Financial Times/Prentice Hall.

Li, V. C. (2005). Life cycle modelling of concrete bridge design: Comparison of engineered cementitious composite link slabs and conventional steel expansion joints. Journal of Infrastructure Systems, 11(1), 51-60.

Liapis, K. J., Kantianis, D. D., & Galanos, C. L. (2014). Commercial property whole-life costing and the taxation environment. *Journal of Property Investment & Finance*, *32*(1), 56-77.

Lindholm, A. and Suomala, P. (2004), "The possibilities of life cycle costing in outsourcing decision making", in Seppa¨, M., Ja¨rvelin, A-M., Kujala, J., Ruohonen, M. and Tiainen, T. (Eds), Proceedings of e-Business Research Forum eBRF 2004, Tampere, Finland, pp. 226-41.

Lindholm, A., & Suomala, P. (2005). Present and future of life cycle costing: reflections from Finnish companies. *LTA*, *2*, 05.

Lopresti, F. (1998) New SPSS Missing Values Analysis Option,http://www.nyu.edu/its/

pubs/connect/archives/98fall/loprestimissing.html, (accessed on January 18, 2013)

Lowe, D. J., Emsley, M. W., & Harding, A. (2006). Predicting construction cost using multiple regression techniques. *Journal of construction engineering and management*, *132*(7), 750-758.

Lützkendorf, T., & Lorenz, D. (2005). Sustainable property investment: valuing sustainable buildings through property performance assessment. *Building Research & Information*, *33*(3), 212-234

Lützkendorf, T., Foliente, G., Balouktsi, M., & Wiberg, A. H. (2014). Net-zero buildings: Incorporating embodied impacts. *Building Research & Information*, *43*(1), 62-81.

Makridakis, S., Weelwright, S.C. & McGee, V.E. (1993) *Forecasting: Methods and Applications*, 2nd ed. John Wiley and Sons, New York.

Malhotra, R., & Malhotra, D. K. (2003). Evaluating consumer loans using neural networks. Omega, 31(2), 83-96.

Mansfield, J. R. (2009). The valuation of sustainable freehold property: a CRE perspective. *Journal of Corporate Real Estate*, *11*(2), 91-105.

Marshall, H.E. (1999) *Technology Management Handbook*, Chapter 8.12. CRC Press, New York.

Masiello G.L. (2002). Reliability, the life cycle driver: An examination of reliability management, culture and practices. Master of Science Thesis. Monterey, CA: US Naval Postgraduate School

McKim, R.A. (1993) A neural network application to construction management. In: Proceedings of the Conference on Organisation and Management of Construction - The Way Forward, CIB W-65, Trinidad, September 1993, pp. 103-127.

MCqueen, R. A. and Knussen, C. (2002) Research Methods for Social Science: A Practical

Introduction, Harlow, Prentice Hall

Memon, A. H. (2013). *Structural modelling of cost overrun factors in construction industry* (Doctoral dissertation, Universiti Tun Hussein Onn Malaysia).

Mickaityte, A., Zavadskas, E. K., Kaklauskas, A., & Tupenaite, L. (2008). The concept model of sustainable buildings refurbishment. *International Journal of Strategic Property Management*, *12*(1), 53-68

Miller, E., & Buys, L. (2008). Retrofitting commercial office buildings for sustainability: tenants' perspectives. *Journal of Property Investment & Finance*,*26*(6), 552-561.

Miller, N., Spivey, J., & Florance, A. (2008). Does green pay off? *Journal of Real Estate Portfolio Management*, *14*(4), 385-400.

Mills, E., (2005) Insurance in a climate of change, Science, 309, August, 1040-1044.

Moselhi, O., Hegazy, T., & Fazio, P. (1991). Neural networks as tools in construction. *Journal of Construction Engineering and Management*, 117(4), 606-625.

Morse, B. C. (2013). Richard Neutra, biorealist.

Munn, P. and Drever, E. (1990) Using questionnaires in small-scale research: A teachers' guide, SCRE, Edinburgh.

Myers, G., Reed, R., & Robinson, J. (2008). Sustainable property-the future of the New Zealand market. *Pacific rim property research journal*, *14*(3), 298-321

Nachtmann, H. and Needy, K.L. (2003), "Methods for handling uncertainty in activity based costing systems", *The Engineering Economist*, Vol. 48 No. 3, pp. 259-82.

Nepak, P. D. (2013). Navigation Control of an Automated Guided Underwater Robot using Neural Network Technique (Doctoral dissertation).

Nalewaik et al (2009), Cost Benefit of Building Green, Cost Engineering Technical Article Peer Reviewed, Vol.5/ No. 1

NATO. (2009). SAS-069 NATO code of practices for life cycle costing.

Newton, L. A., & Christian, J. (2006). Impact of quality on building costs. *Journal of Infrastructure Systems*, 12(4), 199-206.

NIST (1995) Life-Cycle Costing Manual for the Federal Energy Management Program. 1995 Edition ed. Fuller, S. K.; Petersen, S. R. NIST Handbook 135; 1995 Edition

Norman G. Life Cycle Costing. *Property Management*, 1990: 8(4): 344–56

Noor, M., & Aizuddin, N. (2013). Whole Life Cycle Costing and Quality Satisfaction: Public Housing Floor Material. *Advanced Materials Research*, *717*, 877-883.

Oduyemi, O, Okoroh, M and Dean, A (2014) Barriers to life cycle costing usage In: Raiden, A B and Aboagye-Nimo, E (Eds) Procs 30th Annual ARCOM Conference, 1- 3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 785-793.

Ofori, G. and Chan, G. (2001) ISO 9000 Certification of Singapore construction enterprises: its costs and benefits and its role in the development of the industry. *Engineering, Construction and Architectural Management*, 8 (2): 145-157

Okafor, R. O (2004). Statistical Methods and Non-parametric Techniques. JAS Publishers, Lagos

Olubodun, F., Kangwa, J., Oladapo, A and Judith Thompson, (2010),"An appraisal of the level of application of life cycle costing within the construction industry in the UK", *Structural Survey*, Vol. 28 Iss: 4 pp. 254 – 265

Ortiz, O., Castells, F., & Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, *23*(1), 28-39.

Osmani, M., & O'Reilly, A. (2009). Feasibility of zero carbon homes in England by 2016: a house builder's perspective. *Building and Environment*, *44*(9), 1917-1924.

Ozer, E. (2014). Mutualistic relationships versus hyper-efficiencies in the sustainable building and city. *Urban Ecosystems*, *17*(1), 195-204.

Pallant, J. (2013) *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS,* 5th edition, Open University Press, McGraw Hill.

Passer, A., Wall, J., Kreiner, H., Maydl, P., & Höfler, K. (2014). Sustainable buildings, construction products and technologies: linking research and construction practice. *The International Journal of Life Cycle Assessment*, 1-8.

Peças, P., Ribeiro, I., Silva, A., Henriques, E. (2012), ‘’ Comprehensive approach for informed life cycle-based materials selection‘’

Pelzeter, A (2007) Building optimisation with lifecycle costs- the influence of calculation methods. *Journal of Facilities Management,* 5(20), 115-128

Pérez-Lombard, L., Ortiz, J., González, R., & Maestre, I. R. (2009). A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes. *Energy and Buildings*, *41*(3), 272-278.

Perry, J.G. and Hayes, R.W. (1985), Risk and its management in construction projects, Proceedings of the Institution of Civil Engineers, UK, 78(1), pp 499-521

Pewdum, W., Rujirayanyong, T., & Sooksatra, V. (2009). Forecasting final budget and duration of highway construction projects. *Engineering, Construction and Architectural Management*, 16(6), 544-557.

Pivo, G., & Fisher, J. D. (2010). Income, value, and returns in socially responsible office properties. *Journal of Real Estate Research*, *32*(3), 243-270.

Pivo, G. & McNamara, P. (2005) Responsible Property Investing, *International Real Estate Review*, Vol. 8 No. 1, pp: 128-143

Plenty, T., Chen, W. & McGeorge, W. (1999) Accrued value assessment – a dynamic approach for investment appraisal and facilities management. In *Proceedings of 8th International Conference on Durability of Building Materials and Components*, 30 May–3 June, Vancouver, Canada, pp. 1765–73.

Popescu, D., Bienert, S., Schützenhofer, C., & Boazu, R. (2012). Impact of energy efficiency measures on the economic value of buildings. *Applied Energy*, *89*(1), 454-463.

Potts, K., & Ankrah, N. (2014). Construction cost management: learning from case studies. Routledge.

Prlngle, (1975) Engineering and supply m the RAF Aerospace, 27-33.

Ravemark, D. (2004) LCC/LCA Experience. Developing and working with LCC tools. DANTES – EU Life Environment Program

Robinson, J., (2005). Property valuation and analysis applied to environmentally sustainable development. In PRRES, 11th Pacific Rim Estate Society Conference 2005, Melbourne, 23-27 January 2005

Rohracher, H. (2001). Managing the technological transition to sustainable construction of buildings: a socio-technical perspective. *Technology Analysis & Strategic Management*, *13*(1), 137-150

Roseland, M. (2012). *Toward sustainable communities: Solutions for citizens and their governments* (Vol. 6). New Society Publishers.

Roufechaei, K. M., Hassan Abu Bakar, A., & Tabassi, A. A. (2014). Energy-efficient design for sustainable housing development. *Journal of Cleaner Production*, *65*, 380-388.

Sacks, A; Nisbet, A, J.,Nishani H, (2012) "Life cycle cost analysis: a case study of Lincoln on the Lake", Journal of Engineering, Design and Technology, Vol. 10 Iss: 2, pp.228 – 254

Salama, M., & Hana, A. R. (2010). Green buildings and sustainable construction in the United Arab Emirates. *26th Annual ARCOM Conference*, 1397-1405.

Schade, J. (2007). Life cycle cost calculation models for buildings. *InPro Project Avaialbe at http://www. inpro-project. eu/media/lcc_juttaschade. pdf [Accessed at 21 September 2014]*.

Schweber, L. (2013). The effect of BREEAM on clients and construction professionals. *Building Research & Information*, *41*(2), 129-145.

Sekaran, U., & Bougie, R. (2010). Research methods for business: A skill building approach. Wiley.

Shash, A. A. (1993) Factors Considered in Tendering Decisions by top UK Contractors. *Construction Management and Economics*, 11, 111-118.

Shaikh, P. H., Nor, N. B. M., Nallagownden, P., Elamvazuthi, I., & Ibrahim, T. (2014). A review on optimized control systems for building energy and comfort management of smart sustainable buildings. *Renewable and Sustainable Energy Reviews*, *34*, 409-429.

Shiers, D., Rapson, D., Roberts, C., & Keeping, M. (2006). Sustainable construction: the development and evaluation of an environmental profiling system for construction products. *Construction Management and Economics*, *24*(11), 1177-1184.

Sobanjo, J. O., 1999, Facility Life-cycle Cost Analysis Based on Fuzzy Set Theory, Proceedings of the Eighth Int. Conference on Durability of Building Materials and Components, Vancouver, Canada, May 30 - June 3, 1999, Vol. 3, pp. 1798-1809

Sparkling, A. E. (2012). Cost justification for investing in LEED projects. *McNair Scholars Research Journal*, *4*(1), 7.

Stephan, A., Crawford, R. H., & De Myttenaere, K. (2011). Towards a more holistic approach to reducing the energy demand of dwellings. *Procedia engineering*, *21*, 1033-1041.

Sterling, S. (2001). Sustainable education. *UK: Green Books Ltd*.

Stoy, C., Pollalis, S., & Schalcher, H. R. (2008). Drivers for cost estimating in early design: Case study of residential construction. *Journal of Construction Engineering and Management*, *134*(1), 32-39.

Sustainable Buildings Task Group. (2004). *Better Buildings – Better Lives*. Sustainable Buildings Task Group. http://www. dti.gov.uk/construction/sustain/EA_Sustainable_Report_41564_2.pdf [11 January 2014].

Takim, R., Akintoye, A. and Kelly, J. (2004) Analysis of Performance Measurement in the Malaysian Construction Industry, in Ogunlana, S. O., Chareonngam, C., Herabet, P. and Hadikusumo, B. H. W. (Eds.) Globalization and Construction, AIT Conference Centre, Bangkok, Thailand, 533–546.

Thatcher, A., & Milner, K. (2014). Green Ergonomics and Green Buildings. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *22*(2), 5-12.

The New Zealand National Asset Management Steering Group (NAMS), 2004, *Optimised Decision Making Guidelines: A sustainable approach to managing Infrastructure*, NAMS, Thames, New Zealand.

Smith, P. (1999). "Occupancy Cost Analysis". Building in Value – Pre-Design Issues. Arnold. London.

Thunnissen, D. P. (2003). Uncertainty classification for the design and development of complex systems. In *3rd annual predictive methods conference*.

Townsend T. 2005. Why don't we build more sustainable housing? *Urban Design* 95(Summer): 12–13.

US Department Of Defense (2001) Guides/Manuals, DoD Guide LCC- 1, Life Cycle Costing

Verbruggen, A., Marchohi, M. A., & Janssens, B. (2011). The anatomy of investing in energy efficient buildings. *Energy and buildings*, *43*(4), 905-914.

Vidogah, W. and Ndekugri, I. (1998) A review of the role of information technology in construction claims management", *Computers in Industry*, Vol. 35 No. 1, pp. 77-85.

Waak, O. (2004). Cut maintenance and logistics support cost with 50%, a fantasy or a feasibility. http://www.systecon.se

Wanous, M. (2000) *A neurofuzzy expert system for competitive tendering in civil engineering*. Unpublished PhD thesis, University of Liverpool.

Ward, S. C. and Chapman, C. B. (1995) 'A risk management perspective on the project life cycle', International Journal of Project Management, 13(3), 1995, pp. 145-150

Warren-Myers, G. (2012). The value of sustainability in real estate: a review from a valuation perspective. *Journal of Property Investment & Finance*, *30*(2), 115-144.

White, K.H. (1991) Building performance and cost-in-use. *The Structural Engineer*, 69(7), 148–51.

Wilkinson, S. J., & Reed, R. (2011). Examining and quantifying the drivers behind alterations and extensions to commercial buildings in a central business district. *Construction management and economics*, *29*(7), 725-735.

Wilhelm, T. (2012). The incorporation of sustainable features in commercial property valuation. *Journal of Property Investment & Finance*, *30*(4)

Williams, D. E. (2007). *Sustainable design: Ecology, architecture, and planning*. John Wiley & Sons.

Williams K, Lindsay M. (2005). *Oxford Institute for Sustainable Development Working Paper 5: The Extent and Nature of Sustainable Building in England: an Analysis of Progress*. Oxford Brookes University: Oxford.

Williams, K., & Dair, C. (2007). What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments. *Sustainable development*, *15*(3), 135-147.

Winston, N. (2010). Regeneration for sustainable communities? Barriers to implementing sustainable housing in urban areas. *Sustainable Development*, *18*(6), 319-330.

Wong, J. K. W., Li, H., & Wang, S. W. (2005). Intelligent building research: a review. *Automation in Construction*, *14*(1), 143-159.

Wirahadikusumah, R., & Abraham, D. M. (2003). Application of dynamic programming and simulation for sewer management. *Engineering, Construction and Architectural Management*, *10*(3), 193-208.

Woodward, D. (1997), "*Life cycle costing* – theory, information acquisition and application", *International Journal of Project Management*, Vol. 15 No. 6, pp. 335-44

Woodward, D, (2005)"Life cycle costing: Incorporating some non-traditional variables", *Asian Review of Accounting*, Vol. 13 Iss: 1 pp. 73 – 80

Wu, P., & Low, S. P. (2010). Project management and green buildings: lessons from the rating systems. *Journal of Professional Issues in Engineering Education and Practice*, 136(2), 64-70.

Xiao, H. (2002) A comparative study of contractor performance based on Japanese, UK and US construction practice, PhD thesis, SEBE, University of Wolverhampton, Wolverhampton.

Yang, J., & Yang, Z. (2014). Critical factors affecting the implementation of sustainable housing in Australia. *Journal of Housing and the Built Environment*, 1-18

Yin, R.K. (2003) Case study research: Design and Methods, 3rd Edn., Sage Publications, California.

Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Tamošaitiene, J. (2008). Selection of the effective dwelling house walls by applying attributes values determined at intervals. *Journal of Civil Engineering and Management*, *14*(2), 85-93.

Zhai, X., Reed, R., & Mills, A. (2014). Embracing off-site innovation in construction in China to enhance a sustainable built environment in urban housing. *International Journal of Construction Management*, (ahead-of-print), 1-16.

Zhou, L., and Lowe, D. J., (2003) 'UK Building Procurement System and Sustainability', In: Egbu, C. O., and Tong, M. K. L., (Ed.) First Scottish Conference of Postgraduate Researchers of the Built & Natural Environment (ProBE), 18th– 19thNovember 2003, Glasgow Caledonian University, 29-40

Zou, P. X., Zhang, G., & Wang, J. Y. (2006). Identifying key risks in construction projects: life cycle and stakeholder perspectives. In *Pacific Rim Real Estate Society Conference*

APPENDIX ONE

DATA COLLECTION FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

(Please tick options where applicable)

1) How old is the building?

2) Has it achieved a BREEAM or any equivalent rating? If yes, what is it?

3) What type of work has been carried out on the building?

a) New building □

b) Horizontal extension □

c) Vertical extension □

d) Rehabilitation/Conversion/ Modernisation □

4) What is the number of storeys?

5) What is the construction code?

a) Steel framed □

b) Concrete framed □

c) Brick construction □

d) Timber framed □

e) Offsite construction □

6) What is the location code?

a) East midland region □

b) East Anglia region □

c) West Midland region □

d) North West region □

e) Wales region □

f) Scotland region

g) Northern Ireland region □

h) Northern region □

i) Yorkshire and Humberside region □

7) Which of the following costs are available?

Initial Costs	**Maintenance Costs**	**Operating costs**
Land acquisition and associated fees. □	Internal and external decorations □	Utilities costs such as electric, gas and water rates □
Design team fees and associated costs. □	Services such as repair and replacement of the components in the following sub-elements: Plumbing, internal drainage and sanitary ware, heating, ventilating tanks, boilers and similar items; Lifts, escalators and moving walkways; Electric power and lightening and other mechanical installations □	Administrative costs such as provision of towels, soap etc (for toilet facilities); Porterage; Rubbish disposal and property and facilities management □
Construction price □	Client definable costs □	Client definable costs □
Client definable costs □		Taxes (if applicable) □

Client definable costs mean any other costs you feel should be included

8) If available can we have access to the actual figures?

COST BREAKDOWN STRUCTURE	**Cost (£)** **Monthly/ Quarterly/Yearly**
INITIAL COSTS	
Land acquisition and associated fees	
Design team fees and associated costs	
Construction price	
Client definable costs	
MAINTENANCE COSTS	
Internal and external decorations	
Services	
Client definable costs	
OPERATING COSTS	
Utilities costs	
Administrative costs	
Client definable costs	
Taxes	

APPENDIX TWO

CONSENT LETTER FOR QUESTIONNAIRE SURVEY

Faculty of Art, Design and Technology (ADT),

University of Derby

To Whom It May Concern:

Dear Sir or Madam,

RESEARCH INTO LIFE CYCLE COSTING METHODOLOGY IN THE CONSTRUCTION INDUSTRY

The aim of this research is to develop a user-friendly methodology for Life Cycle Costing (LCC) with a focus on sustainable commercial office buildings. This questionnaire is designed such that you can make suggestions as part of your invaluable contributions to this work. I would very much appreciate if you could please spare some few minutes to complete the questionnaire.

There are no correct or incorrect responses, only your opinion. All answers will be treated in absolute confidence and used for academic purposes only. At the end of the research I will delete/destroy all the data gathered. A copy of the dissertation may be kept in the university library, but it will not be available to the general public. Extra space is provided to enable you expand your answers to the questions where necessary.

I do appreciate that the questionnaire will take some of your valuable time but without your kind and expert input the research objectives aimed at improving LCC implementation cannot be realised. Taking part in this research is entirely voluntary; you are able to withdraw at any time if you want to.To this end, I would like to thank you very much for your valued and kind consideration.

SIGN............................ DATE………………………

Contact Information

Olufolahan Oduyemi,

Faculty of Art, Design and Technology (ADT),

University of Derby

o.oduyemi@derby.ac.uk

SECTION A: GENERAL INFORMATION *(Please tick option(s) where applicable)*

1. What is your professional background?

Quantity Surveyor ☐

Builder ☐

Architect ☐

Estate Surveyor ☐

Facilities Manager ☐

Others (Please specify)…………………………………………………………..

2. How many years of work experience do you have? *(Please tick options where applicable)*

0-5 ☐

6-10 ☐

11 and above ☐

3. Academic qualification? *(You may tick more than one)*

Diploma ☐

BSc ☐

MSc ☐

PhD ☐

Others (Please specify)…………………………………………………………..

4. Professional qualification?

RICS ☐

CIOB ☐

BIFM ☐

Others (Please specify)…………………………………………………………..

SECTION B: LCC AWARENESS AND RELATED ACTIONS (*Please tick options where applicable)*

5. Please indicate the level of awareness of the following non-cost elements of LCC?

Non-cost elements	**a.**	**b.**	**c.**	**d.**	**e.**
	Extremely aware	*Moderately Aware*	*Somewhat aware*	*Slightly aware*	*Not at all Aware*
Key Performance Indicators	☐	☐	☐	☐	☐
Economic Performance Measures	☐	☐	☐	☐	☐
Risk Assessment Techniques	☐	☐	☐	☐	☐
Forecasting methods	☐	☐	☐	☐	☐

6. Please indicate the extent of your agreement or disagreement with the following statements about LCC issues in building design and construction. 1 = *strongly disagree*; 2 = *disagree*; 3 = *neither agree nor disagree*; 4 = *agree*; 5 = *strongly agree*

(Please tick box as appropriate)

	Strongly disagree				*Strongly agree*
Statements	**1**	**2**	**3**	**4**	**5**
Key performance indicators and economic performance measures need to be incorporated into LCC	☐	☐	☐	☐	☐
The current LCC techniques are suitable for calculating the costs of buildings	☐	☐	☐	☐	☐
It is important to consider the initial, operating, maintenance and disposal costs of buildings when conducting LCC analysis	☐	☐	☐	☐	☐
Historical costs data is very accurate	☐	☐	☐	☐	☐

SECTION C: APPLICATIONS AND LIMITATIONS OF LCC IN BUILDING DESIGN AND CONSTRUCTION

7. Please indicate your level of agreement with the factors based on the following scale:
1 = S*trongly disagree*; 2 = D*isagree*; 3 = N*either agree nor disagree*; 4 = A*gree;* 5 = S*trongly agree*

APPLICATION OF LCC IN BUILDING DESIGN AND CONSTRUCTION	**1**	**2**	**3**	**4**	**5**
LCC indicates cost category and presents a possibility for investigation into the inter-relationship between the performance of a building and its running costs	☐	☐	☐	☐	☐
LCC acts as a maintenance guide	☐	☐	☐	☐	☐
LCC acts as a management and decision making tool	☐	☐	☐	☐	☐
LCC model can be used to forecast the costs of all the life cycle phases for individual scheme and allows researchers to choose the most viable development on the basis of total performance	☐	☐	☐	☐	☐
Business risks are spotted early on as LCC indicates the cost occurrence of products therefore providing a yardstick for easier cost and revenue forecasts	☐	☐	☐	☐	☐

8. Please indicate your estimated severity with the limitations based on the following scale:
1= *Very low*; 2= *Low*; 3= *Neutral*; 4= *High*; 5= *Very high*

	Estimated Severity				
LIMITATIONS	**1**	**2**	**3**	**4**	**5**
Lack of common and standard methodology	☐	☐	☐	☐	☐
Lack of reliable data	☐	☐	☐	☐	☐
Risk and Uncertainty	☐	☐	☐	☐	☐
Market conditions and assumptions	☐	☐	☐	☐	☐
Dealing with intangible factors	☐	☐	☐	☐	☐
Type of investor/user	☐	☐	☐	☐	☐

Time consuming and cost implications	☐	☐	☐	☐	☐
Lack of awareness/understanding and unclear benefits of LCC to stakeholders	☐	☐	☐	☐	☐

SECTION D: DRIVERS & BARRIERS OF SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

9. Please indicate your level of agreement with the factors based on the following scale:
1 = *strongly disagree*; 2 = *disagree*; 3 = *neither agree nor disagree*; 4 = *agree*; 5 = *strongly agree*

	Level of agreement				
ECONOMIC DRIVERS	**1**	**2**	**3**	**4**	**5**
Return on investment	☐	☐	☐	☐	☐
Increase rental rates and Incentives	☐	☐	☐	☐	☐
Filling a design need	☐	☐	☐	☐	☐
Cost effectiveness	☐	☐	☐	☐	☐
Ease in leasing	☐	☐	☐	☐	☐
SOCIAL DRIVERS					
Increased productivity	☐	☐	☐	☐	☐
High tenants retention rate	☐	☐	☐	☐	☐
Clients requirements	☐	☐	☐	☐	☐
Attracts tenants	☐	☐	☐	☐	☐
Improve overall quality of life and heighten aesthetic qualities	☐	☐	☐	☐	☐

10. Please indicate your level of estimated severity with the barriers based on the following scale:
1= *Very low*; 2= *Low;* 3= *Neutral*; 4= *High*; 5= *Very high*

	Estimated severity				
TECHNOLOGICAL BARRIERS	**1**	**2**	**3**	**4**	**5**
Low demand for sustainable materials and products	☐	☐	☐	☐	☐
Lack of readily accessible and reliable information and guidance	☐	☐	☐	☐	☐
Lack of life cycle costing (LCC)	☐	☐	☐	☐	☐
Lack of knowledge/ awareness/understanding and experience about energy efficient buildings	☐	☐	☐	☐	☐
Lack of appropriate UK certification	☐	☐	☐	☐	☐
NON-TECHNOLOGICAL BARRIERS					
Financial barriers	☐	☐	☐	☐	☐
No perceived consumer demand for sustainable commercial office buildings	☐	☐	☐	☐	☐
Learning period	☐	☐	☐	☐	☐
Status quo in rules and regulations	☐	☐	☐	☐	☐
Sustainability measures are not considered by the government	☐	☐	☐	☐	☐

.

Please return the completed questionnaire to:

Olufolahan Oduyemi,

Faculty of Art, Design and Technology (ADT),

University of Derby,

Markeaton Street,

DE22 3AW,

Derby.

o.oduyemi@derby.ac.uk

07531816306

Would you like a summary of this research, if so please complete this section:

Email ……………………………………………………………………

Telephone: ………………………………… ……………………………………..

APPENDIX THREE

MODELLING OF OPERATING AND MAINTENACE COSTS

The Probability distribution functions of total operating and maintenance costs in Present Value (PV) of total ownership of a building for one year is given as

$$g(PV) = \frac{g(k)}{1 + g(d)}$$

Where, $g(k) = (t1 + t2 + t3 + t4 + t5 + t6)$

Thus, substituting for$g(k)$,

Hence;

$$g(PV) = \frac{t1}{1 + g(d)} + \frac{t2}{1 + g(d)} + \frac{t3}{1 + g(d)} + \frac{t4}{1 + g(d)} + \frac{t5}{1 + g(d)} + \frac{t6}{1 + g(d)}$$

$t1(\text{Engineering services}) = f1 + f2 + f3 + f4 + f5,$

Where,

f1= Design complexity/ Faulty design

f2= Unfamiliarity with local and site conditions

f3= Low concern for future maintenance

f4= Poor LCC techniques

f5= Unfamiliarity of maintenance methods

$t2(Labour) = w1 + w2 + w3$

Where,

w1= Unavailability of skilled labour

w2= Unavailability of the foreign labours to culture

w3= Defects and faulty workmanship in the initial construction

$t3\ (Building\ materials)\ =\ v1 + v2 + v3 + v4,$

Where,

v1= Usage of cheaper substandard materials

v2= Ignorance about the physical and chemical properties of usage of materials

v3= Material selection does not comply with client activities

v4= Fluctuation of prices

$t4\ (Budget\ and\ finance)\ =\ y1 + y2,$

Where,

y1= Poor financial support for maintenance work

y2= Poor financial control onsite

$t5\ (Building\ user -\ behaviour)\ =\ n1 + n2,$

Where,

n1= Misuse

n2= Intensity of use

$$t6\ (Management\ and\ administration) = s1 + s2 + s3 + s4.$$

Where,

s1= Lack of building management manuals

s2= Lack of communication between maintenance contractors and clients

s3= Unavailability of maintenance contractors

s4= Lack of local productivity standard and specification

Hence,

$$g(PV) = \frac{f1}{1+g(d)} + \frac{f2}{1+g(d)} + \frac{f3}{1+g(d)} + \frac{f4}{1+g(d)} + \frac{f5}{1+g(d)} + \frac{w1}{1+g(d)} + \frac{w2}{1+g(d)} + \frac{w3}{1+g(d)} + \frac{v1}{1+g(d)} + \frac{v2}{1+g(d)} + \frac{v3}{1+g(d)} + \frac{v4}{1+g(d)} + \frac{y1}{1+g(d)} + \frac{y2}{1+g(d)} + \frac{n1}{1+g(d)} + \frac{n2}{1+g(d)} + \frac{s1}{1+g(d)} + \frac{s2}{1+g(d)} + \frac{s3}{1+g(d)} + \frac{s4}{1+g(d)}$$

Similarly, the Probability distribution function of total operating and maintenance costs in Present Value (PV) of total ownership of a building for two years is assumed to be;

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2}$$

The above equation can be simplified to obtain;

$$g(PV) = \frac{\left(2+g(d)\right)g(k)}{1+2g(d)+g(d)^2}$$

$$g(k) = t1 + t2 + t3 + t4 + t5 + t6$$

Then,

$$g(PV) = \frac{(2+g(d))t1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t3}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t4}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t5}{1+2g(d)+g(d)^2} + \frac{(2+g(d))t6}{1+2g(d)+g(d)^2}$$

Also, substituting for $t1, t2, t3, t4, t5, t6$;

$$g(PV) = \frac{(2+g(d))f1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))f2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))f3}{1+2g(d)+g(d)^2} + \frac{(2+g(d))f4}{1+2g(d)+g(d)^2} + \frac{(2+g(d))f5}{1+2g(d)+g(d)^2} + \frac{(2+g(d))w1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))w2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))w3}{1+2g(d)+g(d)^2} + \frac{(2+g(d))v1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))v2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))v3}{1+2g(d)+g(d)^2} + \frac{(2+g(d))v4}{1+2g(d)+g(d)^2} + \frac{(2+g(d))y1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))y2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))n1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))n2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))s1}{1+2g(d)+g(d)^2} + \frac{(2+g(d))s2}{1+2g(d)+g(d)^2} + \frac{(2+g(d))s3}{1+2g(d)+g(d)^2} + \frac{(2+g(d))s4}{1+2g(d)+g(d)^2}$$

The relationship between t=1 year and t=2 years of the prob distr..../, represents the linearity of the system. To ascertain this, when t=3,

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2} + \frac{g(k)}{(1+g(d))^3}$$

This can be simplified to obtain;

$$\frac{(g(d)^2+3g(d)+3)g(k)}{1+3g(d)+3g(d)^2+g(d)^3}$$

Therefore, g(Pv) when t=3 is given by;

$$g(PV) = \frac{(g(d)^2+3g(d)+3)f1}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)f2}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)f3}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)f4}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)f5}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)w1}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)w2}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)w3}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)v1}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)v2}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)v3}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)v4}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)y1}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)y2}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)n1}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)n2}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)s1}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)s2}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)s3}{1+3g(d)+3g(d)^2+g(d)^3} + \frac{(g(d)^2+3g(d)+3)s4}{1+3g(d)+3g(d)^2+g(d)^3}$$

Thus, g (PV) is a linear function. Moreover, the g (PV) for nth year, i.e. when t=nth year;

$$\boxed{g(PV) = \sum_{t=1}^{n} \frac{g(\mathrm{k})}{(1+g(d))^t}}$$

$$g(PV) = \frac{g(k)}{1+g(d)} + \frac{g(k)}{(1+g(d))^2} + \frac{g(k)}{(1+g(d))^3} + \cdots + \frac{g(k)}{(1+g(d))^n}$$

Using the programming mathematical language, MAPLE (Version 17);

$$g(PV) = -\frac{g(k)\left(\frac{1}{1+g(d)}\right)^n}{1+g(d)} - \frac{g(k)\left(\frac{1}{1+g(d)}\right)^n}{g(d)(1+g(d))} + \frac{g(k)}{g(d)}$$

$$= -\frac{g(k)\left(\frac{1}{1+g(d)}\right)^{n+1}(1+g(d)}{g(d)} + \frac{g(k)}{g(d)}$$

$$= -\frac{g(k)\left(\left(\frac{1}{1+g(d)}\right)^{n} - 1\right)}{g(d)}$$

$$\Longrightarrow \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n} + 1\right)g(k)}{g(d)}$$

Substituting for g (k);

$$g(PV) = \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)f1}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)f2}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)f3}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)f4}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)f5}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)w1}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)w2}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)w3}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)v1}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)v2}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)v3}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)v4}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)y1}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)y2}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)n1}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)n2}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)s1}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)s2}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)s3}{g(d)} + \frac{\left(-\left(\frac{1}{1+g(d)}\right)^{n}+1\right)s4}{g(d)}$$

APPENDIX FOUR

MODELLING OF ECONOMIC PERORMANCE MEASURES

The general model for Cost/Income ratio for the present year is given by:

$$CIR = \frac{C}{W}$$

The Cost/Income Ratio (CIR) for one year at r interest is given by

$$CIR = \frac{C}{W} + \frac{C}{W(1+r)}$$

The normal of the above equation is given as;

$$CIR = \frac{C \times (W \times (1+r) + W)}{W \times (W \times (1+r))}$$

Where

W (income) = t1+t2+t3

C (cost) = m1+m2+m3+m4+m5+m6+m7+k1+K2+k3+k4+k5+k6

m1=Major replacement costs

m2= Subsequent refurbishment and adaptation costs

m3= Redecorations

m4= Minor replacement, repairs and maintenance costs

m5=Unscheduled replacement, repairs and maintenance

m6= Client definable costs

m7= Grounds maintenance

k1=Utilities costs

k2=Administrative costs

k3=Overhead costs

k4=Client definable costs

k5=Cleaning costs

k6=Taxes

t1= Non-construction costs

t2= Externalities

t3= Income

Substituting income (W) and Cost(C) into CWR;

$$CIR = \frac{(m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6) \times ((t1 + t2 + t3) \times (1 + r) + (t1 + t2 + t3))}{(t1 + t2 + t3) \times ((t1 + t2 + t3) \times (1 + r))}$$

We can expand to give us

$$CIR = \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{(t1 + t2 + t3)} + \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{(t1 + t2 + t3) \times (1 + r)}$$

Also, we take the Cost/Income Ratio (CIR) for two years to be:

$$CIR = \frac{C}{W} + \frac{C}{W \times (1+r)} + \frac{C}{W \times (1+r)^2}$$

It can be also be expressed by;

$$CIR = \frac{C \times \left(W \times (1+r)(W \times (1+r)^2)\right) + W \times (1+r)W + W \times (1+r)^2 W}{W \times \left(W \times (1+r)\right) \times (W \times (1+r)^2)}$$

Also, Substituting for Income (W) and Cost(C):

$$CIR = \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{t1 + t2 + t3} + \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{(t1 + t2 + t3) \times (1+r)} + \frac{m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6}{(t1 + t2 + t3) \times (1+r)^2}$$

The normal of the above becomes;

$$\frac{(m1 + m2 + m3 + m4 + m5 + m6 + m7 + k1 + k2 + k3 + k4 + k5 + k6) \left((t1 + t2 + t3 + (t1 + t2 + t3) \times (1+r))((t1 + t2 + t3) \times (1+r)^2\right) + (t1 + t2 + t3) \times (1+r) \times (t1 + t2 + t3))}{(t1 + t2 + t3) \times \left((t1 + t2 + t3) \times (1+r)\right) \times ((t1 + t2 + t3) \times (1+r)^2)}$$

Note that the relationship of the CIR between the first and second year is linear, to affirm this claim, a check for 3 years is carried out;

$$CIR = \frac{C}{W} + \frac{C}{W \times (1+r)} + \frac{C}{W \times (1+r)^2} + \frac{C}{W \times (1+r)^3}$$

$$CIR = \frac{C \times \left(W \times (1+r)(W \times (1+r)^2)(W \times (1+r)^3)\right) + W \times (1+r)(W \times (1+r)^2)W + W \times (1+r)(W \times (1+r)^2)W + W \times (1+r)^2(W \times ((1+r)^3))}{W \times \left(W \times (1+r)\right) \times (W \times (1+r)^2) \times (W \times (1+r)^3)}$$

Also, Substituting for Income (W) and Cost(C);

$$CIR = \frac{m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6}{t1+t2+t3} + \frac{m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6}{(t1+t2+t3)\times(1+r)} + \frac{m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6}{(t1+t2+t3)\times(1+r)^2} + \frac{m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6}{(t1+t2+t3)\times(1+r)^3}$$

$$CIR = \frac{\left(\left(\left((t1+t2+t3+(t1+t2+t3)\times(1+r)\right)\left((t1+t2+t3)\times(1+r)^3\right)+(t1+t2+t3)\times(1+r)\times(t1+t2+t3)\right)(1+r)^2\right)+(t1+t2+t3)\times(1+r)\times\left((t1+t2+t3)(1+r)^3\right)(t1+t2+t3))(m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6))}{((t1+t2+t3)\times\left((t1+t2+t3)\times(1+r)\right)\times\left((t1+t2+t3)\times(1+r)^2\right)\times((t1+t2+t3)\times(1+r)^3))}$$

Thus, it's easy to see that the Cost/Income Ratio (CIR) is a linear function.

Therefore, following the linear model trend, using the mathematical Programming language, MAPLE17 the CWR for y number of years for the rth interest will become;

$$CIR = \sum_{n=0}^{y}\left(\frac{C}{W\times(1+r)^n}\right)$$

Since C and W are non-function of n then:

$$CIR = \frac{C}{W}\sum_{n=0}^{y}\left(\frac{1}{(1+r)^n}\right)$$

Which can be further expanded to obtain;

$$CIR = \frac{C}{W}\left(1+\frac{1}{1+r}+\frac{1}{(1+r)^2}+\frac{1}{(1+r)^3}+\cdots+\frac{1}{(1+r)^y}\right)$$

Thus,

$$CIR = \frac{C}{W}\left(-\frac{\left(\frac{1}{1+r}\right)^{y+1}(1+r)}{r} + \frac{1+r}{r}\right)$$

Similarly,

$$CIR = -\frac{C \times \left(\left(\frac{1}{1+r}\right)^{y+1}(1+r)\right)}{W \times r} + \frac{C \times (1+r)}{W \times r}$$

Substituting for C and W

$$= -\frac{(m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6)\left(\left(\frac{1}{1+r}\right)^{y+1}(1+r)\right)}{(t1+t2+t3) \times r}$$
$$+ \frac{(m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4+k5+k6) \times (1+r)}{(t1+t2+t3) \times r}$$

This can be further simplified to obtain

$$CIR = \frac{1}{(t1+t2+t3) \times r}\Bigg((m1+m2+m3+m4+m5+m6+m7+k1+k2+k3+k4$$
$$+k5+k6)\left(\left(\frac{1}{1+r}\right)^{y} - 1 - r\right)\Bigg)$$

$$
\begin{aligned}
CIR = {} & \frac{k1}{t1+t2+t3} + \frac{k2}{t1+t2+t3} + \frac{k3}{t1+t2+t3} + \frac{k4}{t1+t2+t3} + \frac{k5}{t1+t2+t3} \\
& + \frac{k6}{t1+t2+t3} + \frac{m1}{t1+t2+t3} + \frac{m2}{t1+t2+t3} + \frac{m3}{t1+t2+t3} + \frac{m4}{t1+t2+t3} \\
& + \frac{m5}{t1+t2+t3} + \frac{m6}{t1+t2+t3} + \frac{m7}{t1+t2+t3} + \frac{k1}{(t1+t2+t3)r} \\
& + \frac{k2}{(t1+t2+t3)r} + \frac{k3}{(t1+t2+t3)r} + \frac{k4}{(t1+t2+t3)r} + \frac{k5}{(t1+t2+t3)r} \\
& + \frac{k6}{(t1+t2+t3)r} + \frac{m1}{(t1+t2+t3)r} + \frac{m2}{(t1+t2+t3)r} + \frac{m3}{(t1+t2+t3)r} \\
& + \frac{m4}{(t1+t2+t3)r} + \frac{m5}{(t1+t2+t3)r} + \frac{m6}{(t1+t2+t3)r} + \frac{m7}{(t1+t2+t3)r} \\
& - \frac{m1\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{m2\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{m3\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{m4\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} \\
& - \frac{m5\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{m6\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{m7\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{k1\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} \\
& - \frac{k2\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{k3\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{k4\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} - \frac{k5\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r} \\
& - \frac{k6\left(\frac{1}{1+r}\right)^y}{(t1+t2+t3)r}
\end{aligned}
$$

APPENDIX FIVE

OVERALL RANKING CORRESPONDING TO THEIR MEAN APPROXIMATED VALUE OF THE MAIN QUESTIONNAIRE

Descriptive Statistics						
	N	Minimum	Maximum	Mean	Std. Deviation	OVERALL RANKING
KEY PERFORMANCE INDICATORS	69	1	3	1.90	.489	SLIGHTLY AWARE
ECONOMIC PERFORMANCE MEASURE	69	1	5	1.97	.664	SLIGHTLY AWARE
RISK ASSESSMENT TECHNIQUES	69	1	5	1.86	.928	SLIGHTLY AWARE
FORECASTING METHOD	69	1	5	2.75	1.418	SOMEWHAT AWARE
KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES NEED TO BE INCORPORATED INTO LCC	69	2	5	4.74	.610	STRONGLY AGREE
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	69	1	4	1.62	.730	DISAGREE
IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING, MAINTENANCE AND DISPOSAL COSTS OF BUILDING WHEN CONDUCTING LCC ANALYSIS	69	4	5	4.94	.235	STRONGLY AGREE
HISTORICAL COSTS	69	1	5	1.94	1.097	DISAGREE

DATA IS VERY ACCURATE						
LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS	69	3	5	4.42	.695	AGREE
LCC ACTS AS A MAINTENANCE GUIDE	69	3	5	4.36	.618	AGREE
LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL	69	2	5	4.23	.750	AGREE
LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE	69	3	5	4.77	.458	STRONGLY AGREE
BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS	69	3	5	4.58	.526	STRONGLY AGREE
LACK OF COMMON AND STANDARD METHODOLOGY	69	4	5	4.94	.235	VERY HIGH

LACK OF RELIABLE DATA	69	3	5	4.65	.510	VERY HIGH
RISK AND UNCERTAINTY	69	2	5	4.65	.564	VERY HIGH
MARKET CONDITIONS AND ASSUMPTIONS	69	2	5	3.94	.745	HIGH
DEALING WITH INTANGIBLE FACTORS	69	3	5	3.88	.676	HIGH
TYPE OF INVESTOR/USER	69	1	4	1.72	.856	LOW
TIME CONSUMING AND COST IMPLICATIONS	69	2	5	4.14	.809	HIGH
LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	69	1	5	2.48	1.267	NEUTRAL
ECONOMIC DRIVER: RETURN ON INVESTMENT	69	1	5	3.72	1.247	HIGH
ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES	69	1	5	3.38	1.139	NEUTRAL
ECONOMIC DRIVER: COST EFFECTIVENESS	69	1	5	3.99	1.182	HIGH
ECONOMIC DRIVER: FILLING A DESIGN NEED	69	1	5	3.30	1.228	INDIFFERENCE
ECONOMIC DRIVER:	69	1	5	3.19	1.275	INDIFFEREN

EASE IN LEASING						CE
SOCIAL DRIVER: INCREASED PRODUCTIVITY	69	1	5	4.19	.809	AGREE
SOCIAL DRIVER: HIGH TENANTS RETENSION RATE	69	1	5	3.57	1.064	AGREE
SOCIAL DRIVER: CLIENTS REQUIREMENTS	69	1	5	3.39	.973	INDIFFEREN CE
SOCIAL DRIVER: ATTRACT TENANTS	69	1	5	3.10	.972	INDIFFEREN CE
SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES	69	1	5	2.87	.821	INDIFFEREN CE
TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS	69	2	5	3.74	.700	HIGH
TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE	69	1	5	3.09	.836	NEUTRAL
TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING(LCC)	69	1	5	4.01	1.254	HIGH
TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARE NESS/UNDERSTANDIN G AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS	69	3	5	4.38	.644	HIGH

TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION	69	1	5	3.01	1.323	NEUTRAL
NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS	69	1	5	4.41	1.005	HIGH
NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINDS	69	1	5	4.19	1.102	HIGH
NON-TECHNOLOGICAL BARRIER: LEARNING PERIOD	69	1	5	1.97	1.098	LOW
NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS	69	1	5	2.54	1.195	NEUTRAL
NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT	69	1	4	3.10	.957	NEUTRAL
Valid N (listwise)	69					

APPENDIX SIX

TABLE CONTAINING CRONBACH ALPHA VALUES FOR EACH VARIABLE OF THE MAIN QUESTIONNAIRE

VARIABLE	CRONBACH ALPHA	Minimum	Maximum	Mean	Std. Deviation
KEY PERFORMANCE INDICATORS	.556	1	3	1.90	.489
ECONOMIC PERFORMANCE MEASURE	.835	1	5	1.97	.664
RISK ASSESSMENT TECHNIQUES	.720	1	5	1.86	.928
FORECASTING METHOD	.306	1	5	2.75	1.418
KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES NEED TO BE INCORPORATED INTO LCC	.945	2	5	4.74	.610
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	.789	1	4	1.62	.730
IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING, MAINTENANCE AND DISPOSAL COSTS OF BUILDING WHEN CONDUCTING LCC ANALYSIS	.330	4	5	4.94	.235

HISTORICAL COSTS DATA IS VERY ACCURATE	.740	1	5	1.94	1.097
LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS	.614	3	5	4.42	.695
LCC ACTS AS A MAINTENANCE GUIDE	.181	3	5	4.36	.618
LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL	.521	2	5	4.23	.750
LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE	.574	3	5	4.77	.458
BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS	.784	3	5	4.58	.526
LACK OF COMMON AND STANDARD METHODOLOGY	.693	4	5	4.94	.235

LACK OF RELIABLE DATA	.042	3	5	4.65	.510
RISK AND UNCERTAINTY	.449	2	5	4.65	.564
MARKET CONDITIONS AND ASSUMPTIONS	.063	2	5	3.94	.745
DEALING WITH INTANGIBLE FACTORS	.079	3	5	3.88	.676
TYPE OF INVESTOR/USER	.474	1	4	1.72	.856
TIME CONSUMING AND COST IMPLICATIONS	.372	2	5	4.14	.809
LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	.069	1	5	2.48	1.267
ECONOMIC DRIVER: RETURN ON INVESTMENT	.974	1	5	3.72	1.247
ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES	.238	1	5	3.38	1.139
ECONOMIC DRIVER: COST EFFECTIVENESS	.307	1	5	3.99	1.182
ECONOMIC DRIVER: FILLING A DESIGN NEED	.504	1	5	3.30	1.228
ECONOMIC DRIVER: EASE IN LEASING	.137	1	5	3.19	1.275

SOCIAL DRIVER: INCREASED PRODUCTIVITY	.432	1	5	4.19	.809
SOCIAL DRIVER: HIGH TENANTS RETENSION RATE	.460	1	5	3.57	1.064
SOCIAL DRIVER: CLIENTS REQUIREMENTS	.446	1	5	3.39	.973
SOCIAL DRIVER: ATTRACT TENANTS	.783	1	5	3.10	.972
SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES	.993	1	5	2.87	.821
TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS	.826	2	5	3.74	.700
TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE	.698	1	5	3.09	.836
TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING(LCC)	.024	1	5	4.01	1.254
TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARENESS/UNDERSTANDING AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS	.138	3	5	4.38	.644

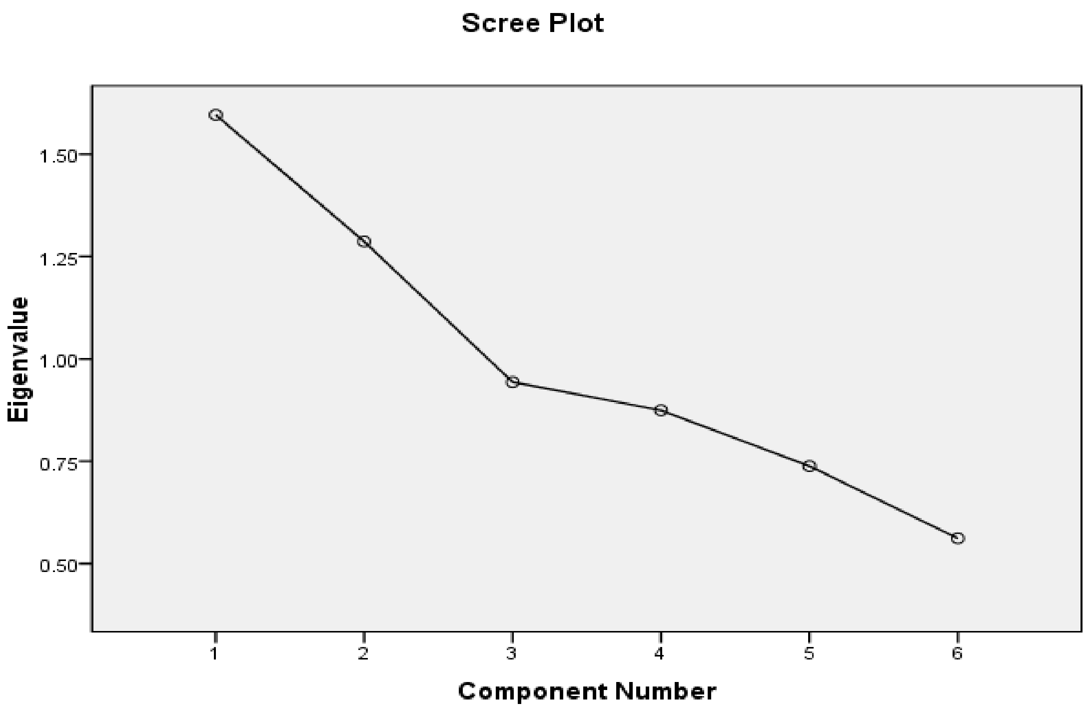
TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION	.055	1	5	3.01	1.323
NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS	.228	1	5	4.41	1.005
NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINDS	.887	1	5	4.19	1.102
NON-TECHNOLOGICAL BARRIER: LEARNING PERIOD	.103	1	5	1.97	1.098
NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS	.616	1	5	2.54	1.195
NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT	.823	1	4	3.10	.957
Valid N (listwise)	.084				

APPENDIX SEVEN

FACTOR ANALYSIS RESULTS OF THE MAIN QUESTIONNAIRE

	Initial	Extraction
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	1.000	.506
LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS	1.000	.479
LCC ACTS AS A MAINTENANCE GUIDE	1.000	.396
LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL	1.000	.626
LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE	1.000	.278
BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS	1.000	.597

Communalities
Extraction Method: Principal Component Analysis.



Communalities

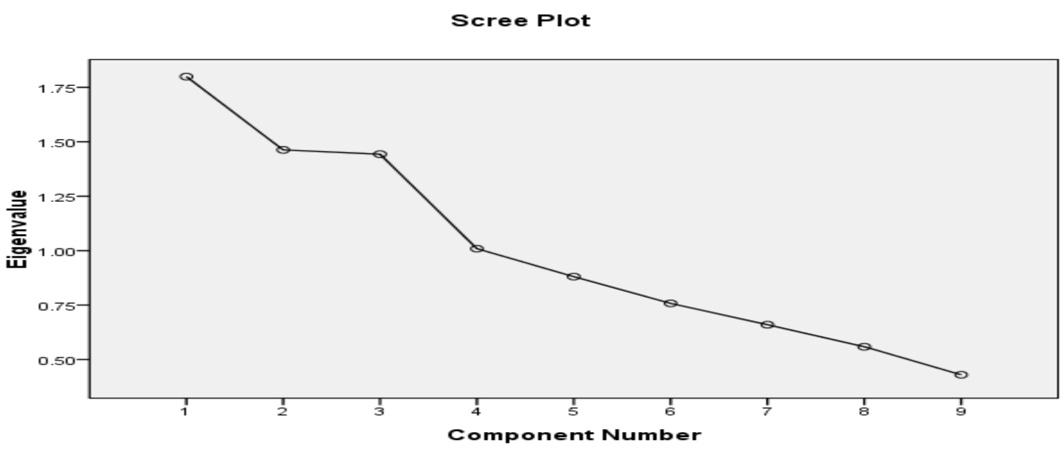
	Initial	Extraction
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	1.000	.430
LACK OF COMMON AND STANDARD METHODOLOGY	1.000	.695
LACK OF RELIABLE DATA	1.000	.591
RISK AND UNCERTAINTY	1.000	.696
MARKET CONDITIONS AND ASSUMPTIONS	1.000	.734
DEALING WITH INTANGIBLE FACTORS	1.000	.668
TYPE OF INVESTOR/USER	1.000	.532
TIME CONSUMING AND COST IMPLICATIONS	1.000	.723
LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	1.000	.644

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.799	19.992	19.992	1.799	19.992	19.992
2	1.463	16.253	36.245	1.463	16.253	36.245
3	1.443	16.033	52.278	1.443	16.033	52.278
4	1.009	11.209	63.487	1.009	11.209	63.487
5	.881	9.784	73.271			
6	.758	8.419	81.690			
7	.660	7.329	89.018			
8	.559	6.206	95.224			
9	.430	4.776	100.000			

Extraction Method: Principal Component Analysis.



Component Matrix[a]

	Component			
	1	2	3	4
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	-.431	.390	-.031	.302
LACK OF COMMON AND STANDARD METHODOLOGY	.794	.087	.165	.174
LACK OF RELIABLE DATA	.452	.170	-.554	.224
RISK AND UNCERTAINTY	-.153	.764	.174	-.242
MARKET CONDITIONS AND ASSUMPTIONS	.123	-.065	.529	-.660
DEALING WITH INTANGIBLE FACTORS	.386	-.022	.661	.287
TYPE OF INVESTOR/USER	-.718	-.017	.087	.091
TIME CONSUMING AND COST IMPLICATIONS	-.274	-.559	.431	.387
LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	.016	-.610	-.410	-.321

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Reproduced Correlations

		THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	LACK OF COMMON AND STANDARD METHODOLOGY	LACK OF RELIABLE DATA	RISK AND UNCERTAINTY	MARKET CONDITIONS AND ASSUMPTIONS	DEALING WITH INTANGIBLE FACTORS	TYPE OF INVESTOR/USER	TIME CONSUMING AND COST IMPLICATIONS	LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS
Reproduced Correlation	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS	.430[a]	-.261	-.044	.286	-.293	-.108	.328	.003	-.329
	LACK OF COMMON AND STANDARD METHODOLOGY	-.261	.695[a]	.321	-.068	.065	.464	-.542	-.128	-.164
	LACK OF RELIABLE DATA	-.044	.321	.591[a]	-.090	-.397	-.131	-.356	-.371	.058
	RISK AND UNCERTAINTY	.286	-.068	-.090	.696[a]	.184	-.031	.090	-.404	-.462
	MARKET CONDITIONS AND ASSUMPTIONS	-.293	.065	-.397	.184	.734[a]	.209	-.101	-.025	.036
	DEALING WITH INTANGIBLE FACTORS	-.108	.464	-.131	-.031	.209	.668[a]	-.193	.302	-.343
	TYPE OF INVESTOR/USER	.328	-.542	-.356	.090	-.101	-.193	.532[a]	.279	-.066

	TIME CONSUMING AND COST IMPLICATIONS	.003	-.128	-.371	-.404	-.025	.302	.279	.723[a]	.036
	LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	-.329	-.164	.058	-.462	.036	-.343	-.066	.036	.644[a]
Residual[b]	THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS		.132	.003	-.109	.225	-.041	-.166	.041	.193
	LACK OF COMMON AND STANDARD METHODOLOGY	.132		-.124	.025	.000	-.137	.096	.018	.110
	LACK OF RELIABLE DATA	.003	-.124		.021	.227	.097	.166	.103	-.002
	RISK AND UNCERTAINTY	-.109	.025	.021		-.127	.039	-.017	.162	.184
	MARKET CONDITIONS AND ASSUMPTIONS	.225	.000	.227	-.127		-.047	.029	.063	-.038
	DEALING WITH INTANGIBLE FACTORS	-.041	-.137	.097	.039	-.047		.163	-.164	.169
	TYPE OF INVESTOR/USER	-.166	.096	.166	-.017	.029	.163		-.157	.054
	TIME CONSUMING AND COST IMPLICATIONS	.041	.018	.103	.162	.063	-.164	-.157		.010
	LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS	.193	.110	-.002	.184	-.038	.169	.054	.010	

Extraction Method: Principal Component Analysis.

a. Reproduced communalities

b. Residuals are computed between observed and reproduced correlations. There are 22 (61.0%) nonredundant residuals with absolute values greater than 0.05.

APPENDIX EIGHT

DESCRIPTIVE STATISTICS OF VARIABLES (FREQUENCY TABLES) OF THE MAIN QUESTIONNAIRE

LACK OF COMMON AND STANDARD METHODOLOGY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HIGH	4	5.8	5.8	5.8
	VERY HIGH	65	94.2	94.2	100.0
	Total	69	100.0	100.0	

LACK OF RELIABLE DATA

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	1	1.4	1.4	1.4
	HIGH	22	31.9	31.9	33.3
	VERY HIGH	46	66.7	66.7	100.0
	Total	69	100.0	100.0	

RISK AND UNCERTAINTY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	1	1.4	1.4	1.4
	HIGH	21	30.4	30.4	31.9
	VERY HIGH	47	68.1	68.1	100.0
	Total	69	100.0	100.0	

MARKET CONDITIONS AND ASSUMPTIONS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	3	4.3	4.3	4.3
	NEUTRAL	12	17.4	17.4	21.7
	HIGH	40	58.0	58.0	79.7
	VERY HIGH	14	20.3	20.3	100.0
	Total	69	100.0	100.0	

DEALING WITH INTANGIBLE FACTORS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	20	29.0	29.0	29.0
	HIGH	37	53.6	53.6	82.6
	VERY HIGH	12	17.4	17.4	100.0
	Total	69	100.0	100.0	

.

TYPE OF INVESTOR/USER

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	35	50.7	50.7	50.7
	LOW	20	29.0	29.0	79.7
	NEUTRAL	12	17.4	17.4	97.1
	HIGH	2	2.9	2.9	100.0
	Total	69	100.0	100.0	

TIME CONSUMING AND COST IMPLICATIONS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	1	1.4	1.4	1.4
	NEUTRAL	15	21.7	21.7	23.2
	HIGH	26	37.7	37.7	60.9
	VERY HIGH	27	39.1	39.1	100.0
	Total	69	100.0	100.0	

LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	21	30.4	30.4	30.4
	LOW	15	21.7	21.7	52.2
	NEUTRAL	16	23.2	23.2	75.4
	HIGH	13	18.8	18.8	94.2
	VERY HIGH	4	5.8	5.8	100.0
	Total	69	100.0	100.0	

ECONOMIC DRIVER: RETURN ON INVESTMENT

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	6	8.7	8.7	8.7
	DISAGREE	5	7.2	7.2	15.9
	NEITHER AGREE NOR DISAGREE	14	20.3	20.3	36.2
	AGREE	21	30.4	30.4	66.7
	STRONGLY AGREE	23	33.3	33.3	100.0
	Total	69	100.0	100.0	

ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	6	8.7	8.7	8.7
	DISAGREE	9	13.0	13.0	21.7
	NEITHER AGREE NOR DISAGREE	16	23.2	23.2	44.9
	AGREE	29	42.0	42.0	87.0
	STRONGLY AGREE	9	13.0	13.0	100.0
	Total	69	100.0	100.0	

ECONOMIC DRIVER: COST EFFECTIVENESS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	6	8.7	8.7	8.7
	DISAGREE	2	2.9	2.9	11.6
	NEITHER AGREE NOR DISAGREE	6	8.7	8.7	20.3
	AGREE	28	40.6	40.6	60.9
	STRONGLY AGREE	27	39.1	39.1	100.0
	Total	69	100.0	100.0	

ECONOMIC DRIVER: FILLING A DESIGN NEED

	Frequency	Percent	Valid Percent	Cumulative Percent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	6	8.7	8.7	8.7
	DISAGREE	13	18.8	18.8	27.5
	NEITHER AGREE NOR DISAGREE	17	24.6	24.6	52.2
	AGREE	20	29.0	29.0	81.2
	STRONGLY AGREE	13	18.8	18.8	100.0
	Total	69	100.0	100.0	

ECONOMIC DRIVER: EASE IN LEASING

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	8	11.6	11.6	11.6
	DISAGREE	13	18.8	18.8	30.4
	NEITHER AGREE NOR DISAGREE	19	27.5	27.5	58.0
	AGREE	16	23.2	23.2	81.2
	STRONGLY AGREE	13	18.8	18.8	100.0
	Total	69	100.0	100.0	

SOCIAL DRIVER: INCREASED PRODUCTIVITY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	1	1.4	1.4	1.4
	DISAGREE	1	1.4	1.4	2.9
	NEITHER AGREE NOR DISAGREE	8	11.6	11.6	14.5
	AGREE	33	47.8	47.8	62.3
	STRONGLY AGREE	26	37.7	37.7	100.0
	Total	69	100.0	100.0	

SOCIAL DRIVER: HIGH TENANTS RETENTION RATE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	3	4.3	4.3	4.3

	DISAGREE	8	11.6	11.6	15.9
	NEITHER AGREE NOR DISAGREE	18	26.1	26.1	42.0
	AGREE	27	39.1	39.1	81.2
	STRONGLY AGREE	13	18.8	18.8	100.0
	Total	69	100.0	100.0	

SOCIAL DRIVER: CLIENTS REQUIREMENTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	3	4.3	4.3	4.3
	DISAGREE	9	13.0	13.0	17.4
	NEITHER AGREE NOR DISAGREE	21	30.4	30.4	47.8
	AGREE	30	43.5	43.5	91.3
	STRONGLY AGREE	6	8.7	8.7	100.0
	Total	69	100.0	100.0	

SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	3	4.3	4.3	4.3
	DISAGREE	16	23.2	23.2	27.5
	NEITHER AGREE NOR DISAGREE	40	58.0	58.0	85.5
	AGREE	7	10.1	10.1	95.7
	STRONGLY AGREE	3	4.3	4.3	100.0
	Total	69	100.0	100.0	

TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	6	8.7	8.7	8.7

	NEUTRAL	10	14.5	14.5	23.2
	HIGH	49	71.0	71.0	94.2
	VERY HIGH	4	5.8	5.8	100.0
	Total	69	100.0	100.0	

TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	4	5.8	5.8	5.8
	LOW	5	7.2	7.2	13.0
	NEUTRAL	45	65.2	65.2	78.3
	HIGH	11	15.9	15.9	94.2
	VERY HIGH	4	5.8	5.8	100.0
	Total	69	100.0	100.0	

TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING (LCC)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	4	5.8	5.8	5.8
	LOW	6	8.7	8.7	14.5
	NEUTRAL	11	15.9	15.9	30.4
	HIGH	12	17.4	17.4	47.8
	VERY HIGH	36	52.2	52.2	100.0
	Total	69	100.0	100.0	

TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARENESS/UNDERSTANDING AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	6	8.7	8.7	8.7
	HIGH	31	44.9	44.9	53.6
	VERY HIGH	32	46.4	46.4	100.0
	Total	69	100.0	100.0	

TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	18	26.1	26.1	26.1
	NEUTRAL	19	27.5	27.5	53.6
	HIGH	27	39.1	39.1	92.8
	VERY HIGH	5	7.2	7.2	100.0
	Total	69	100.0	100.0	

NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	2	2.9	2.9	2.9
	LOW	4	5.8	5.8	8.7
	NEUTRAL	2	2.9	2.9	11.6
	HIGH	17	24.6	24.6	36.2
	VERY HIGH	44	63.8	63.8	100.0
	Total	69	100.0	100.0	

NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINGS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	2	2.9	2.9	2.9
	LOW	6	8.7	8.7	11.6
	NEUTRAL	6	8.7	8.7	20.3
	HIGH	18	26.1	26.1	46.4
	VERY HIGH	37	53.6	53.6	100.0
	Total	69	100.0	100.0	

NON-TECHNOLOGICAL BARRIER: LEARNING PERIOD

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	29	42.0	42.0	42.0
	LOW	23	33.3	33.3	75.4

	NEUTRAL	10	14.5	14.5	89.9
	HIGH	4	5.8	5.8	95.7
	VERY HIGH	3	4.3	4.3	100.0
	Total	69	100.0	100.0	

NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS

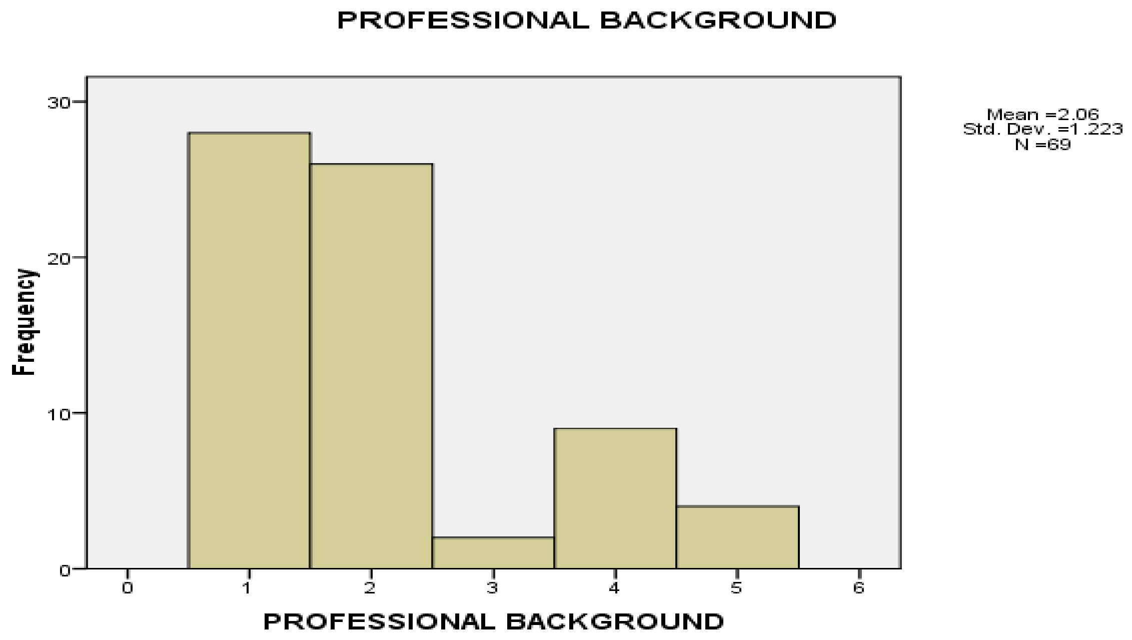
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	16	23.2	23.2	23.2
	LOW	20	29.0	29.0	52.2
	NEUTRAL	17	24.6	24.6	76.8
	HIGH	12	17.4	17.4	94.2
	VERY HIGH	4	5.8	5.8	100.0
	Total	69	100.0	100.0	

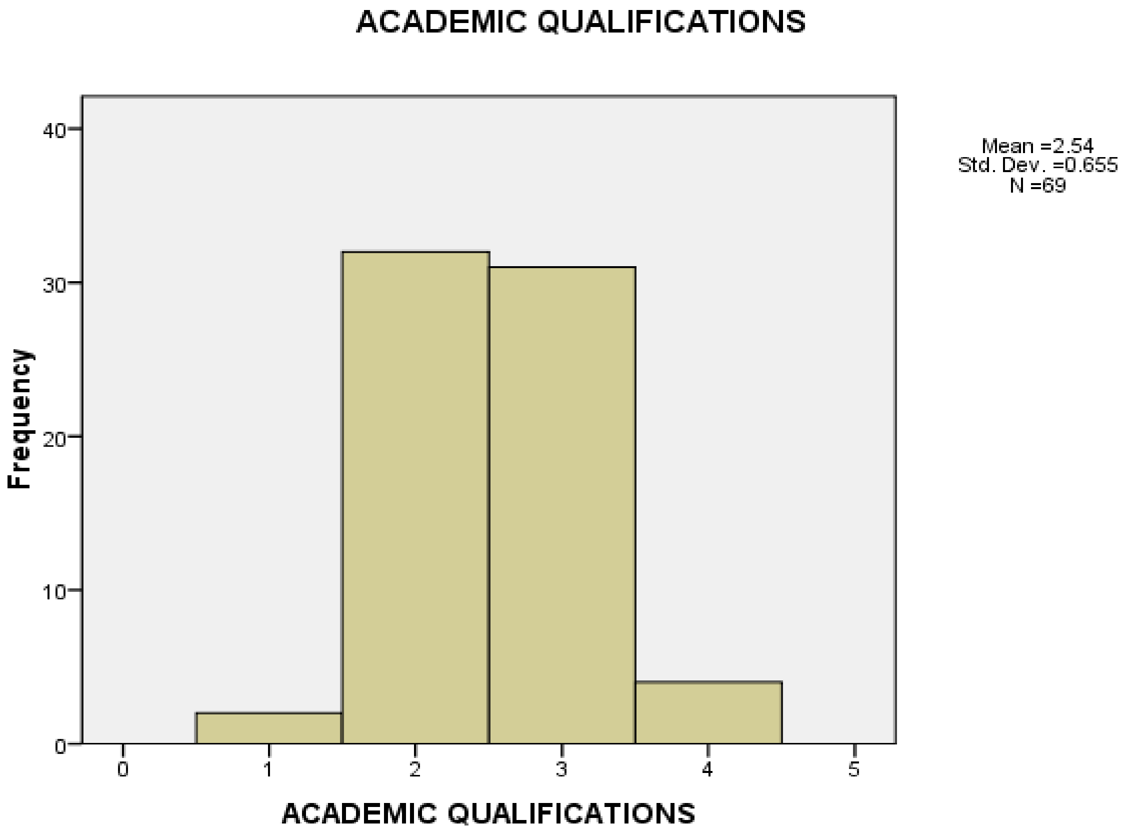
NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT

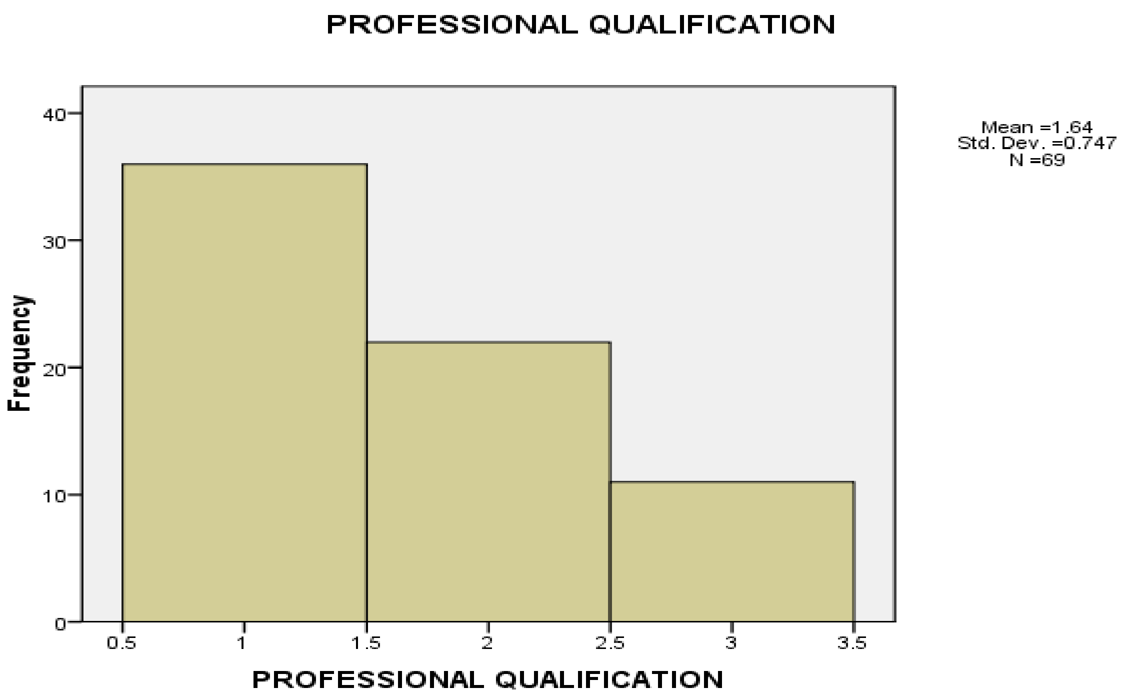
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	4	5.8	5.8	5.8
	LOW	16	23.2	23.2	29.0
	NEUTRAL	18	26.1	26.1	55.1
	HIGH	31	44.9	44.9	100.0
	Total	69	100.0	100.0	

APPENDIX NINE

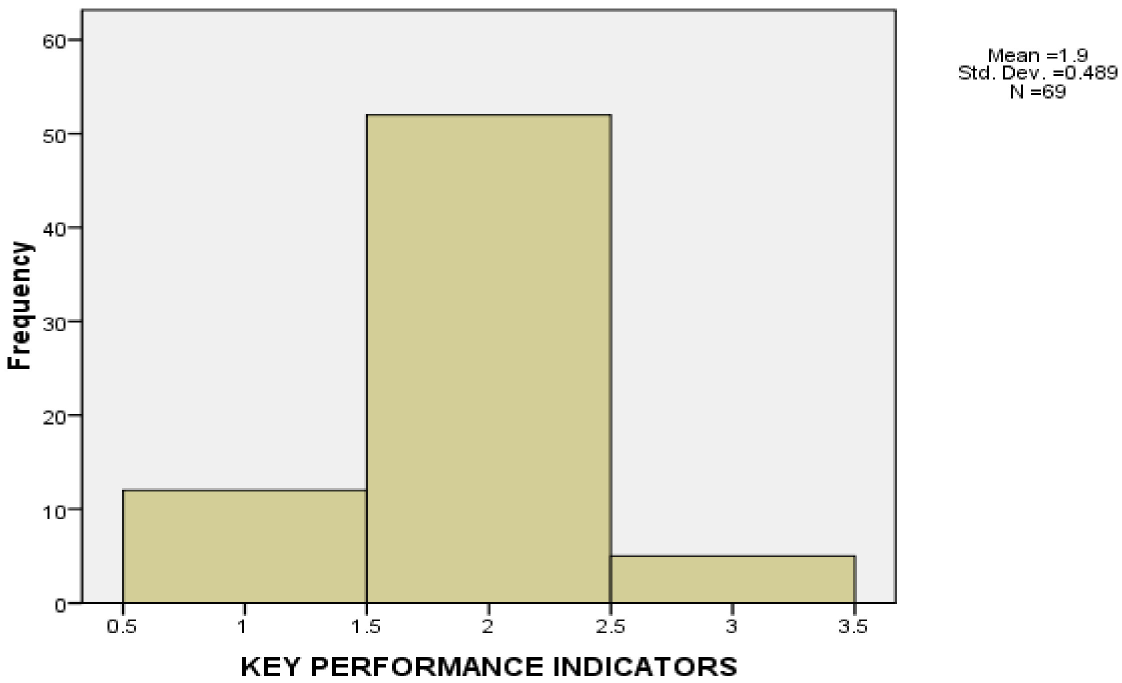
GRAPHICAL REPRESENTATION OF THE DISTRIBUTION OF DATA FOR THE MAIN QUESTIONNAIRE



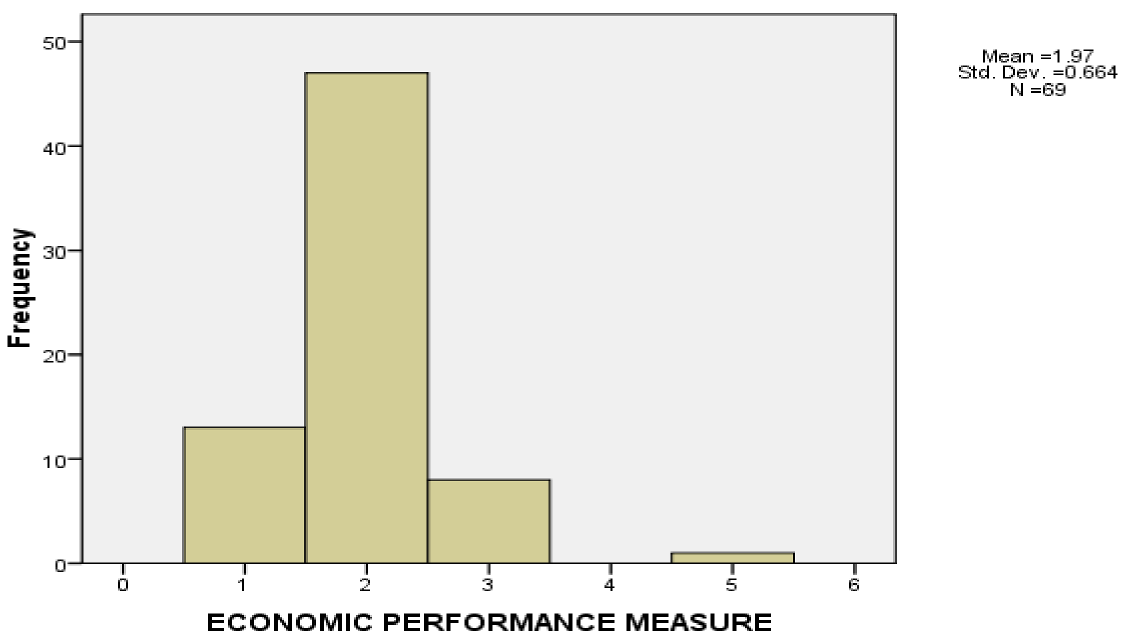

ACADEMIC QUALIFICATIONS
Mean =2.54
Std. Dev. =0.655
N =69
Frequency
40
30
20
10
0
0
1
2
3
4
5
ACADEMIC QUALIFICATIONS

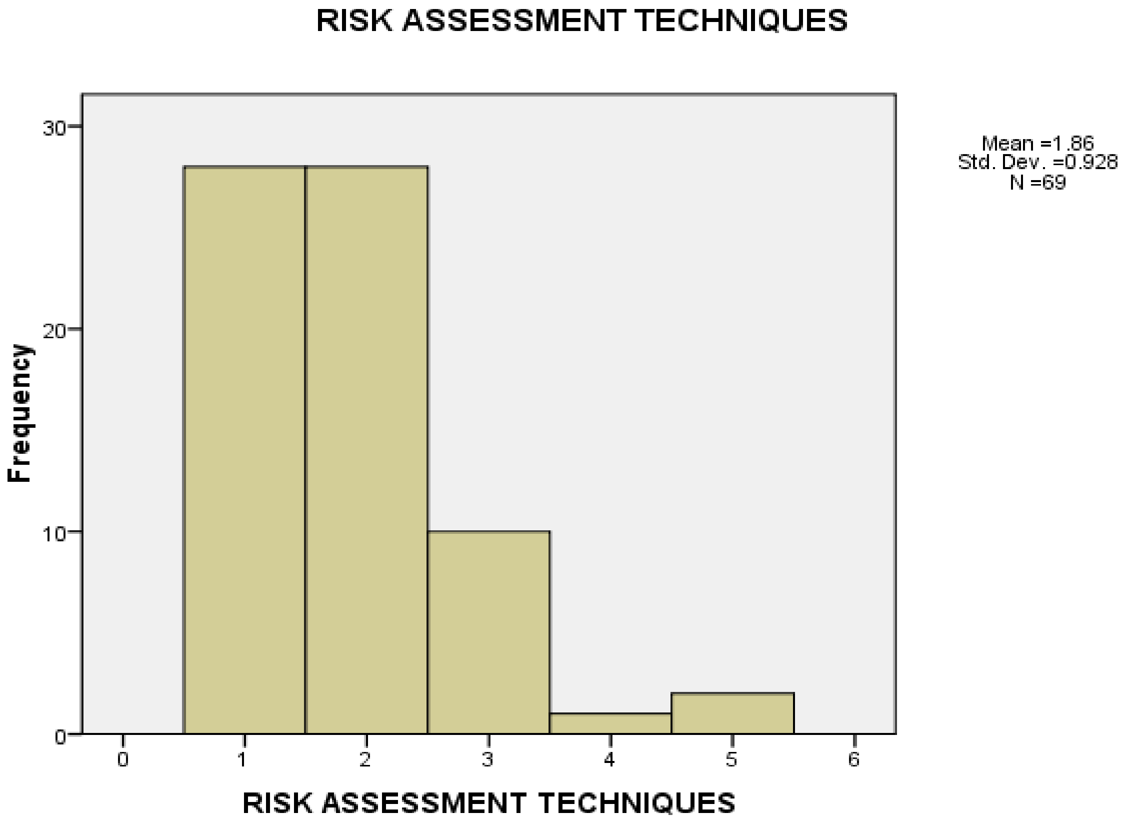

PROFESSIONAL QUALIFICATION
Mean =1.64
Std. Dev. =0.747
N =69
Frequency
40
30
20
10
0
0.5
1
1.5
2
2.5
3
3.5
PROFESSIONAL QUALIFICATION

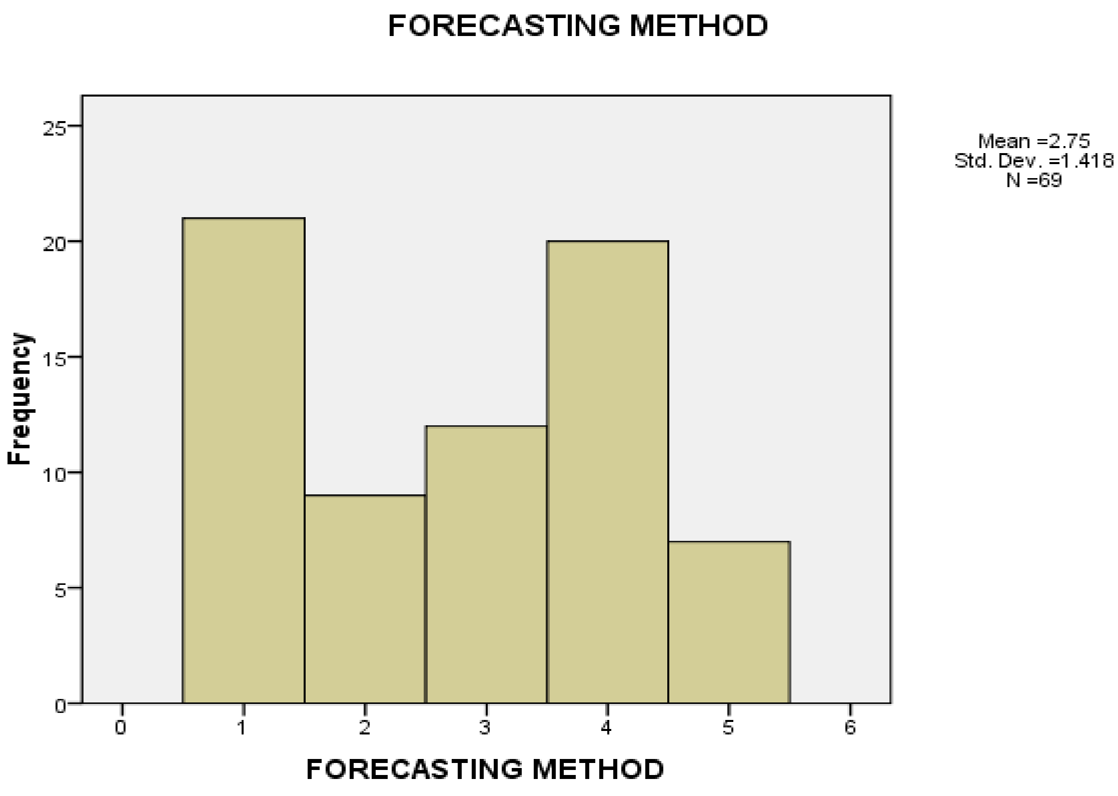
KEY PERFORMANCE INDICATORS



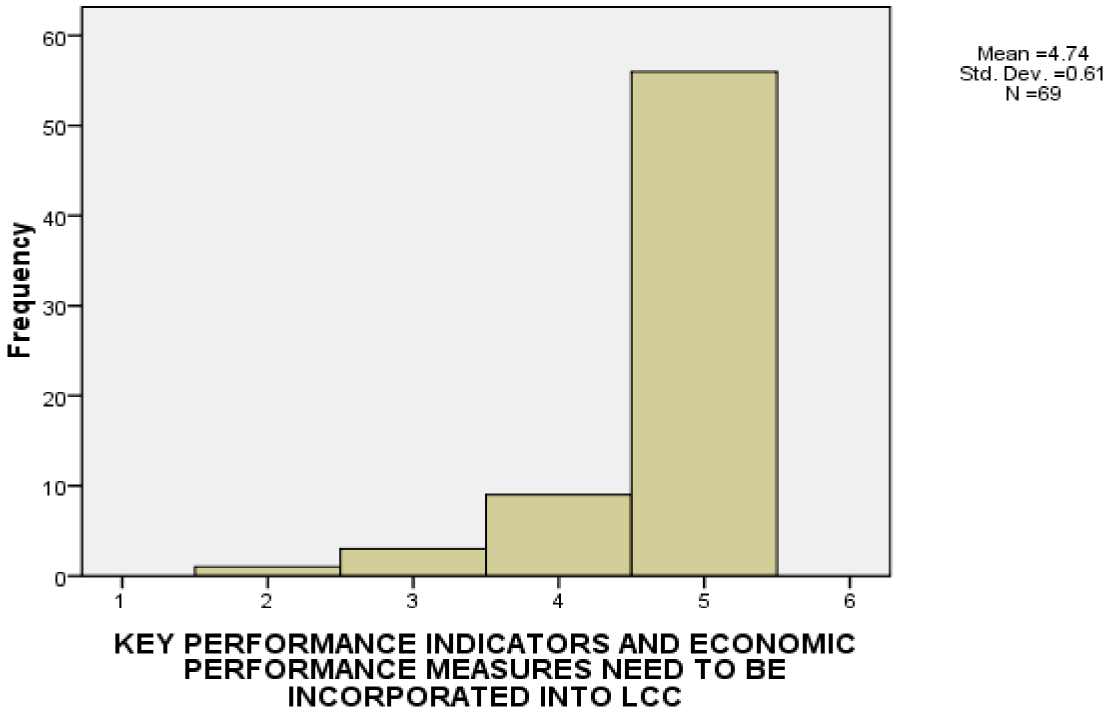
ECONOMIC PERFORMANCE MEASURE



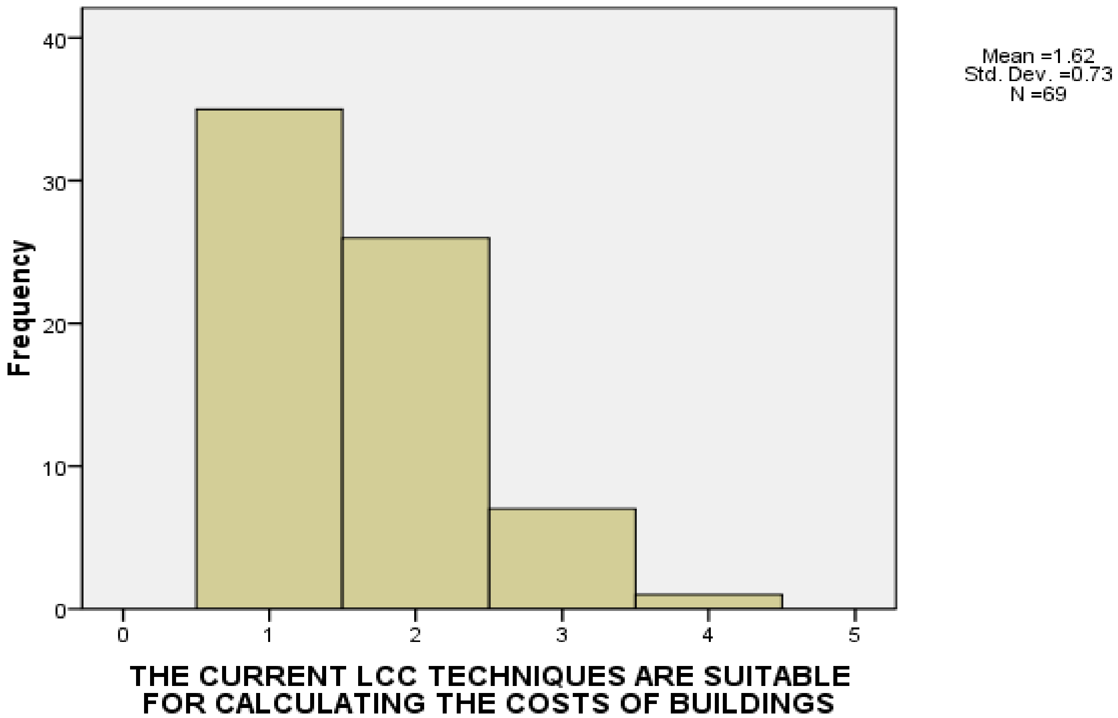

RISK ASSESSMENT TECHNIQUES
Frequency
30
20
10
0
0
1
2
3
4
5
6
RISK ASSESSMENT TECHNIQUES
Mean =1.86
Std. Dev. =0.928
N =69


FORECASTING METHOD
Frequency
25
20
15
10
5
0
0
1
2
3
4
5
6
FORECASTING METHOD
Mean =2.75
Std. Dev. =1.418
N =69

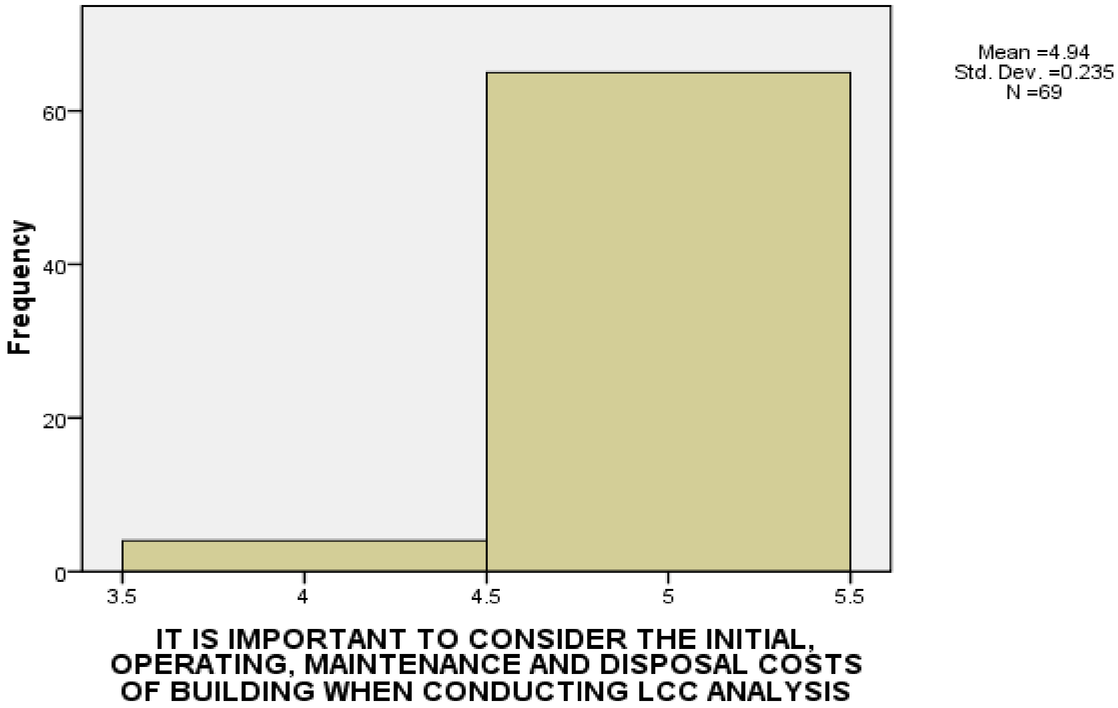
KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES NEED TO BE INCORPORATED INTO LCC



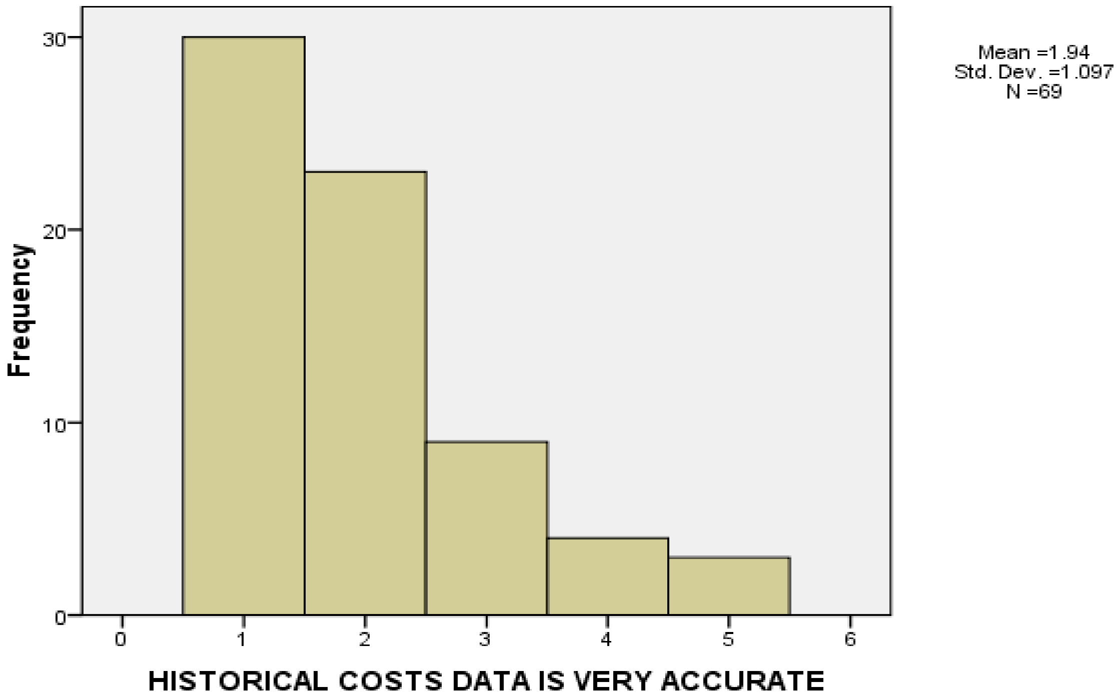
THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS



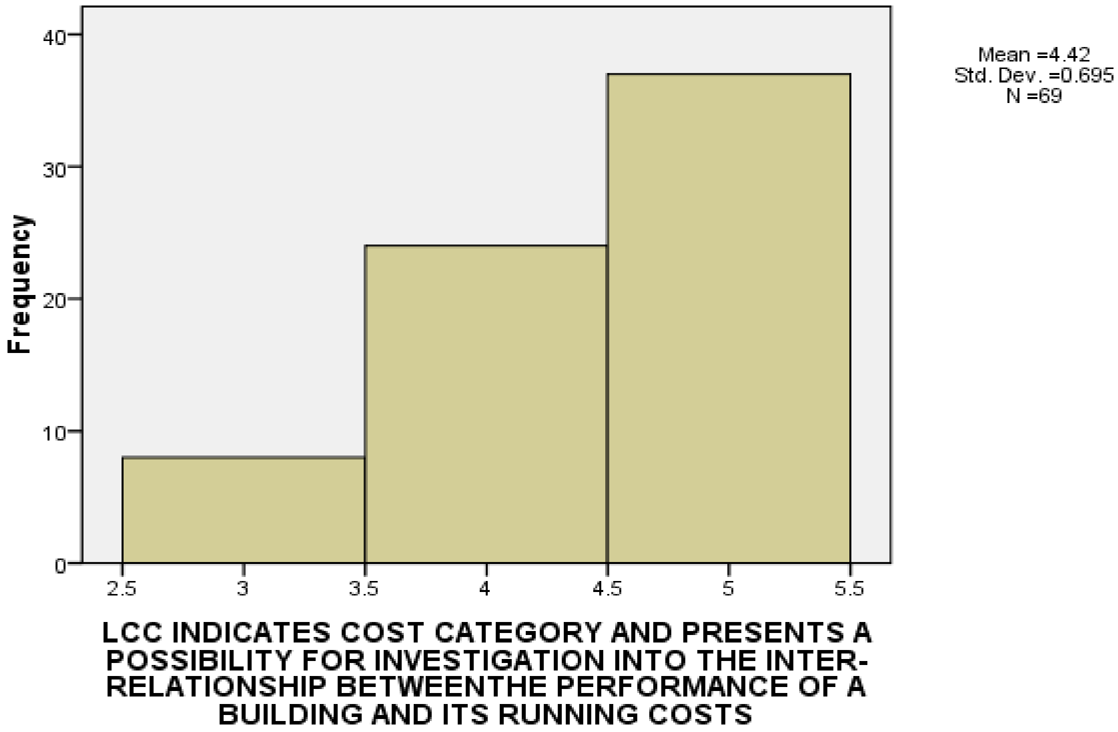
IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING, MAINTENANCE AND DISPOSAL COSTS OF BUILDING WHEN CONDUCTING LCC ANALYSIS



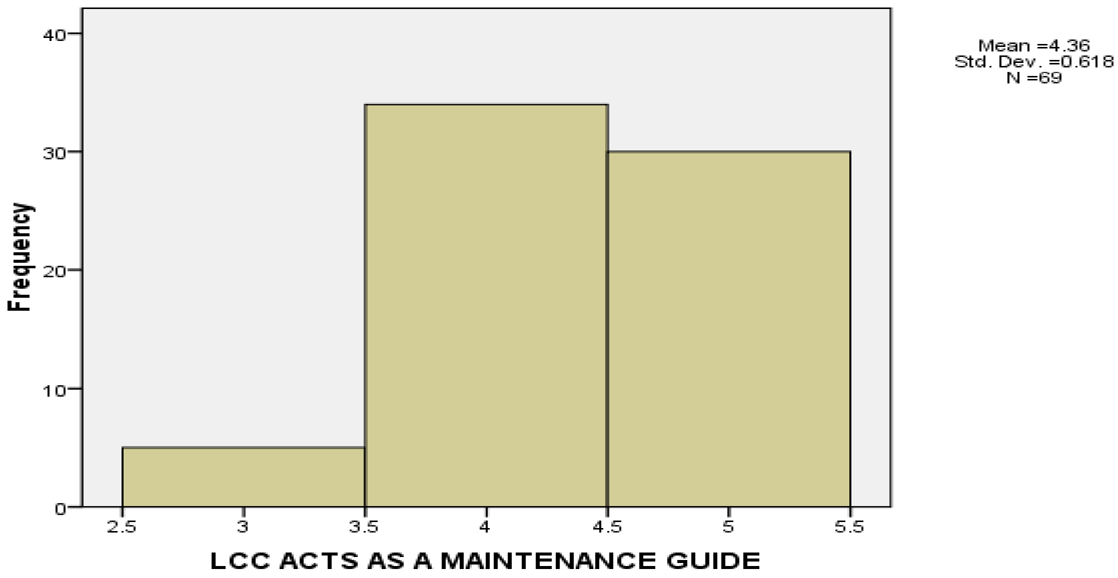
HISTORICAL COSTS DATA IS VERY ACCURATE

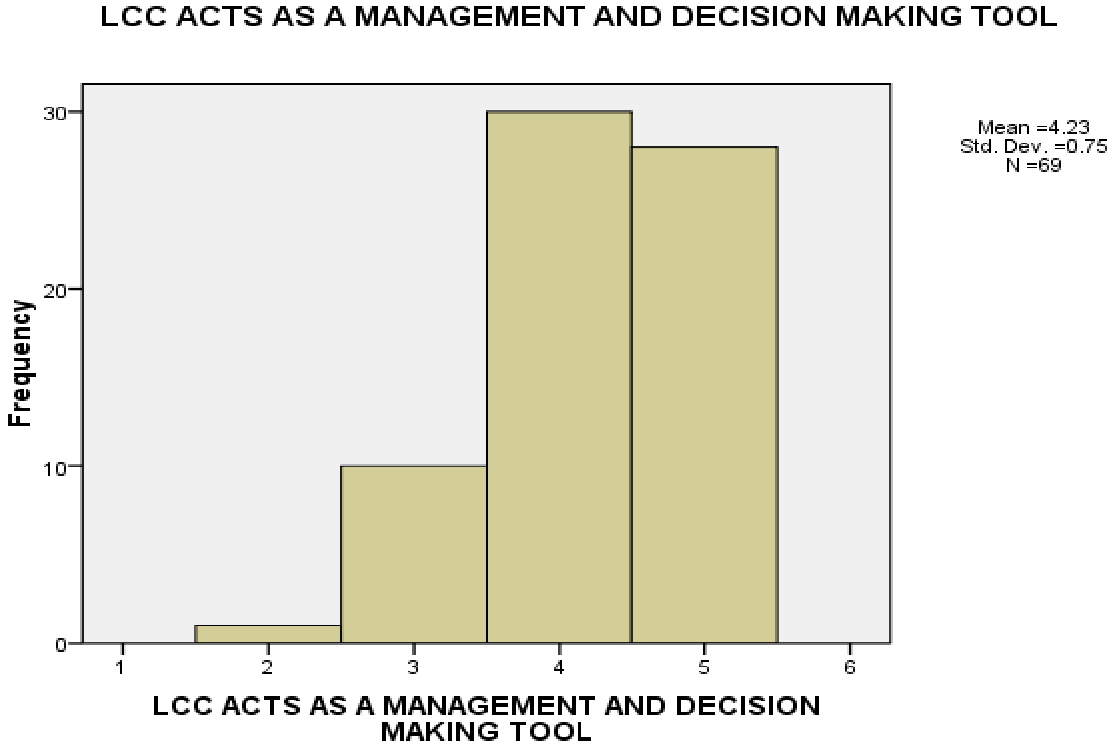


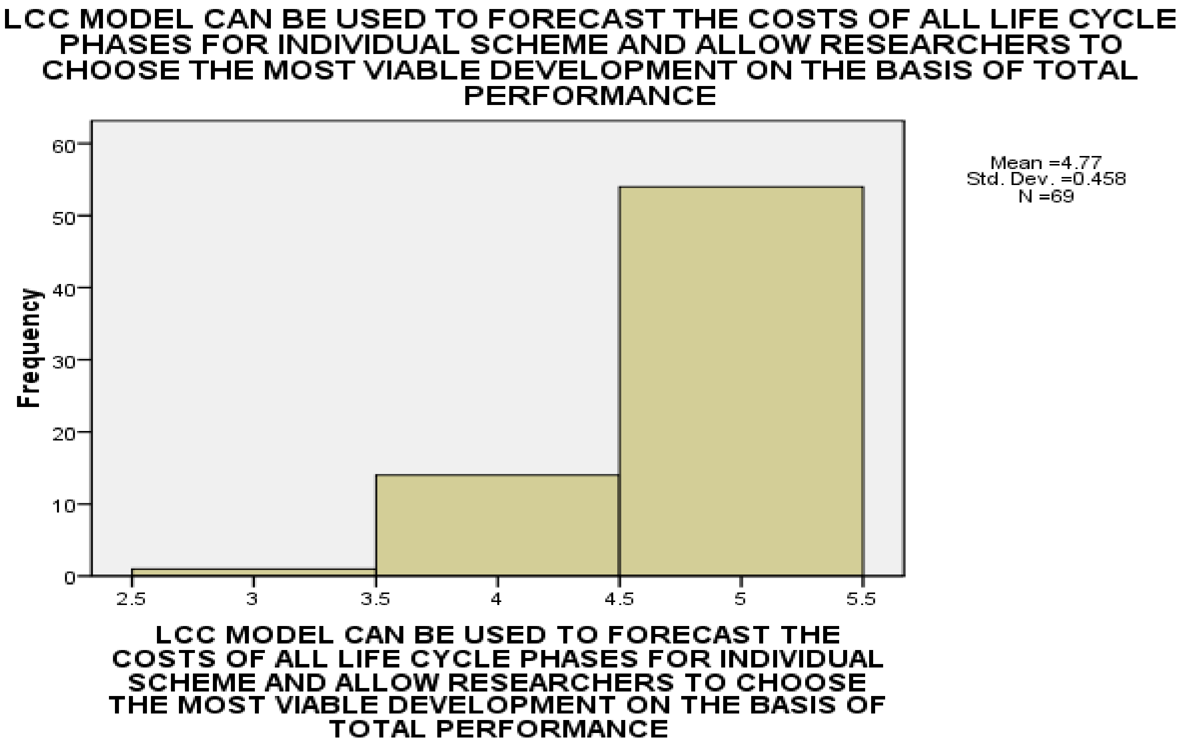
LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS

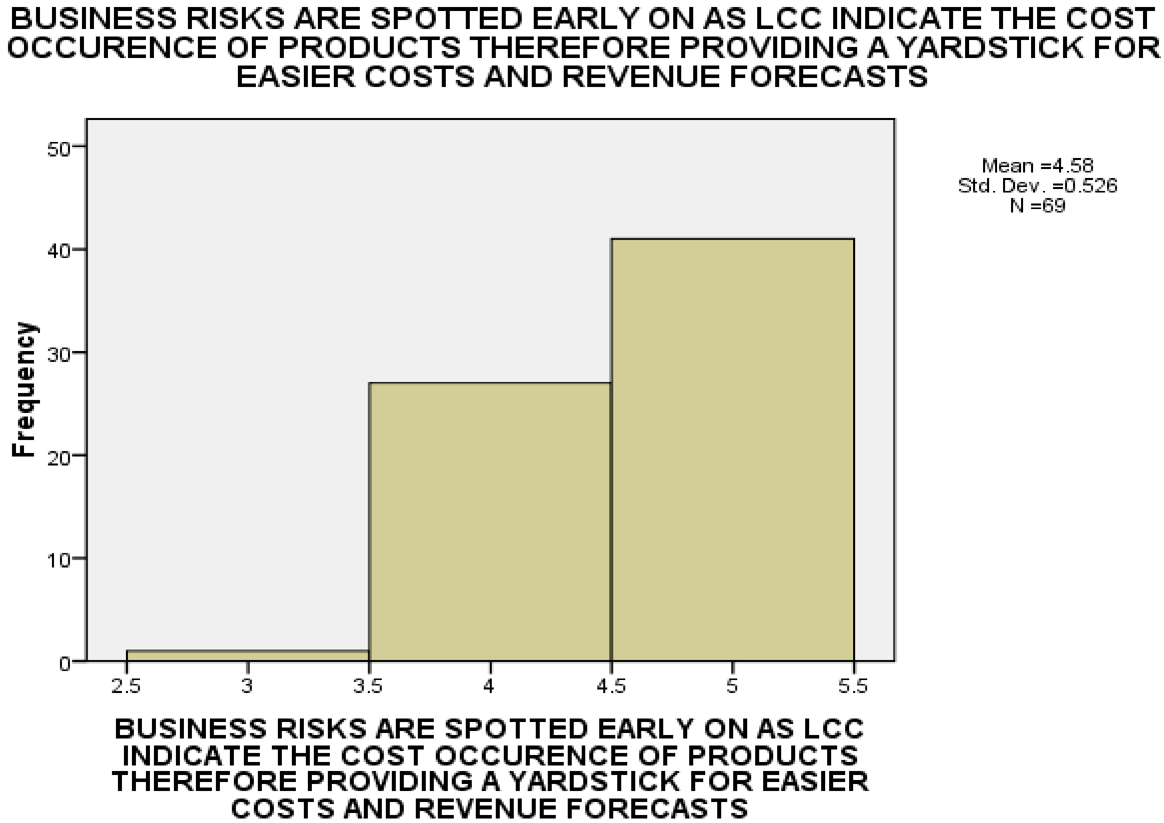


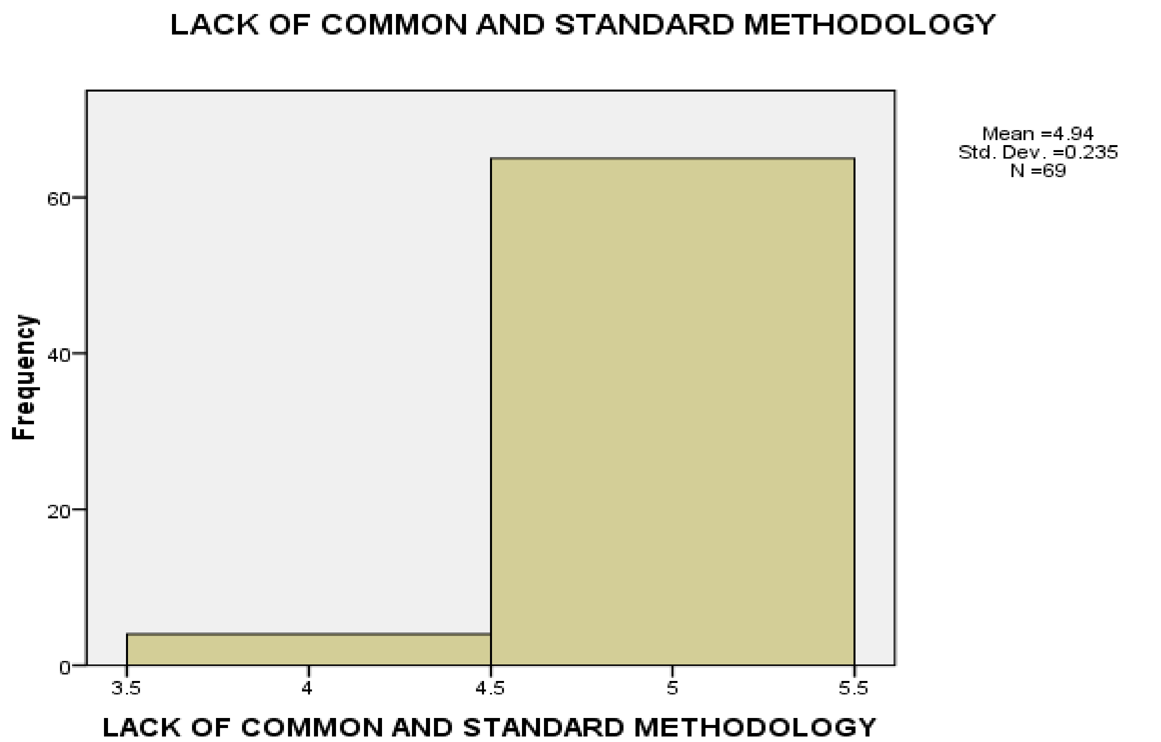
LCC ACTS AS A MAINTENANCE GUIDE

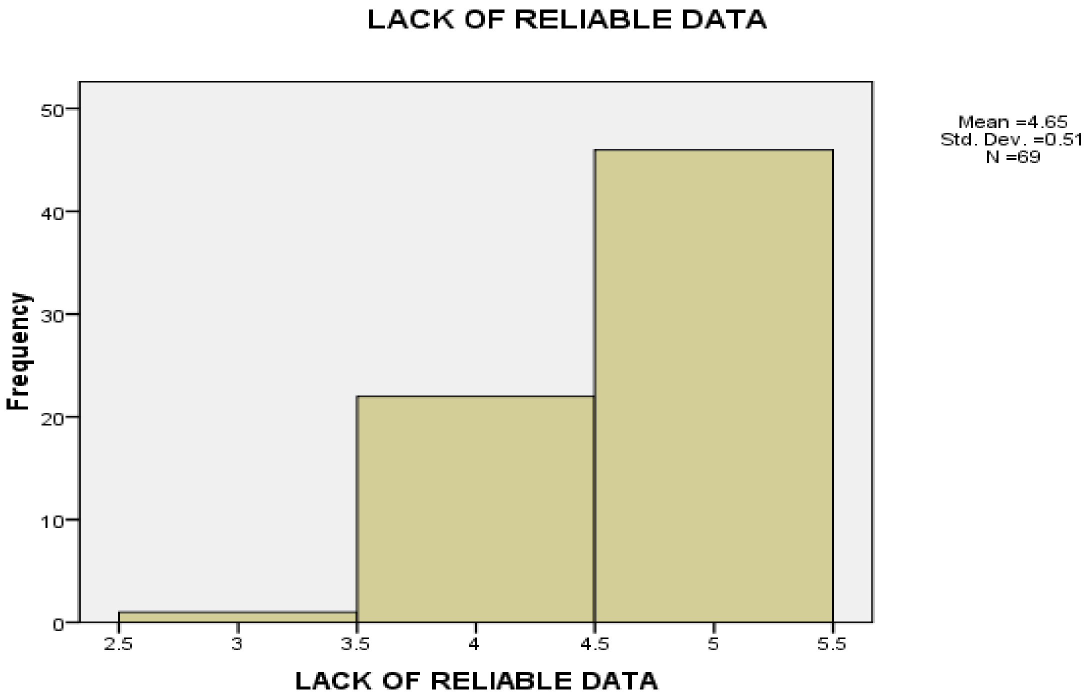


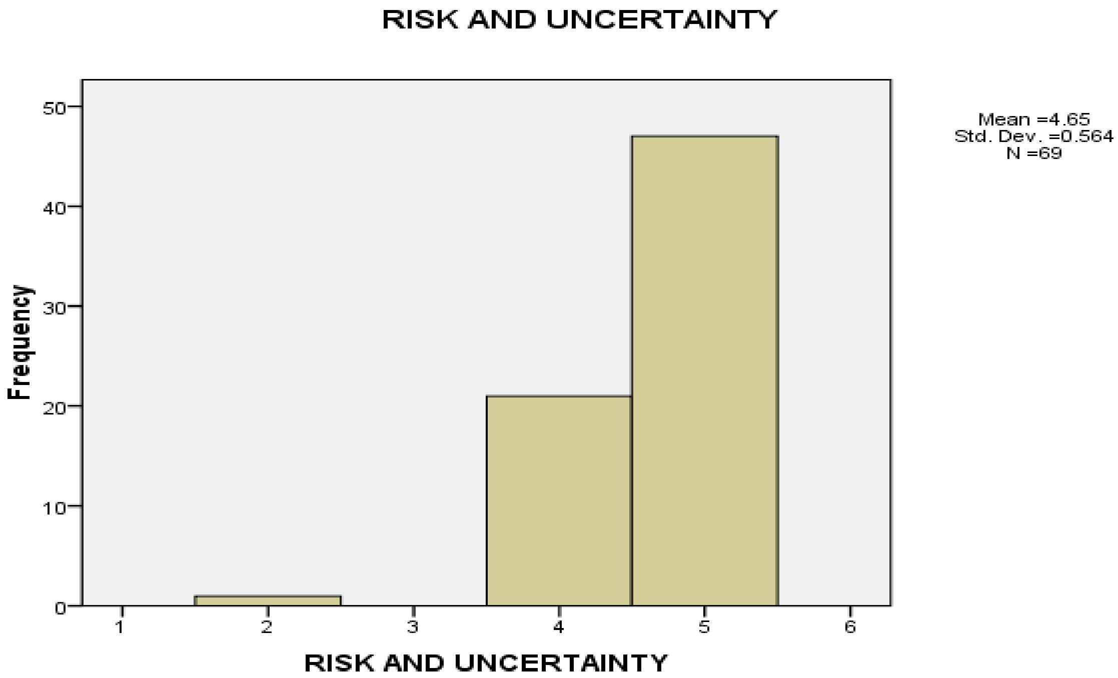

LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL
Frequency
30
20
10
0
1
2
3
4
5
6
LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL
Mean =4.23
Std. Dev. =0.75
N =69

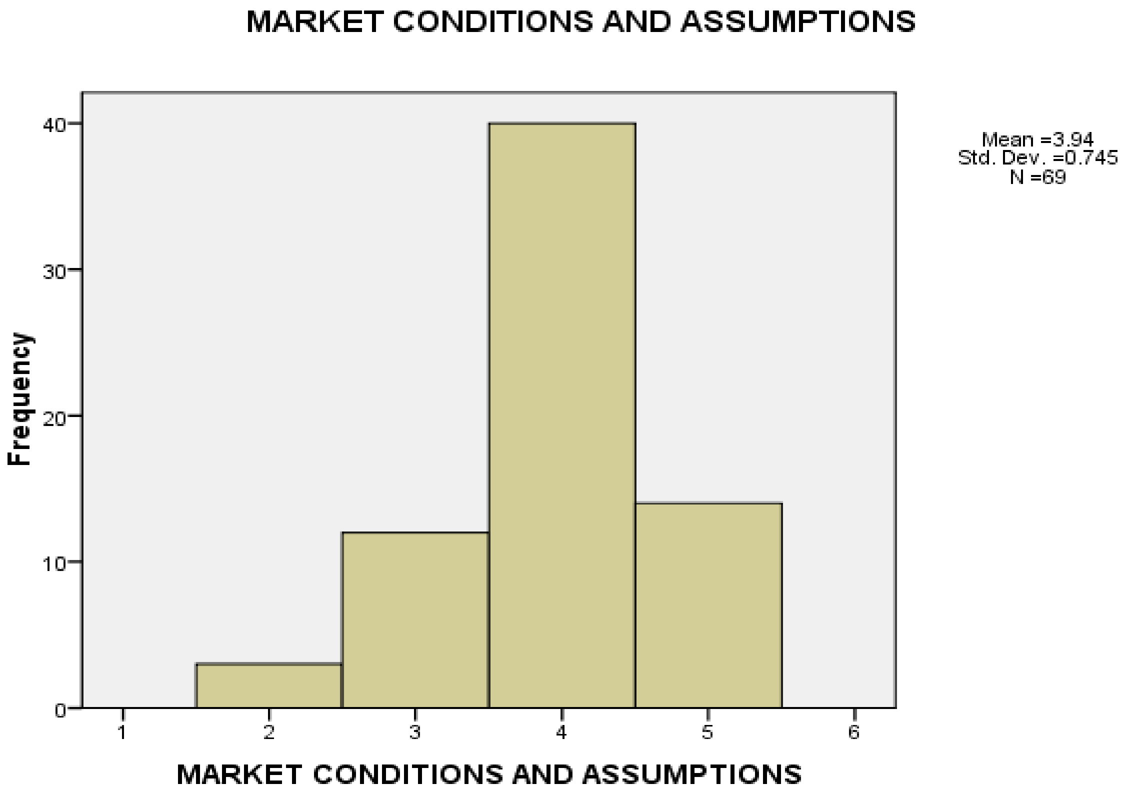

LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE
Frequency
60
50
40
30
20
10
0
2.5
3
3.5
4
4.5
5
5.5
LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE
Mean =4.77
Std. Dev. =0.458
N =69

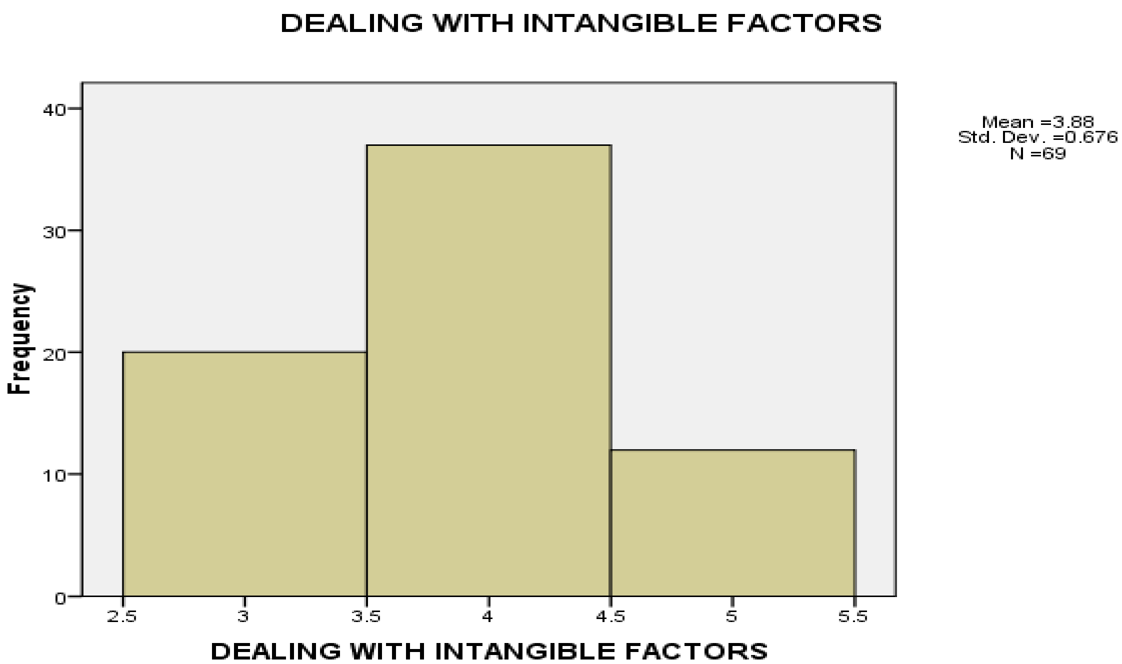

BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS
Mean =4.58
Std. Dev. =0.526
N =69
Frequency
0
10
20
30
40
50
2.5
3
3.5
4
4.5
5
5.5
BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS


LACK OF COMMON AND STANDARD METHODOLOGY
Mean =4.94
Std. Dev. =0.235
N =69
Frequency
0
20
40
60
3.5
4
4.5
5
5.5
LACK OF COMMON AND STANDARD METHODOLOGY

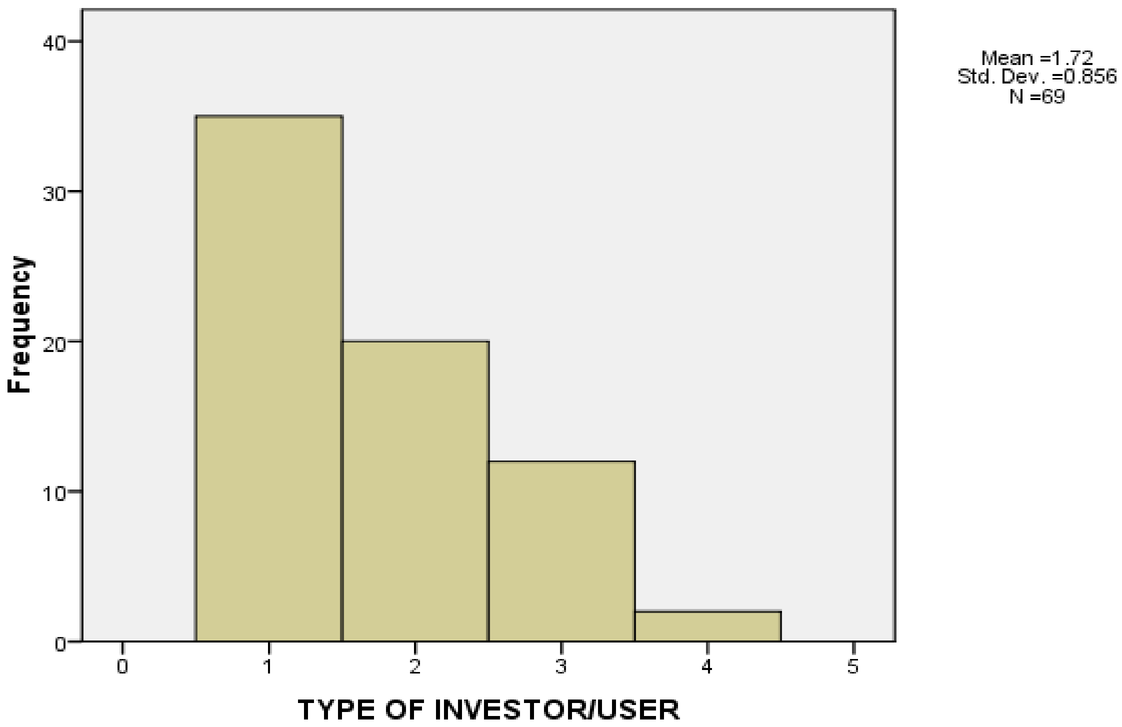

LACK OF RELIABLE DATA
Mean =4.65
Std. Dev. =0.51
N =69
Frequency
LACK OF RELIABLE DATA


RISK AND UNCERTAINTY
Mean =4.65
Std. Dev. =0.564
N =69
Frequency
RISK AND UNCERTAINTY

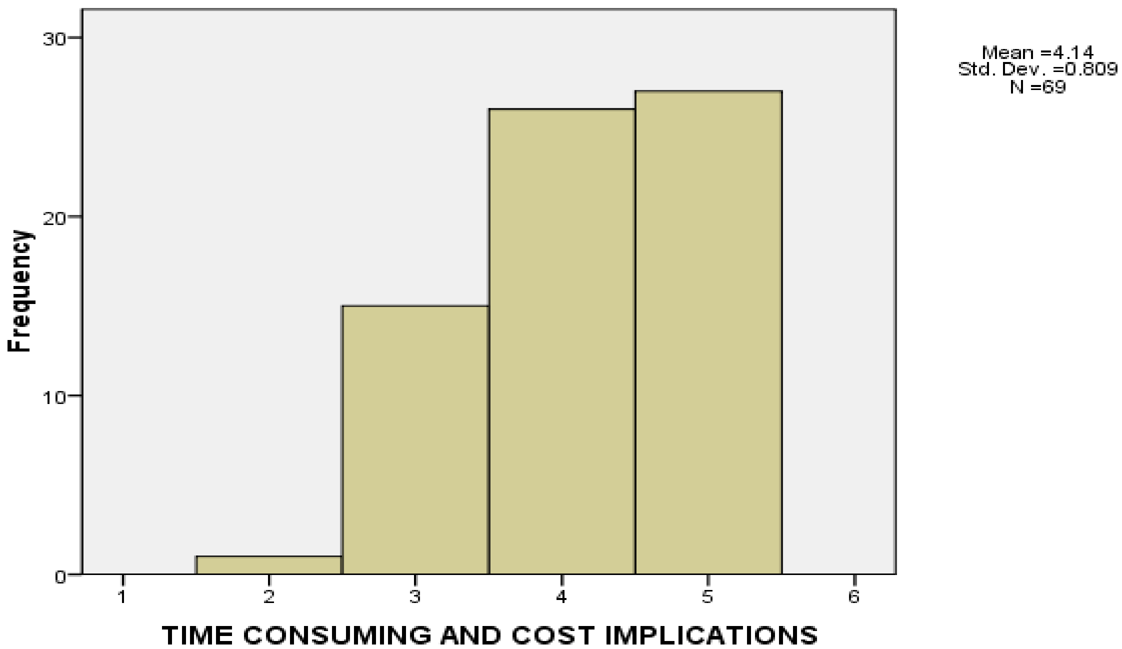

MARKET CONDITIONS AND ASSUMPTIONS
Mean =3.94
Std. Dev. =0.745
N =69
Frequency
0
10
20
30
40
1
2
3
4
5
6
MARKET CONDITIONS AND ASSUMPTIONS

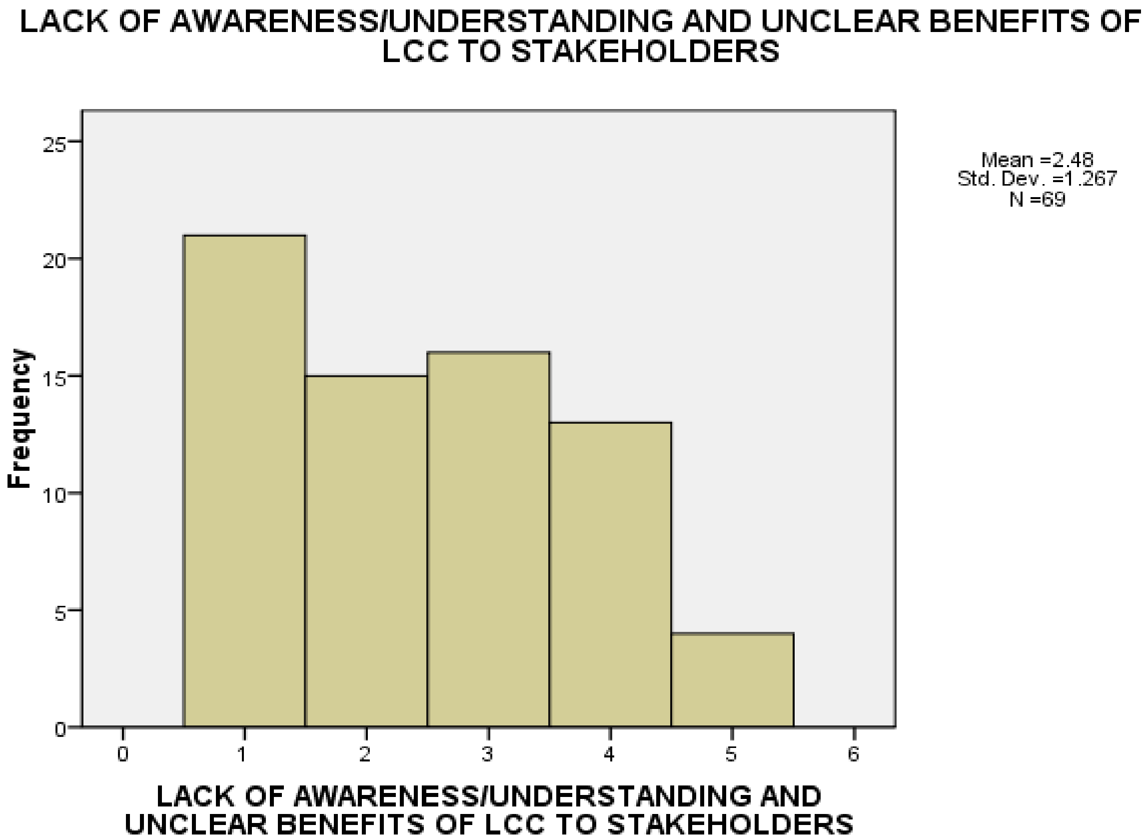

DEALING WITH INTANGIBLE FACTORS
Mean =3.88
Std. Dev. =0.676
N =69
Frequency
0
10
20
30
40
2.5
3
3.5
4
4.5
5
5.5
DEALING WITH INTANGIBLE FACTORS

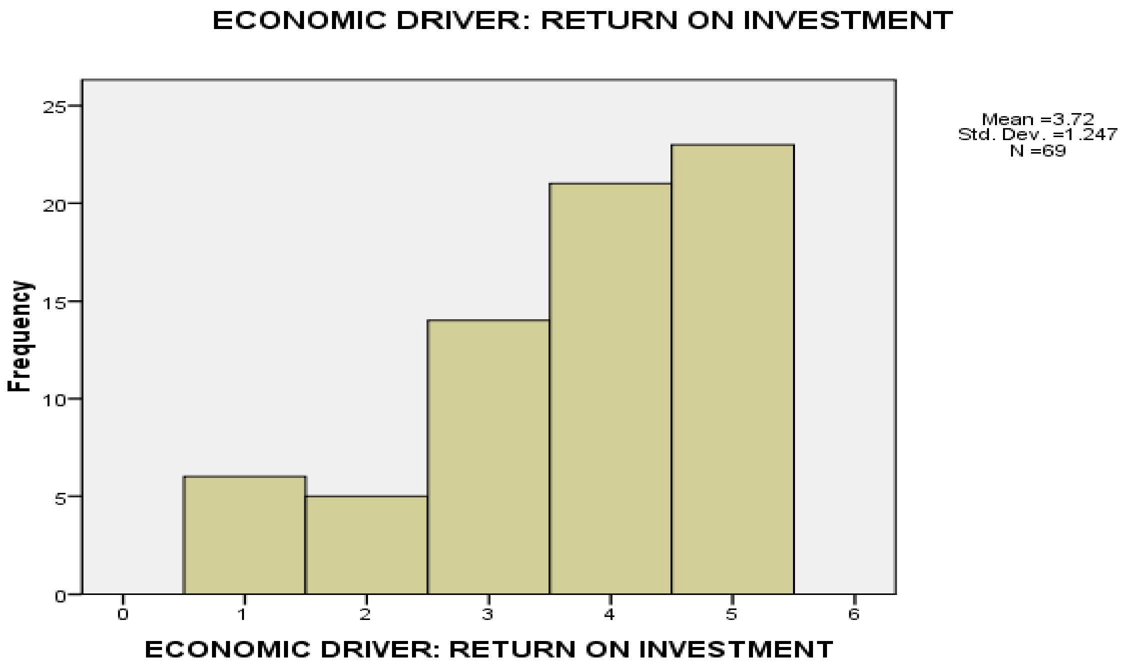
TYPE OF INVESTOR/USER



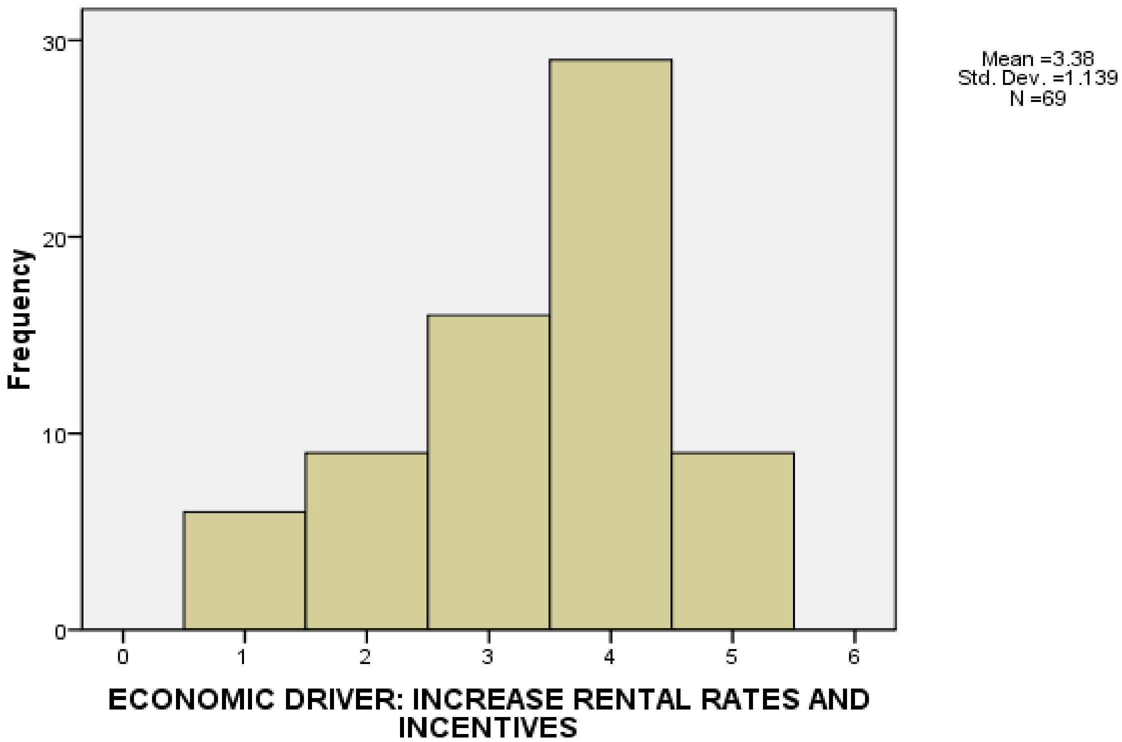
TIME CONSUMING AND COST IMPLICATIONS



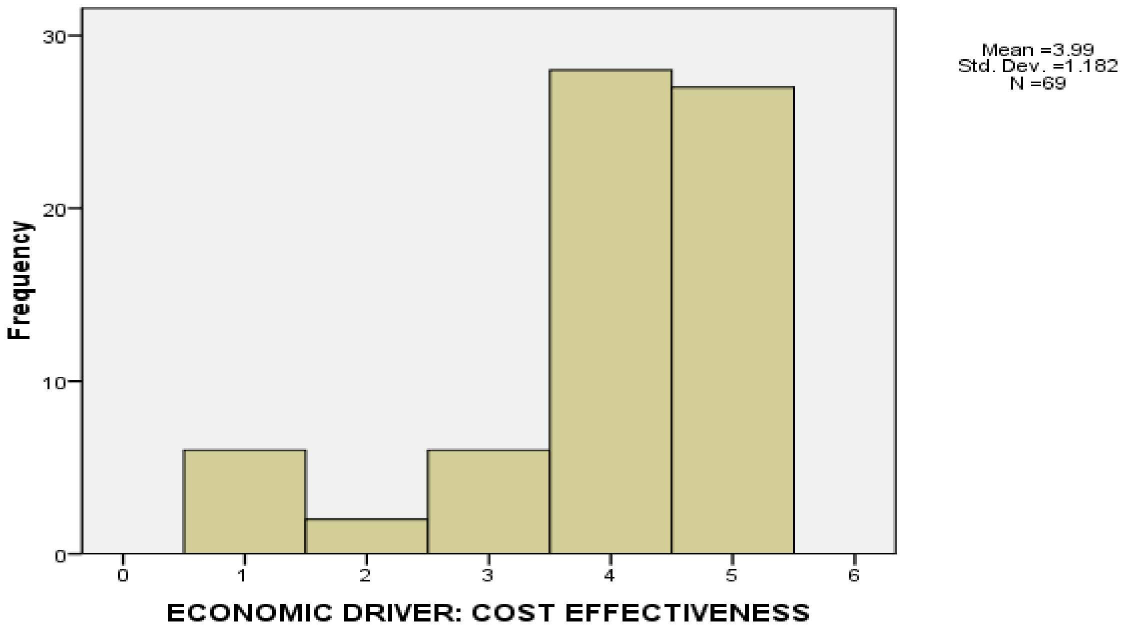

LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS
Mean =2.48
Std. Dev. =1.267
N =69
Frequency
0
5
10
15
20
25
0
1
2
3
4
5
6
LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS


ECONOMIC DRIVER: RETURN ON INVESTMENT
Mean =3.72
Std. Dev. =1.247
N =69
Frequency
0
5
10
15
20
25
0
1
2
3
4
5
6
ECONOMIC DRIVER: RETURN ON INVESTMENT

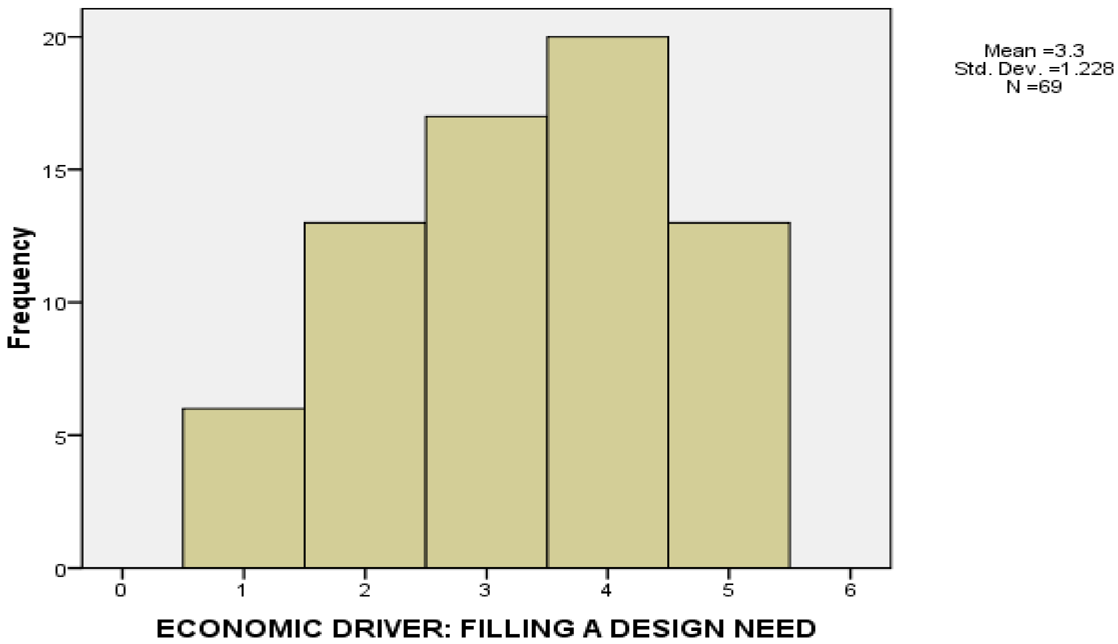
ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES



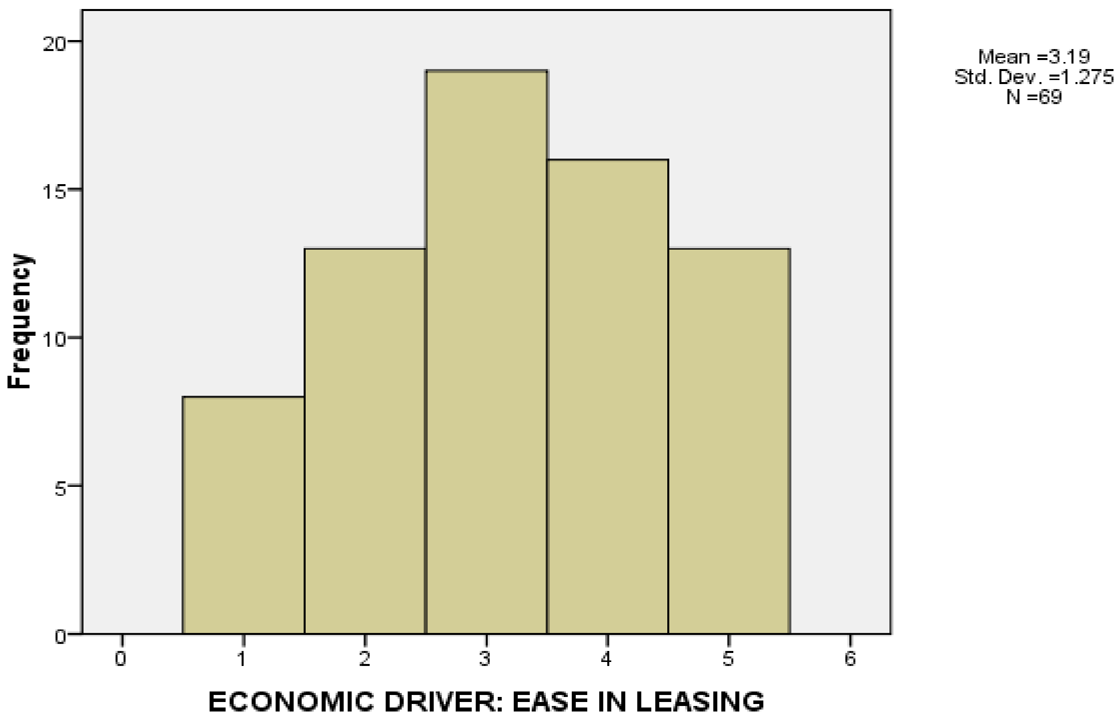
ECONOMIC DRIVER: COST EFFECTIVENESS

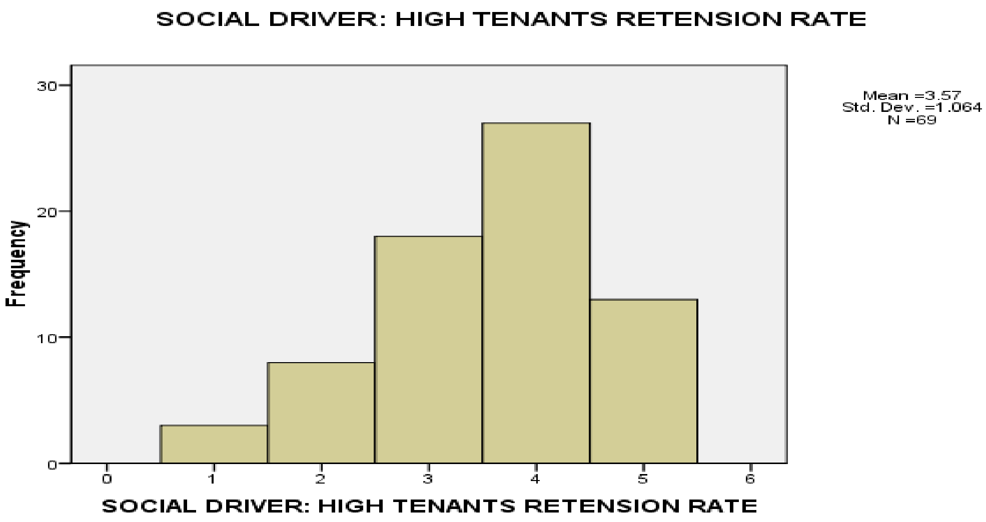


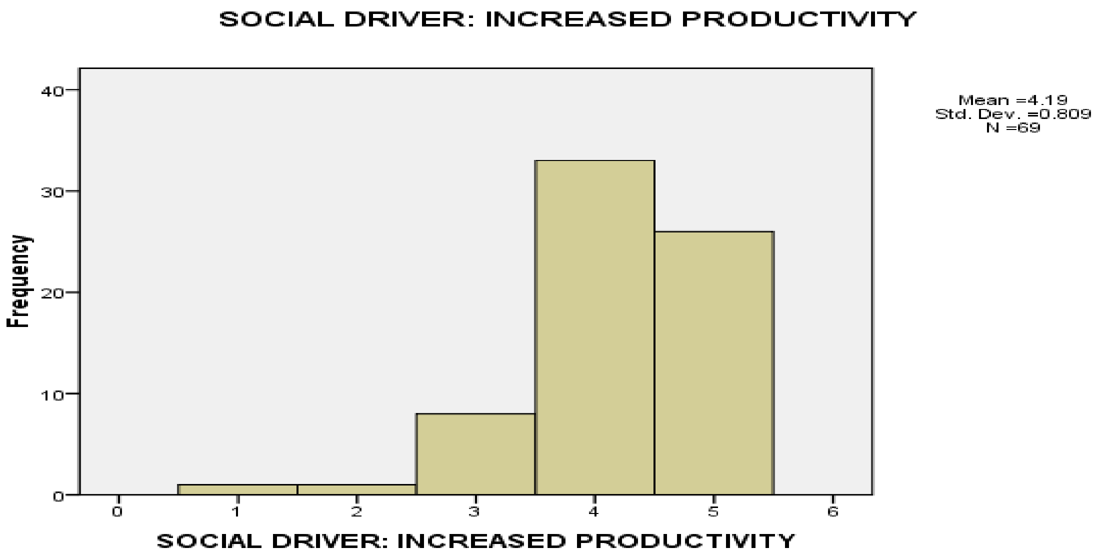
ECONOMIC DRIVER: FILLING A DESIGN NEED



ECONOMIC DRIVER: EASE IN LEASING

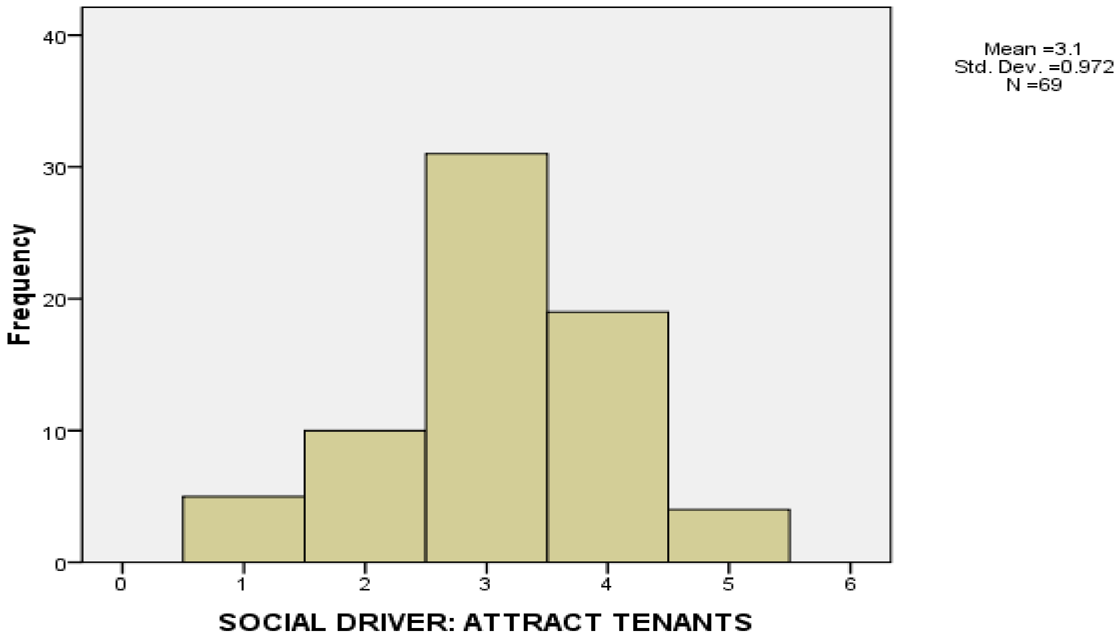



SOCIAL DRIVER: HIGH TENANTS RETENSION RATE
Mean =3.57
Std. Dev. =1.064
N =69
Frequency
0
10
20
30
0
1
2
3
4
5
6
SOCIAL DRIVER: HIGH TENANTS RETENSION RATE

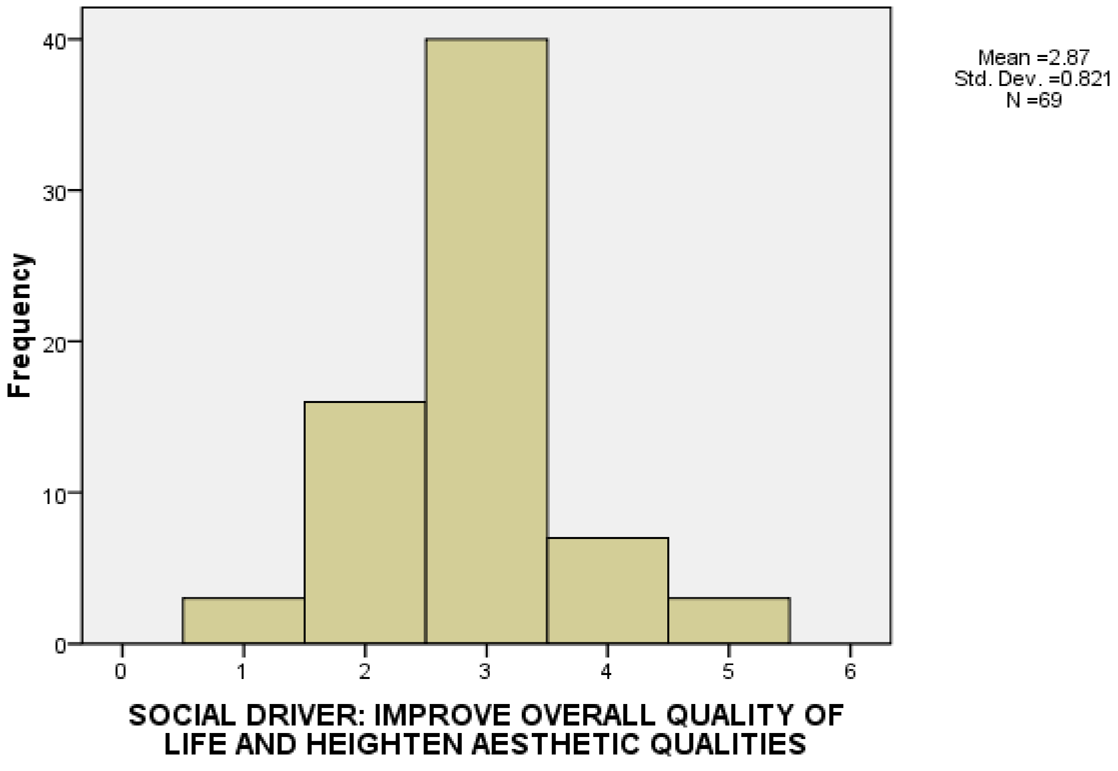

SOCIAL DRIVER: INCREASED PRODUCTIVITY
Mean =4.19
Std. Dev. =0.809
N =69
Frequency
0
10
20
30
40
0
1
2
3
4
5
6
SOCIAL DRIVER: INCREASED PRODUCTIVITY


SOCIAL DRIVER: CLIENTS REQUIREMENTS
Mean =3.39
Std. Dev. =0.973
N =69
Frequency
0
10
20
30
0
1
2
3
4
5
6
SOCIAL DRIVER: CLIENTS REQUIREMENTS

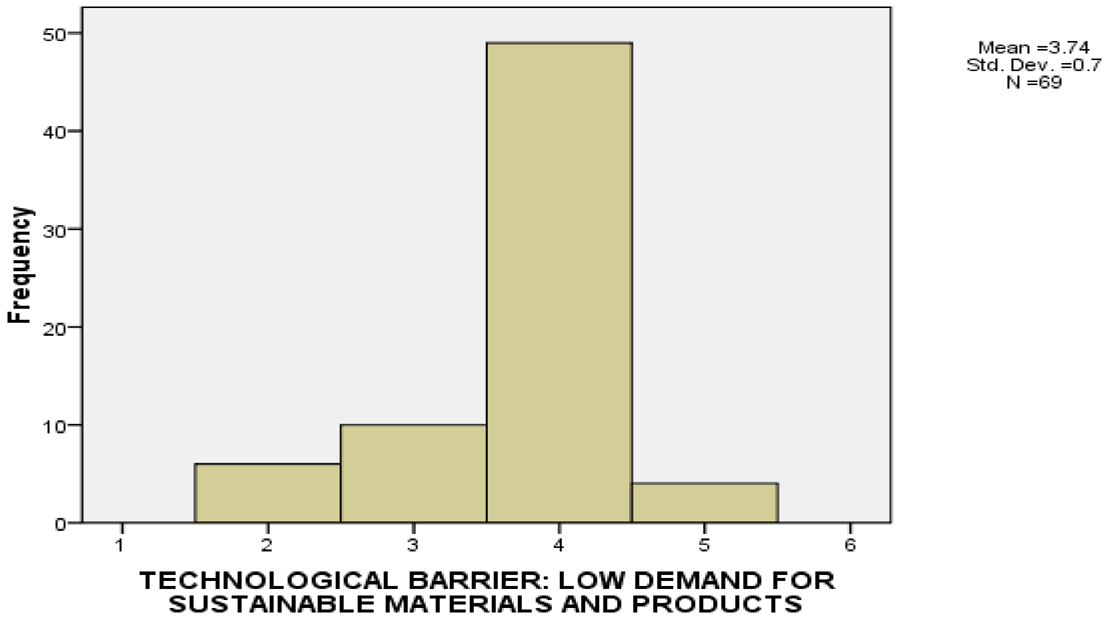
SOCIAL DRIVER: ATTRACT TENANTS



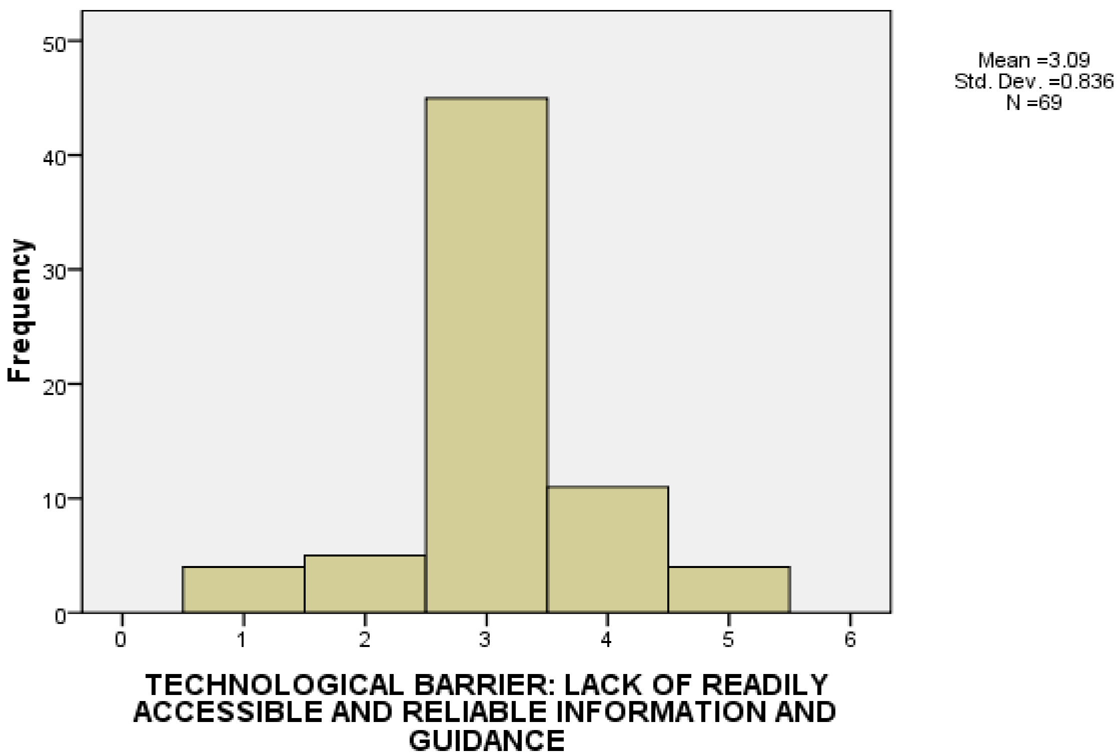
SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES



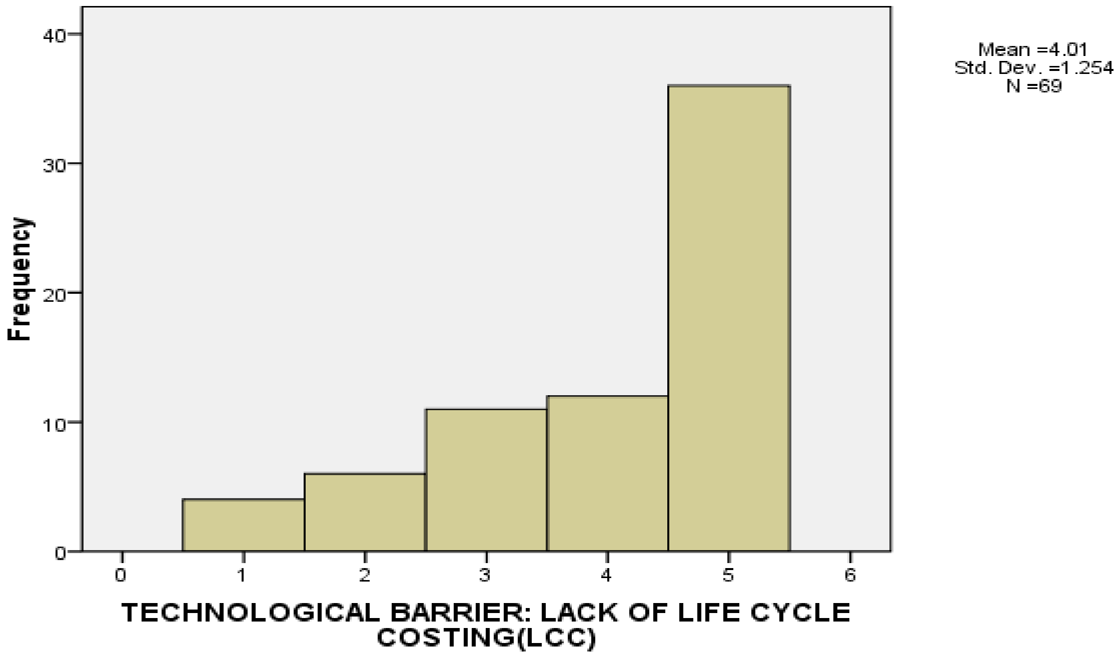
TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS



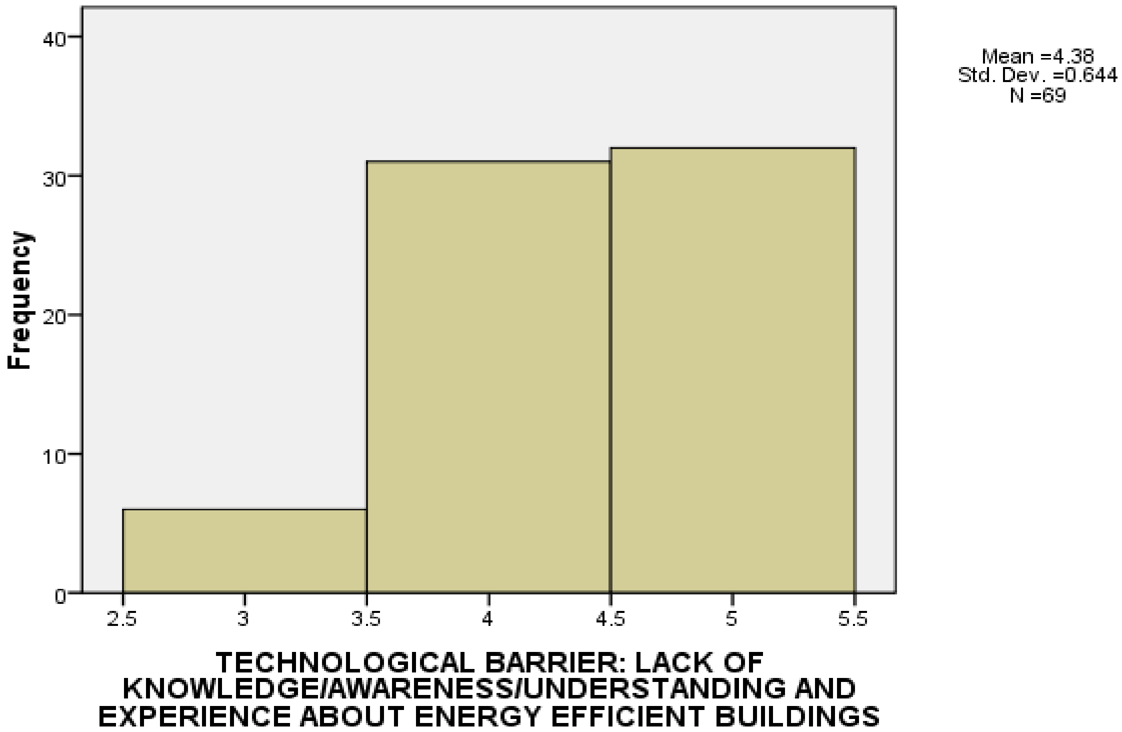
TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE



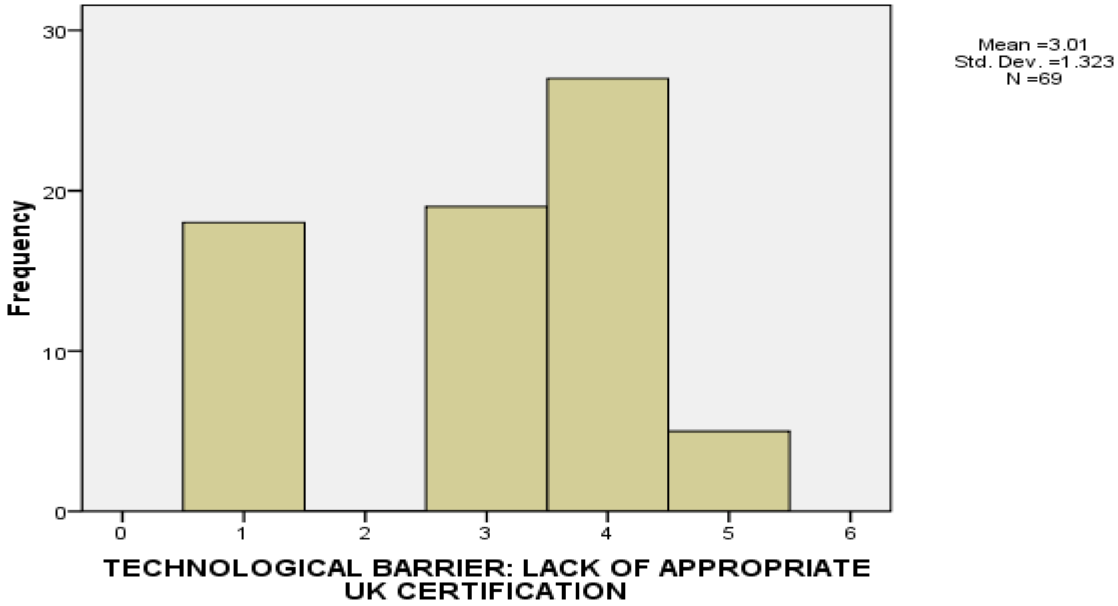
TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING(LCC)



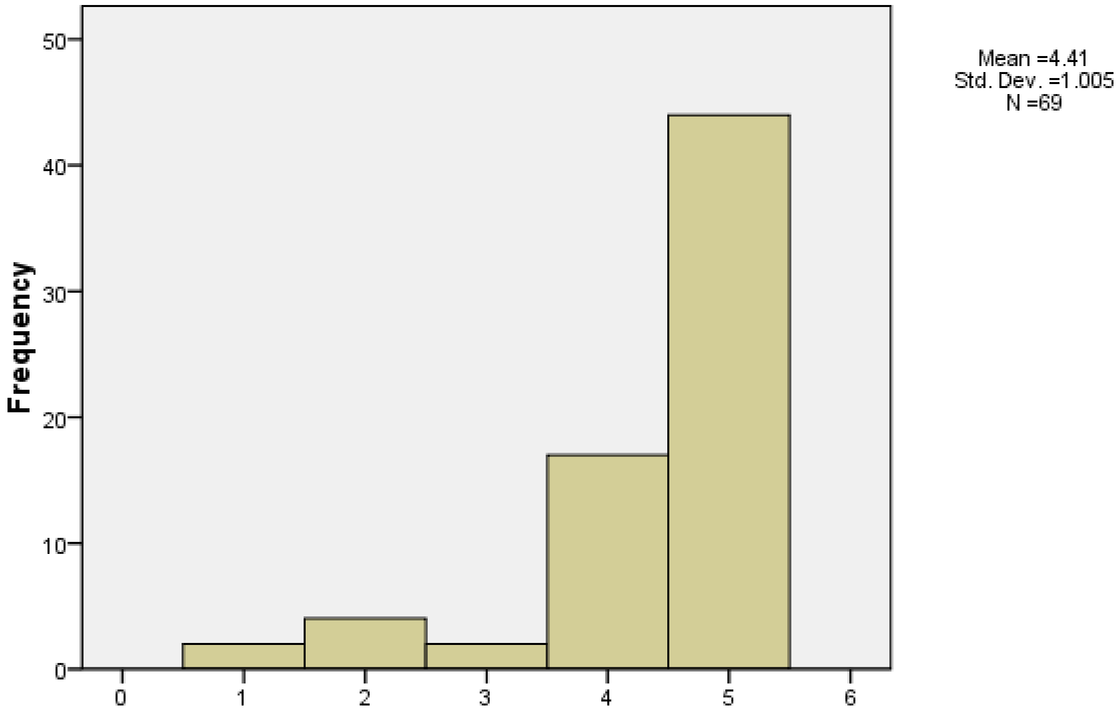
TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARENESS/UNDERSTANDING AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS



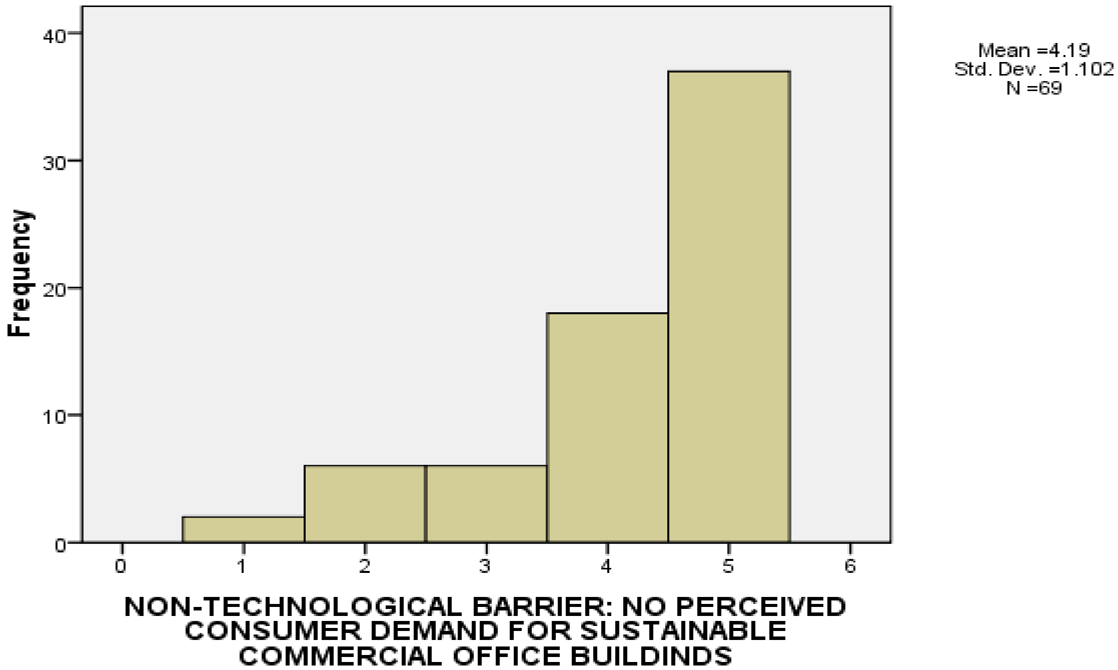
TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION



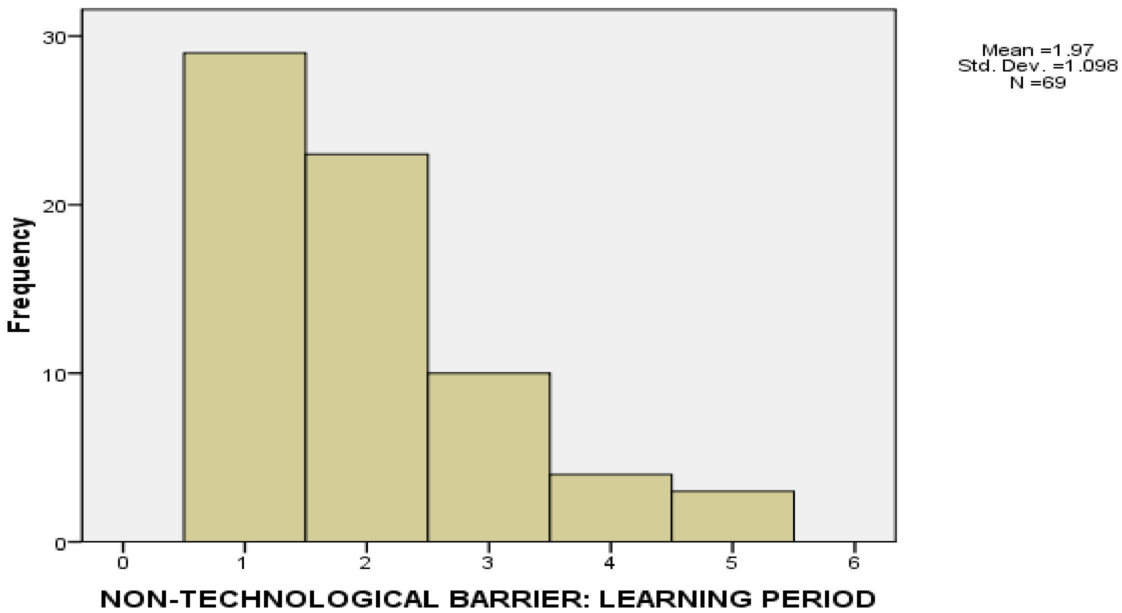
NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS



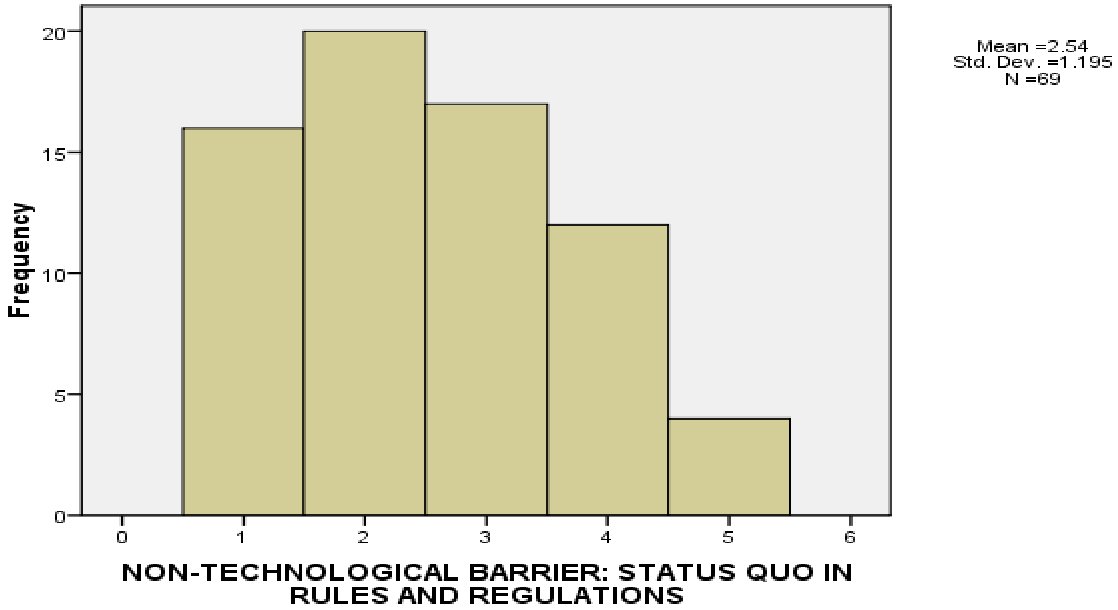
NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINDS



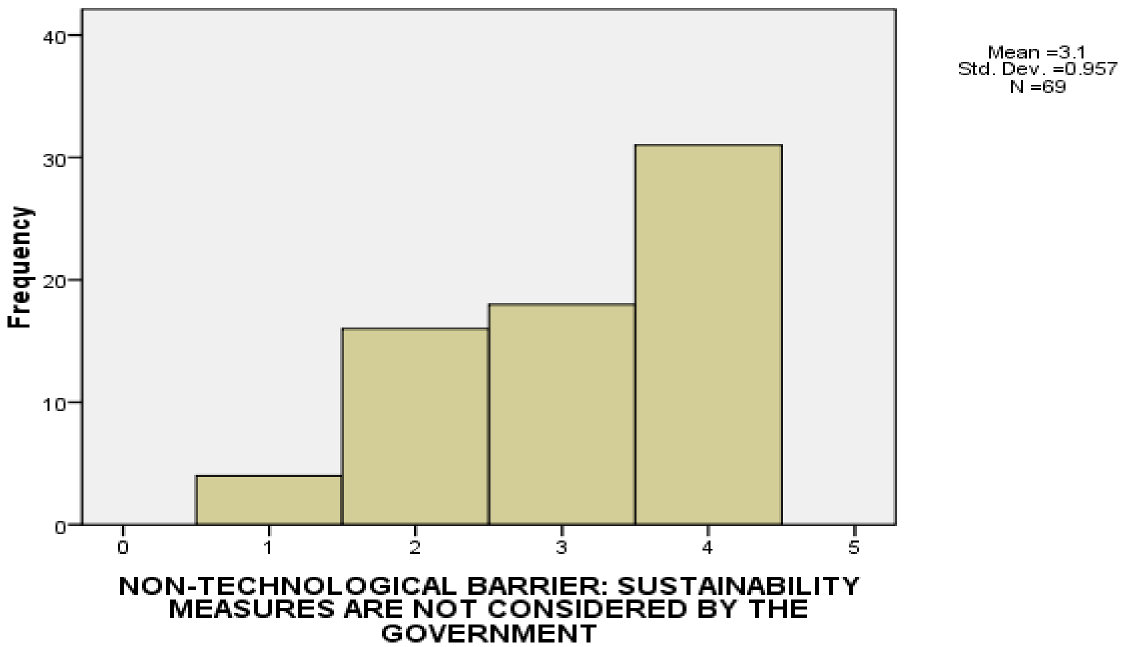
NON-TECHNOLOGICAL BARRIER: LEARNING PERIOD



NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS



NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT



APPENDIX TEN

DESCRIPTIVE STATISTICS (FREQUENCY TABLES) OF VARIABLES OF THE PILOT SURVEY

LCC INDICATES COST CATEGORY AND PRESENTS A POSSIBILITY FOR INVESTIGATION INTO THE INTER-RELATIONSHIP BETWEENTHE PERFORMANCE OF A BUILDING AND ITS RUNNING COSTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	1	3.3	3.7	3.7
	NEITHER AGREE NOR DISAGREE	2	6.7	7.4	11.1
	AGREE	6	20.0	22.2	33.3
	STRONGLY AGREE	18	60.0	66.7	100.0
	Total	27	90.0	100.0	
Missing	System	3	10.0		
Total		30	100.0		

LCC ACTS AS A MAINTENANCE GUIDE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	4	13.3	13.3	13.3
	AGREE	16	53.3	53.3	66.7
	STRONGLY AGREE	10	33.3	33.3	100.0
	Total	30	100.0	100.0	

LCC ACTS AS A MANAGEMENT AND DECISION MAKING TOOL

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	8	26.7	30.8	30.8
	AGREE	12	40.0	46.2	76.9
	STRONGLY AGREE	6	20.0	23.1	100.0
	Total	26	86.7	100.0	
Missing	System	4	13.3		
Total		30	100.0		

LCC MODEL CAN BE USED TO FORECAST THE COSTS OF ALL LIFE CYCLE PHASES FOR INDIVIDUAL SCHEME AND ALLOW RESEARCHERS TO CHOOSE THE MOST VIABLE DEVELOPMENT ON THE BASIS OF TOTAL PERFORMANCE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	AGREE	5	16.7	17.2	17.2
	STRONGLY AGREE	24	80.0	82.8	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

BUSINESS RISKS ARE SPOTTED EARLY ON AS LCC INDICATE THE COST OCCURENCE OF PRODUCTS THEREFORE PROVIDING A YARDSTICK FOR EASIER COSTS AND REVENUE FORECASTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	1	3.3	3.8	3.8
	AGREE	4	13.3	15.4	19.2
	STRONGLY AGREE	21	70.0	80.8	100.0
	Total	26	86.7	100.0	
Missing	System	4	13.3		
Total		30	100.0		

LACK OF COMMON AND STANDARD METHODOLOGY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HIGH	3	10.0	10.3	10.3
	VERY HIGH	26	86.7	89.7	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

LACK OF RELIABLE DATA

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HIGH	11	36.7	39.3	39.3
	VERY HIGH	17	56.7	60.7	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

RISK AND UNCERTAINTY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HIGH	4	13.3	14.3	14.3
	VERY HIGH	24	80.0	85.7	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

MARKET CONDITIONS AND ASSUMPTIONS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	1	3.3	3.3	3.3
	NEUTRAL	1	3.3	3.3	6.7
	HIGH	22	73.3	73.3	80.0
	VERY HIGH	6	20.0	20.0	100.0
	Total	30	100.0	100.0	

DEALING WITH INTANGIBLE FACTORS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	6	20.0	22.2	22.2
	HIGH	14	46.7	51.9	74.1
	VERY HIGH	7	23.3	25.9	100.0
	Total	27	90.0	100.0	
Missing	System	3	10.0		
Total		30	100.0		

TYPE OF INVESTOR/USER

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	7	23.3	30.4	30.4
	LOW	11	36.7	47.8	78.3
	NEUTRAL	5	16.7	21.7	100.0
	Total	23	76.7	100.0	
Missing	System	7	23.3		
Total		30	100.0		

TIME CONSUMING AND COST IMPLICATIONS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	1	3.3	3.4	3.4
	NEUTRAL	6	20.0	20.7	24.1
	HIGH	14	46.7	48.3	72.4
	VERY HIGH	8	26.7	27.6	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

LACK OF AWARENESS/UNDERSTANDING AND UNCLEAR BENEFITS OF LCC TO STAKEHOLDERS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	5	16.7	16.7	16.7
	LOW	9	30.0	30.0	46.7
	NEUTRAL	9	30.0	30.0	76.7
	HIGH	7	23.3	23.3	100.0
	Total	30	100.0	100.0	

ECONOMIC DRIVER: RETURN ON INVESTMENT

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	4	13.3	13.8	13.8
	DISAGREE	3	10.0	10.3	24.1
	NEITHER AGREE NOR DISAGREE	6	20.0	20.7	44.8
	AGREE	11	36.7	37.9	82.8
	STRONGLY AGREE	5	16.7	17.2	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

ECONOMIC DRIVER: INCREASE RENTAL RATES AND INCENTIVES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	DISAGREE	2	6.7	7.1	7.1
	NEITHER AGREE NOR DISAGREE	10	33.3	35.7	42.9
	AGREE	14	46.7	50.0	92.9
	STRONGLY AGREE	2	6.7	7.1	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

ECONOMIC DRIVER: COST EFFECTIVENESS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	3	10.0	10.3	10.3
	DISAGREE	2	6.7	6.9	17.2
	NEITHER AGREE NOR DISAGREE	3	10.0	10.3	27.6
	AGREE	13	43.3	44.8	72.4
	STRONGLY AGREE	8	26.7	27.6	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

ECONOMIC DRIVER: FILLING A DESIGN NEED

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	7	23.3	24.1	24.1
	AGREE	14	46.7	48.3	72.4
	STRONGLY AGREE	8	26.7	27.6	100.0
	Total	29	96.7	100.0	

Missing	System	1	3.3		
Total		30	100.0		

ECONOMIC DRIVER: EASE IN LEASING

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	3	10.0	10.0	10.0
	DISAGREE	10	33.3	33.3	43.3
	NEITHER AGREE NOR DISAGREE	10	33.3	33.3	76.7
	AGREE	3	10.0	10.0	86.7
	STRONGLY AGREE	4	13.3	13.3	100.0
	Total	30	100.0	100.0	

SOCIAL DRIVER: INCREASED PRODUCTIVITY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	2	6.7	7.1	7.1
	AGREE	14	46.7	50.0	57.1
	STRONGLY AGREE	12	40.0	42.9	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

SOCIAL DRIVER: HIGH TENANTS RETENSION RATE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	3	10.0	10.7	10.7
	AGREE	12	40.0	42.9	53.6
	STRONGLY AGREE	13	43.3	46.4	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

SOCIAL DRIVER: CLIENTS REQUIREMENTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	6	20.0	21.4	21.4
	AGREE	16	53.3	57.1	78.6
	STRONGLY AGREE	6	20.0	21.4	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

SOCIAL DRIVER: ATTRACT TENANTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	13	43.3	54.2	54.2
	AGREE	9	30.0	37.5	91.7
	STRONGLY AGREE	2	6.7	8.3	100.0
	Total	24	80.0	100.0	
Missing	System	6	20.0		
Total		30	100.0		

SOCIAL DRIVER: IMPROVE OVERALL QUALITY OF LIFE AND HEIGHTEN AESTHETIC QUALITIES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	DISAGREE	3	10.0	10.7	10.7
	NEITHER AGREE NOR DISAGREE	18	60.0	64.3	75.0
	AGREE	4	13.3	14.3	89.3
	STRONGLY AGREE	3	10.0	10.7	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

TECHNOLOGICAL BARRIER: LOW DEMAND FOR SUSTAINABLE MATERIALS AND PRODUCTS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LOW	6	20.0	21.4	21.4
	HIGH	18	60.0	64.3	85.7
	VERY HIGH	4	13.3	14.3	100.0
	Total	28	93.3	100.0	
Missing	System	2	6.7		
Total		30	100.0		

TECHNOLOGICAL BARRIER: LACK OF READILY ACCESSIBLE AND RELIABLE INFORMATION AND GUIDANCE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	23	76.7	85.2	85.2
	VERY HIGH	4	13.3	14.8	100.0
	Total	27	90.0	100.0	
Missing	System	3	10.0		
Total		30	100.0		

TECHNOLOGICAL BARRIER: LACK OF LIFE CYCLE COSTING(LCC)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	4	13.3	14.8	14.8
	LOW	5	16.7	18.5	33.3
	NEUTRAL	6	20.0	22.2	55.6
	HIGH	6	20.0	22.2	77.8
	VERY HIGH	6	20.0	22.2	100.0
	Total	27	90.0	100.0	
Missing	System	3	10.0		
Total		30	100.0		

TECHNOLOGICAL BARRIER: LACK OF KNOWLEDGE/AWARENESS/UNDERSTANDING AND EXPERIENCE ABOUT ENERGY EFFICIENT BUILDINGS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	3	10.0	10.3	10.3
	HIGH	12	40.0	41.4	51.7
	VERY HIGH	14	46.7	48.3	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

TECHNOLOGICAL BARRIER: LACK OF APPROPRIATE UK CERTIFICATION

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEUTRAL	12	40.0	40.0	40.0
	HIGH	13	43.3	43.3	83.3
	VERY HIGH	5	16.7	16.7	100.0
	Total	30	100.0	100.0	

NON-TECHNOLOGICAL BARRIER: FINANCIAL BARRIERS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HIGH	8	26.7	27.6	27.6
	VERY HIGH	21	70.0	72.4	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

NON-TECHNOLOGICAL BARRIER: NO PERCEIVED CONSUMER DEMAND FOR SUSTAINABLE COMMERCIAL OFFICE BUILDINDS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	2	6.7	8.0	8.0
	LOW	3	10.0	12.0	20.0
	NEUTRAL	2	6.7	8.0	28.0
	HIGH	8	26.7	32.0	60.0
	VERY HIGH	10	33.3	40.0	100.0
	Total	25	83.3	100.0	
Missing	System	5	16.7		
Total		30	100.0		

NON-TECHNOLOGICAL BARRIER: LEARNING PERIOD

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	3	10.0	12.0	12.0
	LOW	10	33.3	40.0	52.0
	NEUTRAL	6	20.0	24.0	76.0
	HIGH	3	10.0	12.0	88.0
	VERY HIGH	3	10.0	12.0	100.0
	Total	25	83.3	100.0	
Missing	System	5	16.7		
Total		30	100.0		

NON-TECHNOLOGICAL BARRIER: STATUS QUO IN RULES AND REGULATIONS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	5	16.7	17.2	17.2
	LOW	9	30.0	31.0	48.3
	NEUTRAL	11	36.7	37.9	86.2
	HIGH	4	13.3	13.8	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

NON-TECHNOLOGICAL BARRIER: SUSTAINABILITY MEASURES ARE NOT CONSIDERED BY THE GOVERNMENT

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VERY LOW	4	13.3	13.8	13.8
	LOW	8	26.7	27.6	41.4
	NEUTRAL	7	23.3	24.1	65.5
	HIGH	10	33.3	34.5	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

KEY PERFORMANCE INDICATORS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	4	13.3	13.8	13.8
	SLIGHTLY AWARE	25	83.3	86.2	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		

ECONOMIC PERFORMANCE MEASURE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	2	6.7	8.3	8.3
	SLIGHTLY AWARE	18	60.0	75.0	83.3
	SOMEWHAT AWARE	4	13.3	16.7	100.0
	Total	24	80.0	100.0	
Missing	System	6	20.0		
Total		30	100.0		

RISK ASSESSMENT TECHNIQUES

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	11	36.7	42.3	42.3
	SLIGHTLY AWARE	11	36.7	42.3	84.6
	SOMEWHAT AWARE	3	10.0	11.5	96.2
	EXTREMELY AWARE	1	3.3	3.8	100.0
	Total	26	86.7	100.0	
Missing	System	4	13.3		
Total		30	100.0		

FORECASTING METHOD

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NOT ALL AT AWARE	8	26.7	28.6	28.6
	SLIGHTLY AWARE	1	3.3	3.6	32.1
	SOMEWHAT AWARE	6	20.0	21.4	53.6
	MODERATELY AWARE	8	26.7	28.6	82.1
	EXTREMELY AWARE	5	16.7	17.9	100.0
	Total	28	93.3	100.0	

Missing	System	2	6.7		
Total		30	100.0		

KEY PERFORMANCE INDICATORS AND ECONOMIC PERFORMANCE MEASURES NEED TO BE INCORPORATED INTO LCC

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	1	3.3	3.3	3.3
	NEITHER AGREE NOR DISAGREE	2	6.7	6.7	10.0
	AGREE	5	16.7	16.7	26.7
	STRONGLY AGREE	22	73.3	73.3	100.0
	Total	30	100.0	100.0	

THE CURRENT LCC TECHNIQUES ARE SUITABLE FOR CALCULATING THE COSTS OF BUILDINGS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	16	53.3	53.3	53.3
	DISAGREE	14	46.7	46.7	100.0
	Total	30	100.0	100.0	

IT IS IMPORTANT TO CONSIDER THE INITIAL, OPERATING, MAINTENANCE AND DISPOSAL COSTS OF BUILDING WHEN CONDUCTING LCC ANALYSIS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NEITHER AGREE NOR DISAGREE	3	10.0	10.0	10.0
	AGREE	4	13.3	13.3	23.3
	STRONGLY AGREE	23	76.7	76.7	100.0
	Total	30	100.0	100.0	

HISTORICAL COSTS DATA IS VERY ACCURATE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	STRONGLY DISAGREE	11	36.7	37.9	37.9
	DISAGREE	8	26.7	27.6	65.5
	NEITHER AGREE NOR DISAGREE	3	10.0	10.3	75.9
	AGREE	4	13.3	13.8	89.7
	STRONGLY AGREE	3	10.0	10.3	100.0
	Total	29	96.7	100.0	
Missing	System	1	3.3		
Total		30	100.0		