

Abstract

There is an increasing drive to achieve sustainability agenda, as well as climate change challenges. The construction industry is facing increasing pressure to address environmental performance earlier in the design process. For UK buildings, design is believed to be the key in delivering the low carbon agenda. Hence, a fundamental change to designers' approach in designing for low impact buildings is needed. The ways design decisions are made can greatly influence the outcomes of design. Fundamental design decisions taken early in the design process have far-reaching environmental impacts later on. Better informed design, from the earliest conceptual stage, will improve the design of individual buildings, and help achieve low impact buildings. For this reason, tools have become a necessity for the early and on-going consideration of environmental performance and an important delivery mechanism to aid architects' design and decision making to deliver the low impact buildings.

However, the existing decision support tools had not addressed in full the expectation of architects. Design-decision support tools, specifically the Building Performance Energy Simulation (BPES) are not fully integrated into the design process, to enable UK architects to make informed decision especially at the early stage of the design process. Thus, the study seeks to provide a decision support framework for architects to achieve low carbon housing (LCHs) design in the United Kingdom (UK). It sets out to determine how UK architects can achieve the design; what the needs of architects are in BPES tools characteristics to deliver the design and what design decision tasks are required, towards development of the decision support framework.

Consequently, the research examined low carbon housing design. Existing statutory and non-statutory regulations, as well as design and decision support tools, which relate to low carbon housing design and delivery, were identified. These were used to frame the questions for the qualitative semi structured, face-to-face and in-depth interviews with practicing architects and academics. Online questionnaires were also administered to a representative sample of UK

architectural practices to investigate the fitness of purpose between decision-support tools and design decision-making to achieve low carbon housing.

Data analysis revealed that there is a lack of fitness between existing decision support tools, in the form of Building Performance Energy Simulation (BPES) tools, and the various stages of the design process. It emerged that architects use BPES tools, primarily at the later stage of the process. Support for the early design stage remains poor, especially at the conceptual stage of the design process. The findings confirmed that design decisions for LCHs vary significantly in terms of level of accuracy, flexibility, and detail. At the early stages of the process, as relatively little information is available, flexibility and approximation in BPES tools is more relevant to support design decisions. As the design develops, and more information becomes available, precision and higher level of detail in BPES tools is required.

Thus, the research developed a decision support framework which defines the characteristics of BPES tools fit for architects design and decision making; it also maps out an integrated building design process (IBDP) that includes the use of BPES tools. Implications of the study on research, software development and design practice are finally examined.

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Declaration

I, the undersigned, hereby confirm and declare that this thesis '*Developing Decision Support Framework for Low Carbon Housing design and delivery in the UK*', submitted for assessment is my own work. Materials of other authors (equations, tables, figures, texts and software) used in this work are accordingly acknowledged at the point of their use. A full list of the references used is also included.

.....
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Table of Contents

Abstract.....	i
Acknowledgements.....	iii
Declaration.....	iv
Table of Contents.....	v
List of Figures.....	xi
List of Tables.....	xii
Chapter One: Introduction.....	1
1 Introduction	1
1.1 Research Background	1
1.2 Problem Definition.....	4
1.3 Rationale for the Research.....	5
1.4 Research Aim and Objectives	6
1.5 Research Questions.....	7
1.6 Research Methods	8
1.7 Organisation of Thesis.....	10
1.8 Summary	11
Chapter Two: Climate Change, Housing Regulations and Guidance	12
2 Introduction	12
2.1 Energy Use and Climate Change.....	12
2.2 Sustainable and Low Carbon Housing	16
2.2.1 Sustainability in Housing	16
2.2.2 Low Energy and Passive Housing Design	19
2.2.3 Low Carbon Housing and Barriers to its Design in UK.....	22
2.2.4 Rationale for Low-Carbon Housing Design.....	23
2.2.5 Policy for Low Carbon Housing Design in the UK	25
2.3 Information for Low Carbon Housing Design.....	26
2.3.1 Housing Policies and Regulations.....	26
2.3.2 Building Regulations, Part L1A	29
2.3.3 Code for Sustainable Homes	31
2.3.4 Green Guide to Specification	38
2.4 Environmental Guidance	39

2.4.1	Environmental Assessment and Sustainable Buildings.....	40
2.4.2	Environmental Tools at Local and National level.....	44
2.5	<i>Existing Guidance and Tools in the UK</i>	46
2.5.1	Planning and Early Design Requirements.....	46
2.5.2	Building Regulations Compliance Tools	48
2.5.3	Tools for Sustainability in the UK	49
2.6	<i>Summary</i>	52
Chapter Three: Design and Decision Delivery Tools		53
3	Introduction	53
3.1	<i>The Role of Architects</i>	53
3.1.1	Architects' Role in the Traditional Building Delivery Process.....	53
3.1.2	Architects' Role in Low Carbon Housing Design and Delivery....	55
3.1.3	Low Carbon Housing Design Principles for UK Architects	57
3.2	<i>Design tools and BIM</i>	58
3.2.1	Computer based drafting and design tools	58
3.2.2	Revit Architecture Suite and BIM.....	62
3.3	<i>Decision Support and Building Performance Simulation (BPS) Tools</i> 65	
3.3.1	Decision Support Tools	65
3.3.2	Background to BPS Tools	67
3.3.3	Application of BPS Tools.....	69
3.3.4	Choice of Building Performance Simulation	71
3.4	<i>Building Performance Energy Simulation (BPES) Tools</i>	73
3.4.1	BPES Tools Functions.....	73
3.4.2	Critique of BPES Tools.....	74
3.5	<i>Summary</i>	75
Chapter Four: Design Process and Decision Making Framework		76
4	Introduction	76
4.1	<i>Design and RIBA Outline Plan of Works</i>	77
4.1.1	Design and its Process.....	77
4.1.2	RIBA Outline Plan of Works	78
4.1.3	RIBA Outline Plan of Work as the Base Line Model	79
4.1.4	The RIBA Design Model and Sustainability.....	81
4.1.5	RIBA Design Stages and Sustainability Assessment.....	84
4.1.6	Critique of the RIBA Outline Plan of Work.....	87
4.2	<i>Conventional Design Process</i>	88
4.2.1	Activities in the Conventional Design Process	89

4.2.2	Critique of the Conventional Design Process.....	91
4.3	<i>Integrated Building Design Process</i>	94
4.4	<i>Other Type of Design Processes</i>	95
4.4.1	Purely Theoretical Models	95
4.4.2	Rational and Reflex -in -Action Process Model.....	96
4.5	<i>Decision Making</i>	98
4.5.1	Decision Making in the Design Process and Sustainability.....	98
4.5.2	Decision Making at the Early Design Stage.....	100
4.5.3	Human Decision-Making Process	105
4.5.4	Decision-Making Models and Support Framework.....	107
4.6	<i>Past Models and Frameworks</i>	108
4.7	<i>Summary</i>	110
5	Introduction	111
5.1	<i>Case Based Documentary Study and Analysis</i>	112
5.1.1	Rationale for Case- Based Documents Identification	113
5.1.2	Credibility of Documents	114
5.1.3	Concept Adopted for the Case-Based Documentary Study	115
5.1.4	Analysis of the Case -Based Documents.....	116
5.2	<i>Case Based Documents</i>	119
5.2.1	Hansen and Knudsrup (2005).....	120
5.2.2	Pearl (2004)	121
5.2.3	Reed and Gordon (2000)	122
5.2.4	Energy Star Building Design Guidance	123
5.2.5	Federal Facilities and Housing Design Guidance	123
5.2.6	Discussion on the Integrated Design Process.....	125
5.3	<i>Level 5, Case-Based Documents</i>	126
5.3.1	Case study 1: The Old Apple Store, Stawell, Somerset.....	126
5.3.2	Case Study 2: CO ₂ Zero, Bristol	129
5.3.3	Case Study 3: Mid Street, South Nutfield, Surrey	130
5.3.4	Synthesis of Case studies: Design Information Requirements (DIR) 132	
5.4	<i>IBDP and Design Information Requirements (DIR)</i>	133
5.4.1	Discussion of some other factors in the IBDP	137
5.5	<i>Summary</i>	143
6	Introduction	144
6.1	<i>Research Design and Methodology</i>	146
6.1.1	Research Design	146
6.1.2	Research Strategy	146

6.1.3	Research Methodology.....	147
6.2	<i>Research Methods</i>	152
6.2.1	Mixed Method Approach.....	154
6.2.2	The Paradigm of the Mixed Method Approach.....	154
6.2.3	Approach Adopted in the Review Chapters.....	157
6.3	<i>Data Collection</i>	158
6.3.1	Interview Design.....	158
6.3.2	Interview Analysis.....	164
6.3.3	Questionnaire Design.....	166
6.3.4	Questionnaire Survey Analysis.....	176
6.4	<i>Development and Evaluation of the DSF</i>	177
6.4.1	Rationale and Development for the Framework.....	178
6.4.2	Validation of Research Findings and Evaluating the DSF.....	178
6.5	<i>Research Ethics and Confidentiality</i>	179
6.6	<i>Summary</i>	180
Chapter Seven: Analysis of Interview Findings.....		181
7	Introduction.....	181
7.1	<i>Overview and Scope of the Interview</i>	181
7.2	<i>Interview Findings</i>	182
7.2.1	Interviewees' Profile.....	182
7.3	<i>Design and Decision Support Tools</i>	184
7.3.1	Decision Support Presentation.....	189
7.3.2	Barrier(s) to Low Carbon Housing Design and Delivery in UK..	191
7.4	<i>Statutory and Non Statutory Regulations: CSH</i>	195
7.4.1	Uptake on other Statutory and Non-statutory Regulations in UK	197
7.5	<i>Design Information Requirements (DIR)</i>	198
7.6	<i>Summary</i>	199
Chapter Eight: Results and Analysis of Questionnaire Survey.....		201
8	Introduction.....	201
8.1	<i>Overview of the Questionnaire Design and Response Rate</i>	202
8.1.1	Response Rate.....	202
8.1.2	Years of experience.....	203
8.2	<i>BPES Tools and Analysis</i>	205
8.2.1	Early Simulation Tools (ETs).....	205
8.2.2	Detail Simulation Tools (DSTs).....	206
8.2.3	ETs and DSTs for Stages of the Design Process.....	206

8.3	<i>BPES Tools and Degree of Frequency</i>	207
8.3.1	Early Simulation Tools (ETs) and Degree of Frequency	207
8.3.2	Detail Simulation Tools and Degree of Frequency	208
8.4	<i>BPES Tools and Stages of Design that needs Focus</i>	209
8.4.1	ETs and Stages of Design Process that needs focus.....	210
8.4.2	DSTs and Stages of Design Process that needs focus	211
8.5	<i>Other Information and Degree of Frequency</i>	212
8.5.1	Other Information and Stages of Design Process that need focus.....	215
8.6	<i>Decision making and Stages of Design</i>	216
8.6.1	ETs and Decision making.....	218
8.6.2	ETs and Decision Making at stages of Design Process.....	219
8.6.3	DSTs and Decision Making	220
8.6.4	DSTs and Decision Making at different Stages of Design process 221	
8.6.5	The Green Guide to Specification and Decision Making.....	222
8.6.6	Green Guide to Specification and Decision Making.....	223
8.7	<i>Reliability</i>	224
8.8	<i>Summary</i>	225
Chapter Nine: BPES Tools and Development of the Decision Support Framework		227
9	Introduction	227
9.1	<i>Existing BPES Tools and Stages of the Design Process</i>	227
9.1.1	Preparation Stages	228
9.1.2	Concept Stage.....	229
9.1.3	Design Development Stage	230
9.1.4	Technical Design Stage	233
9.2	<i>BPES Tools Appraisal</i>	236
9.3	<i>The DSF Conception and Development</i>	239
9.3.1	Developing the DSF	240
9.4	<i>Design Process in the DSF</i>	243
9.4.1	Preparation and Design Phases in the DSF	243
9.4.2	Post Design and Pre-Construction Phase	245
9.5	<i>Summary</i>	246
Chapter Ten: Discussions of Research Findings and Implications		247
10	Introduction	247
10.1	<i>Design-Decision and Support Tools</i>	247
10.1.1	State- of- the- Art on Existing BPES Tools.....	247

10.1.2	BPES Tools and Decision Making in the Design Process.....	250
10.1.3	Ambiguity and Limitation of Design Tools.....	253
10.2	<i>Statutory Regulations: Code for Sustainable Homes</i>	254
10.2.1	Cost of Low Carbon Housing Design and Delivery in the UK	255
10.3	<i>Implication of the Study</i>	256
10.3.1	Implications for Practice.....	256
10.3.2	Implication for Theory.....	259
10.4	<i>Validation of Research Findings</i>	260
10.4.1	External Validation.....	260
10.5	<i>Summary</i>	262
Chapter 11: Conclusions and Recommendations		263
11 Introduction		263
11.1	<i>Achievement of Research Objectives and Questions</i>	263
11.2	<i>Recommendations</i>	266
11.2.1	Recommendations for Software Developers	266
11.2.2	Recommendations for Practice	271
11.2.3	Recommendations for Researchers.....	273
11.2.4	Recommendations for Policy Makers.....	276
11.3	<i>Contribution to Knowledge</i>	276
11.3.1	Dissemination of Research	278
11.4	<i>Limitations</i>	278
11.5	<i>Scope for Future Work</i>	279
11.6	<i>Reflective Summary</i>	280
11.6.1	Conclusion	281
References.....		283
Appendix 1 : Case Based Documents.....		310
Appendix 2a : Interview Questionnaire.....		318
Appendix 2b : Interview Transcripts.....		320
Appendix 3: Questionnaire Survey		326
Appendix 4: Low Carbon House.....		329
Appendix5 : Abstracts.....		333

List of Figures

Figure 1.1: Research Design of Chapters and Objectives in the Thesis	9
Figure 2.1: Initiators of UK low energy housing developments	19
Figure 2.2: Code for Sustainable Homes	32
Figure 4.1: The DSS decision-making process.....	108
Figure 5.1: Method of DIR Development.....	119
Figure 5.2: Phases of an integrated design process	120
Figure 5.3: Iterations in decision making	121
Figure 6.1: Chapter Layout.....	145
Figure 6.2: Research Methods	153
Figure7.1: Nvivo-Result-Preview-on-Key-Words-related to Tools	188
Figure 7.2: Nvivo keywords preview on key words related to Cost	195
Figure 8.1: Years of Experience	204
Figure 9.1: Wizards in eQUEST.....	231
Figure 9.2: General workflow in the schematic design wizard of eQUEST ..	231
Figure 9.3: Data Flow of DOE -2.1 engine	234
Figure 9.4: DIR from the IBDP	241
Figure 9.5: Decision Support Framework	242

Lists of Tables

Table 2.1: UK Emission Reduction Targets	15
Table 2.2: UK Government Policy Framework on Energy Efficiency	27
Table 2.3: Major developments in British building control legislation	30
Table 2.4: Design of new houses to various level of the CSHs.....	34
Table 2.5: Advantage of CSH over Eco-Homes.....	37
Table 2.6: Examples of existing green building rating tools	43
Table 2.7: Rating system by assessment area	44
Table 4.1: Design Process stages split into phases	80
Table 4.2: Green Overlay to the RIBA Plan of Works-1	82
Table 4.3: Green Overlay to the RIBA Plan of Works-2	83
Table 4.4: Preferred decision-making techniques for personality types.....	106
Table 6.1: Questionnaire Validation.....	172
Table 6.2: Survey Software for Questionnaire Administration	174
Table 7.1: Identification of the key word ‘ <i>TOOL</i> ’ -1	186
Table 7.2: Identification of the key word ‘ <i>TOOL</i> ’ -2	187
Table 7.3: Key word identification ‘ <i>Design Process/Stages</i> ’	190
Table 7.4: Identification of the Key word ‘ <i>Cost</i> ’ -1	193
Table 7.5: Identification of the Key word ‘ <i>Cost</i> ’ -2	194
Table 8.1: Respondent years of experience	204
Table 8.2: Degree of Frequency	208
Table 8.3: Percentage distribution of ETs and Stages of Design Process	210

Table 8.4: Percentage distribution of DSTs and Stages of Design Process....	211
Table 8.5: Other Types of Tools and other Information for LCH design	213
Table 8.6: Percentage distribution on BIM and Green guide	215
Table 8.7: Contingency table of Decision Making and Stages of design.....	217
Table 8.8: Chi square Statistical test between ETs and Decision making	219
Table 8.9: Percentage distribution in the use of ETs and Dm1-Dm5.....	219
Table 8.10: Chi square Test between DSTs and Dm1-Dm5	221
Table 8.11: Percentage distribution of DSTs and Dm1 -Dm5.....	222
Table 8.12: Chi square test between Green Guide and DM	223
Table 8.13: Percentage distribution in Green Guide and Decision Making ...	224
Table 8.14: Reliability Test	224
Table 8.15: Reliability Analysis	225
Table 9.1: Existing BPES Tools at Stages of Design Process.....	228
Table 9.2: Functions of Tools and Application	236
Table 9.3: Contrasting Capabilities of existing BPES tools.....	237
Table 9.4: Strengths and Weaknesses of BPES tools in the UK	238
Table 9.5: Strengths and Weaknesses of widely used BPES tools.....	239

Chapter One: Introduction

1 Introduction

This study seeks to provide a decision support framework for architects to achieve low carbon housing (LCH) design in the United Kingdom (UK). It investigates the requirements of decision-support tools to support the various stages of the design process to deliver low impact housing.

This is the introductory chapter, which presents the background study, problem definition and the rationale of the research. The aim, objectives, outline of the research methods and overview of the thesis are also presented in this chapter. The content of the chapter can be summarised as follows:

- Research Background;
- Problem Definition;
- Rationale for the Research;
- Research Aim and Objectives;
- Research Methods;
- Organisation of Thesis; and
- Summary.

1.1 Research Background

Climate change is caused by emission of greenhouse gases into the atmosphere. The consequences of it, coupled with the long term and persistent nature of its impact highlights the need for government intervention. Hence, tackling of energy use through design and development of buildings has become a priority for the UK government, towards adapting low carbon action to have impact on the climate change (Crosbie *et al.*, 2010).

Buildings account for approximately forty per cent of carbon emissions in the UK and across the European Union (Carbon Trust, 2010). They have been described as complex entities involving a wide range of stakeholders drawn

from a large number of disciplines (Dibley *et al.*, 2012). Within the building industry, the housing sector alone was responsible for over a quarter (twenty-eight per cent) of the total carbon emission (DEFRA, 2005). The current trend is that this will increase due to new technologies, such as digital radios, plasma TVs, and air conditioning requiring higher energy inputs (CLG, 2007a; Seyfang, 2008). Forbes (2007) posits the existence of environmental concerns in light of anthropogenic climate change have impact on the housing sector, because it is the major energy-consuming, and carbon dioxide producing sectors. Despite some buildings having green credentials, Scofield (2002) observed, they were found to be responsible for as much energy consumption and pollution as comparable to conventional buildings.

This is because, environmental design decisions are taken late in the design process to validate design after critical decisions have already been made (Dunsdon *et al.*, 2006). Early in the design, architects often make decisions regarding the building form, orientation, fenestrations and construction materials with little or no support (Hong *et al.*, 2000). These issues have been observed to have important implications in achieving the low impact building agenda. The way design decisions are made have great influence on the outcome of the design. Fundamental design decisions taken early in the design process have far reaching environmental impacts later on.

Consequently, it is increasingly acknowledged that in order to address climate change challenges, a fundamental alteration to designing for low impact building (LIB) is needed. Thus, design and decision support mechanisms, such as building performance energy simulation (BPES) tools that aid architects' design and decision making, as well as fitting into various stages of the design process, have become a necessity for the early and on-going consideration of environmental performance. It has also become important for the delivery of low impact housing, especially in the UK.

However, there is poor support of design decision-making, especially at the early design stages. Architects are increasingly challenged to address the environmental performance of buildings earlier in the design process, along

with planning permission requiring technical substantiations of how carbon dioxide emissions target will be met (Royal Institute of British Architects, 2009b). Yet, available design and decision support tools are often criticised as raising barriers between disciplines and between successive design phases (TSB, 2009). These concerns were also reiterated by Dunsdon *et al.*, (2006), who acknowledged that tools in trend, especially those relating to the design of new homes in the UK, such as energy simulation tools, are inadequate to support and inform the design of low carbon buildings, especially at the early stage of the design process. They referred to the fact that simulation tools currently available are only proficient in performing decision already made by the architects before the energy assessment and, consequently there exists low-level adoption of these tools by architects.

Subsequently, rather than playing a role of decision support in the design, analysis is used primarily to verify and rationalise decisions already made (Hopfe and Hensen, 2009). Limitations in both tools and process pose challenges to the integration of simulation in early design. The conversion of 3D models between design and analysis representations is not well supported by existing data transformation mappings, and typically requires expert translation and interpretation (Augenbroe *et al.*, 2004). Furthermore, most simulation tools necessitate detailed information about a building's construction and services before even an indicative analysis can be performed; information that may not be available at the conceptual design stage (Ellis and Mathews, 2001). These incompatibilities inhibit the development of an interactive information exchange network where design and simulation analysis processes are active simultaneously, and serve as barrier, rather than to reinforce conventional practice (Nicholas and Burry, 2007).

Mora *et al.*, (2006) laid emphasis on how computer support for conceptual design of building structures is still ineffective, mainly because existing structural engineering applications fail to recognise that structural and architectural design are highly interdependent processes. To deliver low impact buildings in UK, the loop between building design, operation and performance must be closed (Technology Strategy Board, 2009): hence, the industry is

challenged to deliver a ‘new generation’ of tools in the design for LIB (Hong *et al.*, 2000; Morbitzer *et al.*, 2001; Mirani and Mahdjoubi, 2012).

1.2 Problem Definition

Traditionally, architects tend to follow an essentially iterative process by which the existing simulation methods have been primarily used to assess designs at the later stages of the process. This is because energy performance has not been a major concern for architects. It has been seen as a subsequent responsibility of service engineers, who are tasked with implementing an already formulated design by adding mechanical systems to address indoor environment conditions (Soebarto and William, 2001). Consequently, if simulation tools are used in design at all by architects, their use is usually confined to optimisation and verification at detailed design development, or late in the project, rather than at conceptual design, where most of the important decisions relating to energy efficiency components are made (Soebarto and William, 2001).

Morbitzer (2003) carried out a survey, which questioned UK architects on the reasons for the limited use of simulation within the architectural design process. The findings revealed that architects are visual professionals and they see simulations as being too abstract. Consequently, the role of energy analysis has been simply to give endorsement to a completed design, rather than to assist the designer during the design process (Morbitzer, 2003). This issue was also stressed by Rudy and Jaksch (2004), who reported that, computer-based design guidance is still largely based on the working concerns of engineers and reflects little of the case-based reasoning style of architects. It was further supported by Lawson (2010) who stated that the downside of the use of such precise programs in the early design stage tends to limit creativity and can encourage poor design.

Thus, advanced computer tools are typically entered at the later stage in the design process when many global, but crucial, decisions about the design have already been made. Hence, the focus of architects in use of simulation tools has shifted more to the detailed specification stage instead of the early design stage of the design process (Aliakseyeu *et al.*, 2006). More recently, TSB (2009)

made the following observations about the current generation of design and decision support tools:

- Design support at the conceptual stage is particularly poor;
- Designers cannot easily predict the impact of alternative design decisions on building performance and cost, whether capital cost, whole life financial cost or carbon cost;
- Design professionals work in different ways, through sketches, physical models, 2D and 3D computer representations, and analytically, thus have different requirements for representing and communicating design developments;
- Current tools only address the needs of one specialism or specific phase of the design process;
- Many current tools are not ‘mainstream’ or accessible to professionals in smaller practices; and
- Available tools do not help communicate the impact of design options and decisions between professionals or between professional designers and their clients. It is difficult to incorporate learning from design outcomes in subsequent designs.

Clearly, better-informed design, from the earliest conceptual stages, will improve the design of individual buildings. Consequently, a new generation of tools to support design-decision-making is needed (Hong *et al.*, 2000; Morbitzer *et al.*, 2001).

1.3 Rationale for the Research

Both personal and academic interests motivated this research. Being an architect with special interest in housing and sustainability, there arise the need to provide insights into architects’ way of design and decision making. Thus, the research is oriented with the ultimate aim of providing a Decision Support Framework (DSF), which defines the required characteristics of BPES tools for architects to achieve low carbon housing design in the UK. This is to fill the gap in knowledge, since current plans, policies, programmes, trends,

guides, design tools, although so many, and from variety of sources, seem not to be sufficient towards realisation of the specified target for new homes design in the UK. This is in support of researchers such as William and Lindsay (2007), who argue, the information base available to undertake sustainable review is inadequate.

The construction industry is facing increasing pressure to deliver low carbon buildings (Royal Institute of British Architects, 2009a). Designers, especially architects, have been identified as central to the delivery of low carbon buildings. They play a crucial role in achieving the low carbon targets for homes in the UK because their decisions at the conceptual stage of the design have a major impact on the performance of the building (Oyedele and Tham, 2007). However, existing tools have not been adopted widely by architects, because they do not fit in with the way architects make design decision at various stages of the design process. Hence, adequate decision-support tools to support designers to achieve low carbon housing are seen as critical to achieve more environmentally efficient buildings. Consequently, it is important for architects to have appropriate BPES tools that are in tune with design decisions (Mahdavi, 1998; Soebarto and Williams, 2001) at the various stages of the design process. These tools need be in a format easily understood and interpreted by non-specialist designers (Mahdavi and Silvana, 2003), such as the architects.

1.4 Research Aim and Objectives

The aim of this research is to develop a decision support framework that defines the characteristics of design decision-support tools to enable architects achieve the design of low carbon housing in the UK. For the purpose of this study, low carbon housing in the UK as a '*catch all*' term refers to homes built in the last five to six years to higher standards of energy efficiency than that required by the applicable building regulations. These include those built to Levels 3, 4, and 5 of the Code for Sustainable Homes (CSH). Thus, the specific objectives towards achieving the aim are:

1. Review low carbon housing design in the UK along with design and Building Performance Energy Simulation (BPES) tools.
2. Evaluate the state-of-the art of BPES tools and other support for architects to deliver the design in UK.
3. Design and develop a theoretical model of design information requirements to deliver low carbon buildings;
4. Develop a decision support framework that defines the characteristics of design decision-support (BPES) tools;
5. Determine the adequacy between design decisions, taken at the various stages of the design process, and Building Performance Energy Simulation (BPES) tools;
6. Outline the implication of research findings on practice, policy and research communities.

1.5 Research Questions

Achievement of the stated aim (to develop the decision support framework) and implication of research towards recommending the findings on practice, policy and research communities, necessitates the qualitative and quantitative elements to answer the following research questions:

- What are the requirements of architects in decision support tools, at the different stage of the design process?
- Why are UK architects not using the existing design -decision support tools?
- If at all they do, what stage (s) of the design process do they use the tools?
- What stage of the design process do architects make major design decision?
- What are the design decision tasks for architects to deliver the design?
- How can UK architects achieve low carbon housing design?

However, within the research there was a tendency to mix in other methods in accordance with the pragmatic research philosophy incorporating expert

opinion, questionnaire comments, and textual analysis into the design and interpretation of the quantitative data. This is to provide a deeper understanding of the problem than statistical analysis alone. On the wider context of contribution to knowledge and towards fulfilling the main aim of the research, literatures on integrated design processes (IDP) of /low energy/sustainable housing were reviewed. In this way a conceptual model of the design information requirements, comprising the design decision tasks at each stage of the design process were established, towards the development of the decision support framework, which also, define the characteristics of Building Performance Energy Simulation (BPES) tools, to enable architects achieve the low carbon housing design in the UK.

1.6 Research Methods

A mixed-method approach has been adopted in this study. It has substantial advantages especially when qualitative and quantitative methods are used (Adeyeye *et al.*, 2007; Osmani and O'Reilly, 2009; Isiadinso *et al.*, 2011). Key concepts relating to low carbon housing design in the UK are first examined. Based on this analysis, existing design and decision support tools and other information, which relates to the design and its delivery, were identified to develop informed questions for the qualitative, semi structured, face-to-face in-depth interviews, and the quantitative online questionnaire survey.

The in-depth interviews, which involved a sample of practicing architects, examined potential of the CSH, (being the latest tool for assessment and evaluation of LCHs in UK) as a design delivery. It further investigated the effectiveness of design and decision support tools, as well as identified requirements of Building Performance Energy Simulation (BPES) tools for design decisions at the various stages of the design process. The quantitative questionnaire was developed as the result of the analysis of the results from the interviews. The questionnaire examine the adequacy/inadequacy between design and decision support tools, especially that of BPES tools and other information for architects to deliver the design.

The case-based documentary study and analysis of integrated design processes helped to develop the theoretical model of design information requirements. The analysis assisted in the development of the decision support framework. The research design process is outlined in Figure 1.1.

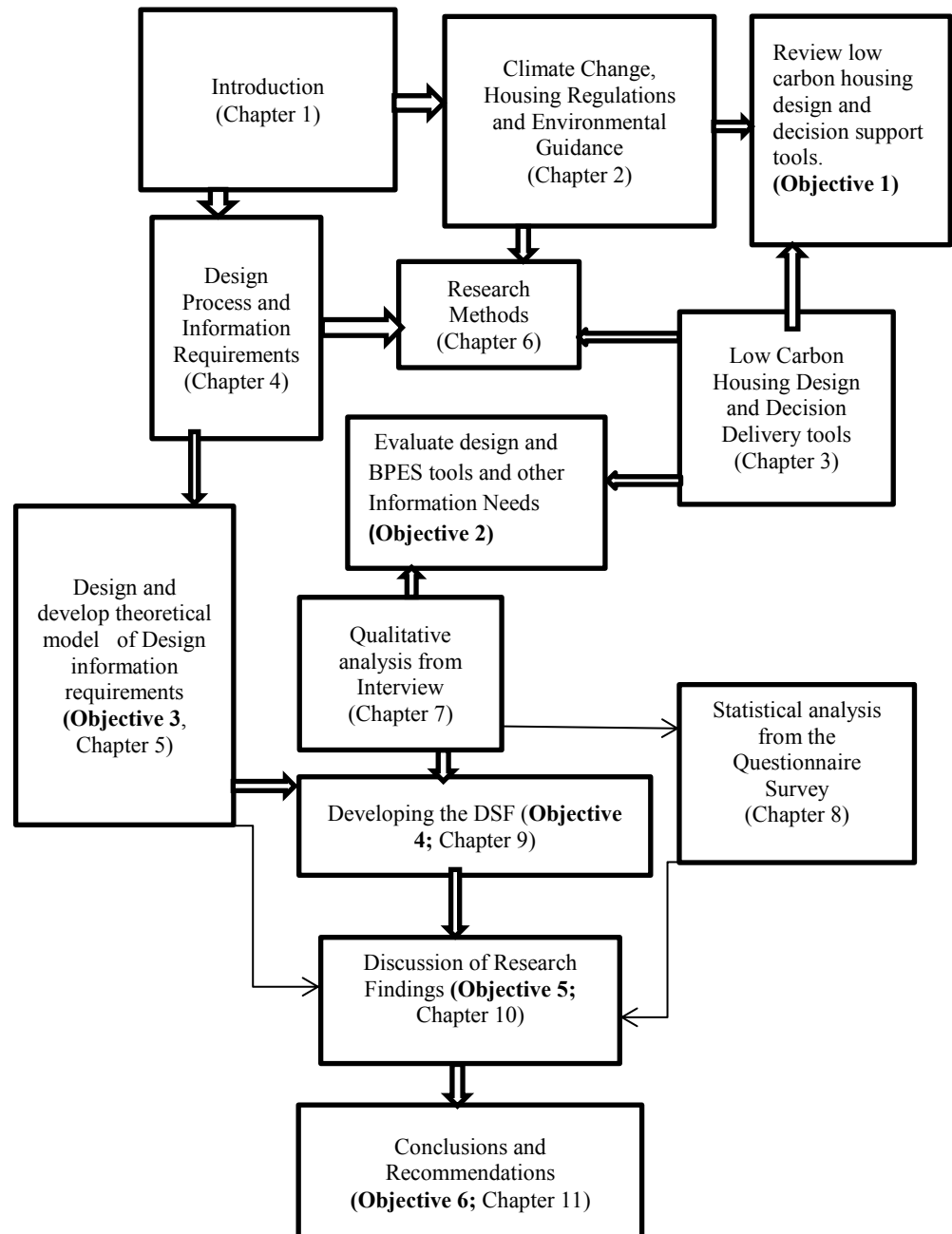


Figure 1.1: Research Design of Chapters and Objectives in the Thesis

1.7 Organisation of Thesis

Chapter one provides the rationale and context for the study, and outlines the aim and objectives of the research (Figure 1.1).

Chapter two reviews the available literature that address issues on climate change, sustainability, existing regulations, and standards in the UK housing sector. It further discussed the building regulations, Code for sustainable homes (CSH), housing policies, and other relevant guidance.

Chapter three focuses on low carbon housing design and decision delivery tools. It identifies design tools, along with definitions and characteristics of BPES tools for low carbon housing design.

Chapter four examines design information requirements, and decision making at various stages of the design process.

Chapter five presents the theoretical model of design information requirements that helps the classification of the design tasks in the decision support framework.

Chapter six provides a rationale for the methodology and adopted research methods of the study.

Chapter seven presents the results of the interviews with a sample of practicing architects to shed light on the adequacy/inadequacy of the decision support tools, along with their requirements to support architects' design-decision making.

Chapter eight presents the findings from the questionnaire survey, which seeks to elucidate the relationship between design-decision support tools and information requirements/decision-making at the various stages of the process.

Chapter nine presents the proposed DSF.

Chapter ten discusses the research findings along with the implications of the research findings.

Chapter eleven presents the conclusions and evaluates the objectives of the research. The recommendations from the research are also discussed.

1.8 Summary

This is the introductory chapter, which outlines the rationale and context for the research. It also highlighted the aim and objectives of the research, as well as presenting an overview of the research methods adopted for this study. The structure and organisation of the thesis was also outlined.

The next chapter examines issues on climate change, sustainability, existing regulations, and standards in the UK housing sector.

Chapter Two: Climate Change, Housing Regulations and Environmental Guidance

2 Introduction

The aim of this chapter, is to define the requisites and rationales that surround the term ‘*low carbon housing and its design*’ in the UK. The chapter serves as the background study, as well as fulfilling the first part of objective one, which is to review low carbon housing design in the UK.

To accomplish this, there is the need to appraise existing research efforts through both published/unpublished academic work and documentary studies of relevant reports. In summary, the chapter sets out to review the following issues:

- Energy Use and Climate Change;
- Sustainable and Low Carbon Housing;
- Information for Low Carbon Housing Design;
- Environmental Guidance;
- Existing Guidance and Tools in the UK, and
- Summary.

2.1 Energy Use and Climate Change

Levine *et al.*, (2007) presented the breakdown of energy end-use in the residential and commercial sectors for the United States (US) and China. The single largest user of energy in residential buildings in both regions is for space heating, followed by water heating. In the UK, space heating increased from 21.3 million tonnes of oil equivalent in 1970 to 24.6 million tonnes in 1990. Domestic energy consumption has been increasing slowly but steadily since the 1970s largely as a result of the spread of installed central heating and the increase in the number of energy-using goods (Department of Trade and Industry, 2007). However, in 1996, good progress towards fuel poverty targets reduction in the number of households in the UK was made from around 61/2 million to around 2 million in 2004 (Department of Trade and Industry, 2007).

The fourth assessment report on Intergovernmental Panel on Climate Change (IPCC) estimated that between 1970 and 2004, global greenhouse gas emission rose by 70 per cent (IPCC, 2007). From the period of 2004 to 2006, overall costs of fuel and light increased by 35%, while gas prices increased by 45% and electricity prices by 29% in real terms. These price increases represent significant challenges to the fuel poverty targets (Department of Trade and Industry, 2007). The increases are estimated to have driven up total fuel poverty levels by around 1.6 million households in England alone, with income improvements offsetting this by around 300,000 households and energy efficiency improvements by a further 100,000 households. This leads to an estimated additional 1.2 million households in fuel poverty in 2006 compared to 2004. On the central price/income scenario it was estimated that 1.5 million households will remain in fuel poverty in 2010 and 700,000 in 2016 (Department of Trade and Industry, 2007). This includes the effect of installing energy efficiency measures under the fuel poverty programmes.

Estimates of energy used by and in buildings vary, and are highly dependent on the criteria included, in particular, how electricity is generated. Oreszczyn and Lowe (2010) consider 45 per cent to be a conservative estimate for current UK energy use. This, was due to both the general decline in the industrial sector over time and adoption of energy efficient practices (United Nations Environmental Programme, 2009). Hence, if heating, cooling and water heating energy consumption can be reduced to near zero then significant savings can be made in CO₂ emissions. The energy consumption during the operational phase of a building depends on a wide range of interrelated factors such as climate and location; level of demand, supply, and source of energy; function and use of building; building design and construction materials; and the level of income and behaviour of occupants. Climatic conditions and the type of environment of which a building is found, affect every aspect of a building's energy use over its lifetime. Most countries and even states within countries have multiple climate zones.

In a survey of seventy countries, about two thirds of the surveyed countries have a national energy efficiency agency, with over 90 per cent having a

ministry department dedicated to energy efficiency (World Energy Council, 2008). The experience of countries that have implemented energy efficiency measures, following the two major energy crises of the 1970s, show that current barriers to energy efficiency in buildings can be overcome. To do this, UNEP (2009) states that decision makers must have a number of essential '*building blocks*' in place. These include energy performance requirements, information about the building sector, the capability to analyse this data and the ability to coordinate and facilitate policies, which address Green House Gas (GHG) emissions from buildings (United Nations Environmental Programme, 2009).

Energy use in buildings is a significant source of greenhouse gas (GHG) emissions, responsible for thirty-three per cent of the total global energy-related emissions in 2002 (Urge-Vorsatz and Koepfel, 2007). These result in climate change, which have become a global concern to the building-design profession (Urge-Vorsatz and Koepfel, 2007). The government belief, is that climate change is the greatest long-term challenge facing the world (CLG, 2007c), hence, within the construction industry and especially for a sustainable development of housing stock in the UK, there is the need to address the issue.

Many other organisations and councils (Cambridge County Council and Cambridge Horizon, 2005; Approach Principles Collaboration Development, 2006), both in the UK and at the international level, share this assessment on the need to address climate change. They established that most organisations are actually working to promote and deliver sustainable practices in the design and construction of buildings through the introduction of various policies and assessment schemes. These include, 'The Building Research Establishment's Eco-Homes scheme' (that has now been replaced by Code for Sustainable Homes) and BREEAM schemes (Cambridge County Council and Cambridge Horizon, 2005). Banfill and Peacock (2007) and the Department of Communities and Local Government (CLG, 2007c), further highlight the huge increase in awareness of issues surrounding climate change due to GHG emissions.

The Intergovernmental Panel on Climate Change (IPCC) established how climate change is linked to the release of carbon dioxide into the atmosphere, caused from the use of fossil fuels into the built environment (IPCC, 2007). Hence, the Climate Change Act established a legally binding target to reduce the UK's greenhouse gas emissions by at least eighty per cent. The scientific consensus is that the eighty per cent reduction over 1990 baseline levels of world green gas emissions is required by 2050 for the developed world to stand a good chance of avoiding the dangerous climate change (Boardman, 2007; Adeyeye *et al.*, 2007; Energy Savings Trust, 2008; Reeves *et al.*, 2010). To drive progress and set the UK on a pathway towards this target, the Act introduced a system of carbon budgets which provide legally binding limits on the amount of emissions that may be produced in successive five-year periods, started in 2008 (Table 2.1) (Morant,2012).

Table 2.1: UK Emission Reduction Targets

Carbon Budget	Percentage Reduction over Base year(1990)
2008 to 2012	22%
2013 to 2017	28%
2018 to 2022	34%
2023 to 2027	50%
2050	80%

Source: Morant (2012)

A number of studies such as McManus *et al.*, (2009) and Elforgani and Rahmat (2010) had also explored the technical feasibility of reducing the carbon emissions, especially from the UK housing stock. Their conclusions support the scientific consensus from the different organisations and research studies that the required reduction in carbon emission targets of eighty per cent by 2050 may actually be possible.

Some researchers (Goodbun,2008; Broer and Titheridge,2010), however, argue that there exists an equally high level of confusion and uncertainty regarding the precise nature and scale of climatic change, along with the difference that various levels of reduction in the greenhouse gas emission will make to the degree of the problem. Levine *et al.*, (2007) emphasised how climate change literacy, awareness of technological, cultural, and behavioural choices, are important preconditions to fully operating policies. Applying these policy approaches needs to go ‘hand in hand’ with programmes that increase the building-design profession (Levine *et al.*, 2007). This includes, producing tools that fit architects’ design and decision making, along with awareness of the necessary information for design and delivery of low carbon housing stock in the UK. This will reduce carbon emission right from the onset of the architectural design, as well as promote climate change literacy within the profession and the construction industry at large.

2.2 Sustainable and Low Carbon Housing

2.2.1 Sustainability in Housing

‘Sustainability’ is any development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The present inhabitants of the world have a duty to pass it on to the next generation in a state which is no worse than it is now (Brundtland, 1987). Cole (1999) claimed, sustainability emerged as an overarching notion for the environmental discourse and must, therefore, give direction to the structure and application of environmental assessment methods.

Sustainability, as environmental, social and economic dimensions, embraces all facets of human activity (industry, transportation, food production among others), and spans local actions through to redressing the major inequities that exist between developed and developing nations (Cole, 1999). Given the political and economic interdependencies, where the actions of one nation profoundly affect others, the notion of ‘sustainability’ from Cole (1999) is meaningful only when applied at a global scale. Nevertheless, some researchers, such as Priemus (2005) have criticised the global orientation of

'sustainability' as being inadequate. Their belief is that sustainable development takes place on different scales, and, as such, the quality and availability of water, soil pollution, and noise nuisance etc., all play various roles at different local and regional levels.

The concept of 'sustainability' was developed as a result of an adage and a challenge associated with, amongst other things: participatory design processes; planning practices; the economy; the environment; health; nature conservation in urban areas; ecological dimensions; compact human settlements and livable cities (Lawrence, 2000). However, Sodager and Fieldson (2008) argue that tackling environmental sustainability alone is not enough, as there is need for a holistic approach to address all three principles of sustainable development. The holistic approach suggested by Sodager and Fieldson (2008) relies on the collaboration of all stakeholders in the building industry to quantify and interpret emissions throughout the building lifecycle. They further addressed the following three questions:

- Why sustainable buildings are required?
- What defines a sustainable building?
- How they can be obtained?

'Sustainability', has various aspects. Amongst the dimensions are: the use of energy and its effect; resources and materials; water and its disposal; pollution; waste; health; well-being, and the effects of human actions on the biosphere and habitats (Banfill and Peacock, 2007). However, the one that has been continuously receiving attention, both internationally, and within UK, is the use of energy and its effect, due to the link with greenhouse gas emissions (CLG, 2007c; Banfill and Peacock, 2007). The definition of 'sustainability' has often been stretched in discussions on the theoretical and practical aspects of it. To make a house sustainable, it must exhibit a minimum of negative environmental impacts in terms of climate change (greenhouse effect); the quality of air, water, and soil, noise; the stock of non-renewable materials and bio-diversity.

In the UK, the term, 'sustainable housing,' emerged as a support alliance in the early 1970s. It was then characterised as an advocacy coalition due to the deep 'green' environmental values and beliefs, shared by members whose political activities focused on practical demonstration and life style choice. Sustainable homes were then seen as an extension of the members' deep values and government policy. However, by the 1990s, government and other mainstream institutions became interested in sustainable housing as a solution to a range of policy problems (Baba *et al.*, 2012a).

In the broad literature on sustainable housing, 'sustainable' seems to refer to a wide range of concepts. However, it is about ecology and the environment, more than technology. It is also about social cohesion, community sustainability, citizen participation, and lifestyles. The term '*sustainable housing*' in its broadest sense, is to ensure a better quality of life, not just for now but also, for future generations. It should combine protection of the environment, sensible use of natural resources, economic growth, and social progress (Edwards and Turrent, 2005). This notion goes back to the 1990s, but until recently was simply regarded as a methodical or social construct useful in bringing together a heterogeneous set of policies (like the building regulations and planning policy) that directly or indirectly (energy policy and fuel poverty) affect housing sustainability. Sustainable housing is not a new term, as a small number of designers had actually embraced and designed it in the UK. The majority of the design (sustainable housing) is within the social housing sector (Figure 2.1) (Lovell, 2005).

In the last few years, there have been extensive developments in sustainable housing. Several publications have also addressed issues surrounding the term 'sustainable housing or low energy housing'. This ranges from how to build an individual Eco House (Roaf, 2001; Vale and Vale, 2002) to low energy community housing (eco village) like the Beddington village in London (Bio-Regional Development Group, 2007), built by Bill Dunster. Pamphlets had been produced as guidance from organisations, such as, Energy Saving Trust (EST) and Building Research Establishments, on how to achieve sustainable housing in the UK.

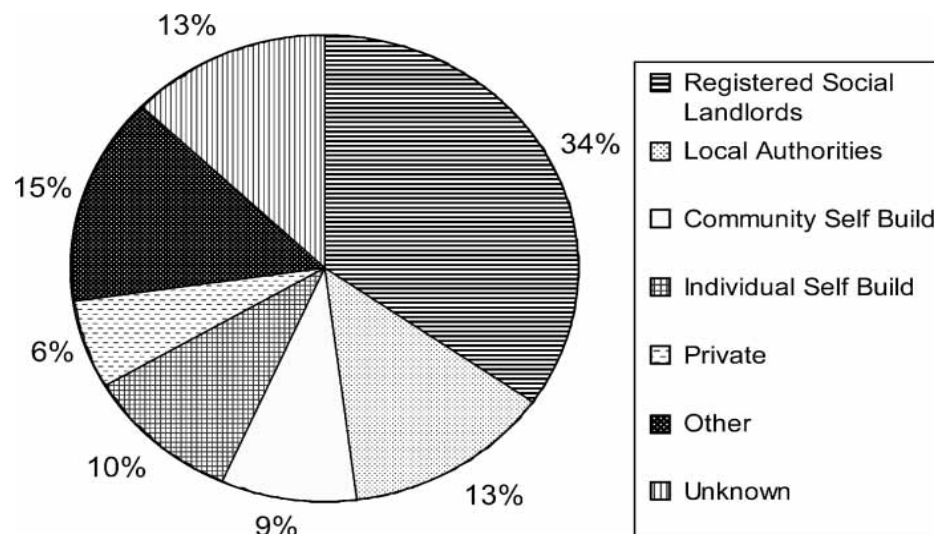


Figure 2.1: Initiators of UK low energy housing developments by housing sector

Source: Lovell (2005)

Exhibitions, seminars, and conferences, including Eco-build, also target various sustainability issues. The Royal Institute of British Architects (RIBA) contributes through holding exhibitions, working collaboratively with other stakeholders on sustainability issues, and most recently, the introduction of the Green Overlay to the RIBA Outline plan of work. The introduction of the CSH has also increased coverage of sustainable housing in the UK. It has continued to grow in popularity because the government, local authorities, private sector, media, and the public have all acknowledged the seriousness of sustainability, especially in relation to climate change.

2.2.2 Low Energy and Passive Housing Design

Low-energy housing is any type of house, which from design, technologies, and building products, uses less energy from any source, than a traditional or average contemporary house. The practice of sustainable design and architecture, low energy building, energy efficient landscaping and low-energy houses, often use active solar and passive solar building design techniques and components to reduce their energy expenditure (Feist, 2005). The meaning of the term '*low-energy house*' has changed over time. In Europe, it refers to a

house that uses around half of the German or Swiss low-energy standards for space heating. The annual heat requirement of low-energy houses (LEH) is below 70 kWh/(m²a) (Feist, 1997). The heat consumption of low-energy houses is thus at least 50% lower than required by the 1984 German Ordinance. Good thermal insulation, reduced thermal bridges, air tightness, low-energy glazing and mechanical ventilation are decisive features (Feist, 2007).

Low-energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration and heat recovery ventilation, to lower heating and cooling energy (Hansen and Knudstrup, 2005). It should be noted that national standards vary considerably around the world, and 'low-energy' developments in one country may not meet the 'normal practice' in another. Amongst these standards, the passive house concept is regarded as one of the more successful approaches (Hansen and Knudstrup, 2005); hence, many countries look towards Germany to learn how to achieve similar results (Gauzin-Müller, 2002).

Passive solar building design techniques or active solar technologies are also sometimes used, to achieve low energy buildings. The solar building designed homes may use hot water heat recycling technologies to recover heat from showers and dishwashers, while lighting and miscellaneous energy use is alleviated with fluorescent lighting and efficient appliances (Fosdick, 2012). Professor Bo Anderson suggested the idea of the passive house in 1987 (Hansen and Knudstrup, 2005). Since then, it has been further developed by Dr. Wolfgang Feist (Feist, 2010). A passive house (PH) is a building in which the heat requirement is so low that a separate heating system is not necessary and there is no loss of comfort; in Germany, this is the case if the annual heat requirement is below 15 kWh/(m²a). Through efficient electricity usage, the total end-use energy requirement inclusive of household electricity and domestic hot water is lower than 33 kWh/(m²a) (Feist, 1997).

Passive House principles do not set any demands or present any methods on how to ensure architectural quality in the buildings, and could, therefore, be

regarded as an engineering method (Hansen and Knudstrup, 2005). To achieve the design, the following guidelines are usually applied:

- Compact form and good insulation: All components of the exterior shell of the house are insulated to achieve a U-factor that does not exceed $0.15 \text{ W}/(\text{m}^2\text{K})$ ($0.026 \text{ Btu}/\text{h}/\text{ft}^2/^\circ\text{F}$) (Feist,1997);
- Southern orientation and shade considerations: Passive use of solar energy is a significant factor in passive house design (Hansen and Knudstrup, 2005);
- Energy-efficient window glazing and frames: Windows (glazing and frames, combined) should have U factors not exceeding $0.80 \text{ W}/(\text{m}^2\text{K})$ ($0.14 \text{ Btu}/\text{h}/\text{ft}^2/^\circ\text{F}$), with solar heat-gain coefficients around 50 per cent (Feist,2005);
- Building envelope air-tightness: Air leakage through unsealed joints must be less than 0.6 times the house volume per hour (Hansen and Knudstrup, 2005);
- Passive preheating of fresh air: Fresh air may be brought into the house through underground ducts that exchange heat with the soil. This preheats fresh air to a temperature above 5°C (41°F), even on cold winter days (O'Keefe, *et al.* 2010).
- Highly efficient heat recovery from exhaust air using an air-to-air heat exchanger: Most of the perceptible heat in the exhaust air is transferred to the incoming fresh air (heat recovery greater than 80per cent) (Hansen and Knudstrup, 2005);
- Hot water supply using regenerative energy sources: Solar collectors or heat pumps provide energy for hot water (Hansen and Knudstrup, 2005);
- Energy-saving household appliances: Low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc. are indispensable in a passive house (Hansen and Knudstrup, 2005).

2.2.3 Low Carbon Housing and Barriers to its Design in UK

The Carbon Trust define a low carbon building as one that uses significantly less energy and emits less carbon than current industry benchmarks while providing a comfortable and productive space. However, it is generally perceived across the industry that a ‘low carbon building’ is one that achieves an Energy Performance Certificate rating of ‘A’ or a BREEAM rating of Excellent (Morant, 2012). Low carbon building (LCB) is used by various literatures to cover the whole suite of new and future buildings that have low carbon footprints, and specifically designed and engineered with the intention to reduce CO₂. This, according to Williams (2007), is a building that emits significantly less CO₂ than conventional buildings over their lifetime.

The various technologies for LCBs will play a major factor towards achieving Government targets for new domestic homes from 2016 to 2050. Roaf *et al.*, (2004) identified the potential role of the LCBs technologies and construction in the built environment towards reduction of energy use in modern society. The technologies and construction will invariably contribute positively and clearly to the climate change agenda (Roaf *et al.*, 2004), outlined in Section 2.1. Goodbun (2008) argues that most of what is packaged and discussed within construction as being sustainable practices is actually just carbon emission reduction. Although, the development of a wide range of low carbon technologies, materials and processes is essential to secure our future, on their own they can only, at best, delay the onset of climate change (Goodbun, 2008).

Thus, low carbon housing derived from definitions of *sustainable housing*; *low energy housing*; and *low carbon buildings*, can be referred to as dwelling (house or flat) or housing development whose energy consumption is at a level below that demanded by the current building standards. It can also be defined as housing developments which exceed the current UK energy building regulations by incorporating one or more of the following features:

- Renewable energy technologies;
- Thermally efficient built form; and
- Passive low energy design.

For the purpose of this study, low carbon housing in the UK as a ‘*catch all*’ term refers to homes built in the last five to six years to higher standards of energy efficiency than that required by the applicable building regulations. These include those built to Levels 3, 4, and 5 of the Code for Sustainable Homes (CSH).

Nevertheless, there are barriers to the design and delivery of low carbon housing in the UK. Many studies and articles on policy measures have discussed barriers to energy efficiency, either to illustrate the need for policy measures or to explain why the tools are not as successful as expected. The number of barriers are substantial and higher in the building sector than any other sector (Ürge-Vorsatz and Koeppel, 2007). Barriers such as: economic/financial barriers; hidden costs and benefits; market failures; behavioral and organisational constraints, political and structural barriers and information barriers were recognised in Urge-Vorsatz and Koeppel (2007), while those to sustainable housing design were emphasised in Hakkinen and Belloni (2011). Adeyeye *et al.*, (2007), nevertheless, documented barriers to the integrated low energy architectural design process.

However, the barriers to adoption of LCH design methods , which this study is addressing is in the fact that existing decision support tools had not addressed in full the expectation of architects. Design-decision support tools, specifically the Building Performance Energy Simulation (BPES) are not fully integrated into the design process, to enable UK architects to make informed decision especially at the early stage of the design process. This is due to lack of fitness of the tools with the stages of the design process. Thus, there is the need for tools that provide better decision support for architects at various stages of the design process. The tools should be able to integrate with information typically available for each stage of the design process.

2.2.4 Rationale for Low-Carbon Housing Design

The imperative of climate change signifies that building technologies need to develop in order to meet the demands of climate change predictions, while

simultaneously reducing the contribution they make to CO₂ emissions. Housing plays a significant part in the UK's emissions (CLG, 2007b). The Department for Environment, Food and Rural Affairs (DEFRA, 2005) further confirm how housing is responsible for over a quarter (28 per cent equivalent to around 150 million tonnes of carbon a year) of the UK's CO₂ emissions. These are attributed to heating, lighting, and the running of domestic buildings, which include almost three-quarters of space and water heating, discussed in Section 2.1. Appliances and lighting account for around 22 per cent of the domestic emissions (Seyfang, 2008).

All these contribute to increase in carbon emissions from the housing sector; thus, there is need for a rethink in the way we build, design, and power our homes (CLG, 2007a). The following include the social, economic and environmental rationale for low carbon housing design in the UK.

- Energy prices have raised dramatically in recent years, with average UK household gas bills rising by 109 per cent and electricity bills by 70 per cent, between January 2003 and March 2008. The average annual household fuel bills amount to £1060, resulting in a rise in fuel poverty. Energy-related indebtedness (measured in terms of consumers owing more than £600 on their utility bills) had also risen sharply in line with these increases. Between 2004 and 2007, it rose by 64 per cent for electricity consumers and by 19 per cent for gas customers (Energywatch, 2008).
- Water supplies have been stressed, particularly in south-eastern England. This is due to high population density, high levels of water use, increase in households and low rainfall. Thus, across the UK, water and sewerage prices have risen accordingly above-inflation levels (Seyfang, 2008). Applying the language of carbon neutrality, the UK government is implementing measures to promote 'water neutrality' in areas of new development to offset the water resource impacts of building new housing, with water conservation efforts such as rainwater harvesting, water conservation and metering. The aim is that the total water demand will remain unchanged after the development (Environment Agency, 2008).

- Projections for the future indicate these trends will worsen. Climate change is expected to bring more periods of extreme hot weather in summer, with peak summer temperatures up to 7° C higher by the 2080s than today (Seyfang, 2008). Further, in the summer 2003, during the European heat wave, temperatures reached 38° C in the UK for the first time; this would become the norm (Hulme *et al.*, 2002). Based on these changing conditions, the buildings we live and work in may not be able to cope with extreme high temperatures in the summer. A modelling study found that in traditional 19th century terraced houses, and 1960s-built houses, the reduced need for heating over the next 80 years will be offset by increased energy use for air conditioning, resulting in overall increases in emissions of 30- 40 per cent by the 2080s (Hacker *et al.*, 2005).
- All these calculations point to the need to retrofit existing buildings, and design new ones (Sodagar and Fieldson, 2008). In this way, there will be no need to rely on air conditioning to maintain thermal comfort, but rather draw on cooling socio-technologies traditionally employed in warmer climates, such as shading from the sun, thermal mass to stabilise temperature, passive heating and cooling systems and afternoon siestas (Hacker *et al.*, 2005; Seyfang, 2008).

2.2.5 Policy for Low Carbon Housing Design in the UK

The UK residential sector is to deliver 80 per cent reduction in carbon emissions by 2050 (Boardman *et al.* 2005; BRE, 2005; Boardman, 2007; EST, 2008; WWF, 2008; Reeves *et al.*, 2010). The reduction is vital due to the growing impact of climate change, which now presents a major challenge that requires some hard, but necessary, decisions to be made. The efficiency in the improvement of housing stock, according to the UK Government from 2016 to 2050 is to occur through altering the standard of existing stock, the quality of new- build and the relative proportions of each (Sodagar and Fieldson, 2008).

An important, but often overlooked, determinant of success in reducing greenhouse gases from building lies in the capacity of governments, and other

stakeholders in the building sector, to design and implement policies effectively (Sustainable Development Commission, 2007). Pickvance (2009) categorises sustainable housing policy measures into four main types: domestic energy saving measures; sustainability rating scheme; building regulations and planning policy.

The following are some current policies from the DCLG (CLG, 2007a; CLG, 2007b) reports, with targets to increase the quality of new housing in the UK:

- Construction rates should be on the increase to replace the demolished homes and to meet the rise in demand for housing due to growing population;
- New Builds should make up a third of the housing stock by 2050;
- The New Builds construction should be equivalent to average construction rate of 220 000 per annum; and
- The new homes are to be built to a very high-energy efficient standard with an average net heating demand of 3000kWh pa in all new dwellings from 2020.

2.3 Information for Low Carbon Housing Design

2.3.1 Housing Policies and Regulations

Energy consumption and efficiency discussed in section 2.1 has come to play an important factor in preventing carbon emissions rising any higher in the UK. Some researchers (Gaterell and McEvoy, 2005; Sayce, 2007; Adeyeye *et al.*, 2007; Urge-Vorsatz and Koeppl, 2007) observed how policy makers, both at the international level and within UK, acknowledged the urgent need to adopt energy efficiency measures and practices in response to the general climate change, energy security, and energy poverty issues. The policies and priorities for action, both in the UK and at international level, is to reduce emissions of the greenhouse gases to 12.5 per cent below 1990 levels (CLG, 2007a). This has been recognised from the UN Rio de Janeiro Earth Summit in 1992 to UN Kyoto Earth Summit (1997) and the Copenhagen summit in December 2009.

The government's policy on energy efficiency for new homes in the UK (Table 2.2) being the main target for reducing carbon emission, was compiled by Ko and Fenner (2008). Of importance in Table 2.1, is the building regulation, Part L1A and Code for Sustainable Homes (CSH).

Table 2.2: UK Government Policy Framework on Energy Efficiency in New Homes

Policies	Plans	Programmes
Climate Change Bill 2008(draft 13 March 2007)	Building A Greener Future: Towards Zero Carbon	Building Regulations, Part L1A 2006 Code for Sustainable Homes
Energy White Paper 2007 Pre-Budget Report 2006	Development (December 2006 consultation paper)	Government funding for social housing and developers only if they meet CSH level 3 or better. New houses by English Partnerships to comply with CSH level 3 or better
Climate Change and Sustainable	Climate Change Programme (revised in 2006)	
Energy Act 2006	Energy Efficiency: The Government's Plan for Action 2004	Energy Efficiency Commitment 2 (2005–2008), succeeded by Carbon Emissions Reduction
EU Energy Performance of Buildings Directive 2002	Sustainable Communities Plan 2003	Target Energy Efficiency Commitment (2008–2011) for electricity and gas suppliers (usually relates to energy efficiency in existing houses)
Housing Act 2004		
Electricity Act 1989		Energy performance certificates and housing information packs
Gas Act 1986		Improved metering and billing information for homeowner. In 2008–2010, free real-time electricity displays for homeowners who request one
		Energy Saving Trust product endorsement (energy labels) and building design information Low Carbon Buildings Programme (funding for energy supply technologies but has energy efficiency requirements)
		Stamp duty land tax exemption for zero-carbon homes
		Reduced VAT rate of 5per cent for energy-saving materials like insulation, draught stripping, hot water and central heating controls
		Research and dialogue programmes including Carbon vision programme (buildings) and Foresight (sustainable energy management and the built environment)

Source: Ko and Fenner (2008)

The various policies, plans, and programmes are having a slow uptake and seem not to be sufficient in taking UK on the trajectory towards the 2016 target for all new homes (Adeyeye *et al.*, 2007; Osmani and O'Reilly, 2009). Bell and Lowe (2000) present a critique of the energy efficiency aspects of the building regulations for England and Wales, as related to dwellings. It is argued that a significant improvement in the regulations is required if large reductions in CO₂ emissions are to be achieved with almost ninety per cent reductions in space heating (Bell and Lowe, 2000). Regulatory systems for the building sector vary between countries (Gann *et al.*, 1998), and there appears to be increasing international convergence in the approach to regulation, with a strong emerging preference for 'performance' rather than 'prescriptive' regulations. Building regulations usually shape the architectural form, which many architects see as a set of rules to be adhered to (Gann *et al.*, 1998). They are usually seen as ephemeral, even incidental, to the creative process of design (Fischer and Guy, 2009). Building regulations are entwined with, and are constitutive of architects' practices; they influence aspects of creative practice and processes in architecture and, as such, ought to be given greater attention (Fischer and Guy, 2009).

Drawing on survey and interview data, Imrie and Street (2009) described and evaluated architects' understanding of, and responses to, what they perceive to be increased exposure to risk and its regulation in the design process. Gann *et al.*, (1998) and Imrie (2007) further conducted studies on the impact of regulation on the work of architects in terms of stifling or encouraging design creativity. They conclusively agreed, along with other researchers (Raman and Shove, 2000; Imrie and Street, 2009), that there is a gap on the wider impact of changing regulation on the working practices of design professionals.

A typical example of this impact can be cited from the major earthquake that happened in central China, in May 2008. It led to an estimated of 5.36 million buildings collapsing, a further 21 million damaged and estimated deaths that exceeded 70 000 people (United States Geological Survey, 2008; Imrie and Street, 2009). The event was attributed, in part, to the inadequacy of the region's building codes and construction practices and, in particular, to the absence of a uniform code for quake-resistant public buildings, the use of

cheap materials and the lack of enforcement of the building regulations (Chan, 2008; Lee, 2008; Imrie and Street, 2009).

There is plethora of regulations stemming from external sources relating to building form and performance and, seemingly, much emphasis on risk identification and its management, particularly in relation to the processes underpinning the development and delivery of building projects. In past years, there has been an expansion in the number of building regulations and a much greater emphasis on health and safety procedures. In 1999, the UK health and safety executive introduced the Construction and Design Management regulations (CDM) to identify hazards, reduce risk, save lives and eliminate injury. An extension to CDM regulations in April 2007 further requires architects to consider the safety of buildings' end-users and make clients responsible for appointing a dedicated CDM co-coordinator (United States Geological Survey, 2008; Imrie and Street, 2009). Consequently, an implication of the CDM and the introduction of other regulations has become a responsibility placed on professionals, such as architects, to manage and reduce risk in the design and construction process.

2.3.2 Building Regulations, Part L1A

The UK building regulations are the statutory instruments that seek to ensure that the policies set out in the Building Act 1984 are carried out in the design and construction of buildings. Over the last few years in England and Wales, the building regulations have raised the standard of new build homes, with the thermal efficiency of new homes being considerably higher than the average UK housing stock (Sustainable Development Commission, 2007).

It involves a consultative process led by the DCLG building regulations advisory committee, which has a large membership that includes the main industry and professional groups. It consists of 14 sections, each with an accompanied approved document. The different sections are usually revised on a cyclical basis every 3-5 years. The revision is a slow process and usually takes about 4 years, as it involves both informal and formal consultations,

regulatory impact assessment, and consultation on proposal (HM Government, 2010)

Part L (Consumption of fuel and power) of the building regulations regulates energy efficiency of buildings. It has undergone regular revision, including further strengthening in 2010, to make new homes more thermally efficient. Currently, the minimum standards for new housing, acknowledged through Part L, ‘Conservation of fuel and Power’, is split into four parts with effectiveness since 1st, October 2010. The four parts are: Part L1a for new dwellings, Part L1b for existing dwellings, Part L2a for new buildings other than dwellings and Part L2b for existing buildings other than dwellings (CLG, 2010). Table 2.3 summarises the main legislation in the history of British building regulations; the rationale for the regulations, such as Part L, aimed at conserving fuel and power, has changed over time. The current version of building regulations, Part L1a (2010) at the time of writing this thesis, has some key changes in its design standards over the 2006 version.

Table 2.3: Major developments in British building control legislation

Date	Regulation	Scope
1845	Public Health Act	First legislation to cover structure, dampness, sanitation, fire, light and ventilation in housing.
1877	Model Bylaws	First minimum standard housing guidelines for local authorities.
1952	Model Bylaws Series IV	Mandatory standards of performance and universal adoption.
1965	Building Regulations	First comprehensive set of regulations for England and Wales.
1981	White Paper on future of building control	First major shift from prescriptive to performance-based approach.
1984	Building Act	New regulatory structure containing schedules and procedures.
1991	Building Regulations Revision	Includes Approved Document L as a performance-based standard.

Source: Gang *et al.*, (1998)

Raman and Shove (2000) followed the processes of revising Part L of the building regulations. They observed an increasing blurring of boundaries between business practice and regulation, due to both government's decision to open up the process to private regulators and to the building industry's ability to influence the policy-making process. The shift towards a performance-based building code should pave way towards new forms of government and industry interaction (Raman and Shove, 2000).

Todd *et al.*, (2001) further reviewed the proposals for amending the energy efficiency provisions in the building regulations for dwellings. They identified the main requirements and changes in the building regulations Part L1a (2006) for new dwellings, along with the implications for designers and other professionals who will be involved with compliance issues. To support their argument, Todd *et al.*, (2001) provide guidance on how compliance might be achieved. They concluded that the changes would make new dwellings twenty per cent more efficient than the current practice achieves.

2.3.3 Code for Sustainable Homes

In the United Kingdom (UK), the standard used over the past years before 2007 for assessment of the environmental performance of grant-funded affordable housing was the Eco-Homes, now replaced by the Code for Sustainable Homes (CSH). McManus *et al.*, (2010) declare CSH as the most important policy currently used to combat the issue of environmental standard and performance. The CSH is especially significant to the social housing sector because of their obligation to comply with the standard to produce a considerable increase in the sustainability quality of housing delivery in the UK (McManus *et al.*, 2010). According to the former Office of the Deputy Prime Minister (ODPM), the CSH, if put in place, will secure the health and safety of building users. It will also promote energy efficiency and make access easier for disabled people (Beadle, 2008).

The CSH is important in this study, because, it is the most current and national standard for sustainable design and construction of new homes in the UK. It has the aim to reduce carbon emissions and create homes that are more

sustainable. It applies in England, Wales, and Northern Ireland. Launched in December 2006, the CSH became operational in April 2007 and mandatory since 1st, May 2008, (Figure 2.3) for the public sector, such as the social housing developments and housing schemes funded by the Home and Community Agency (HCA).

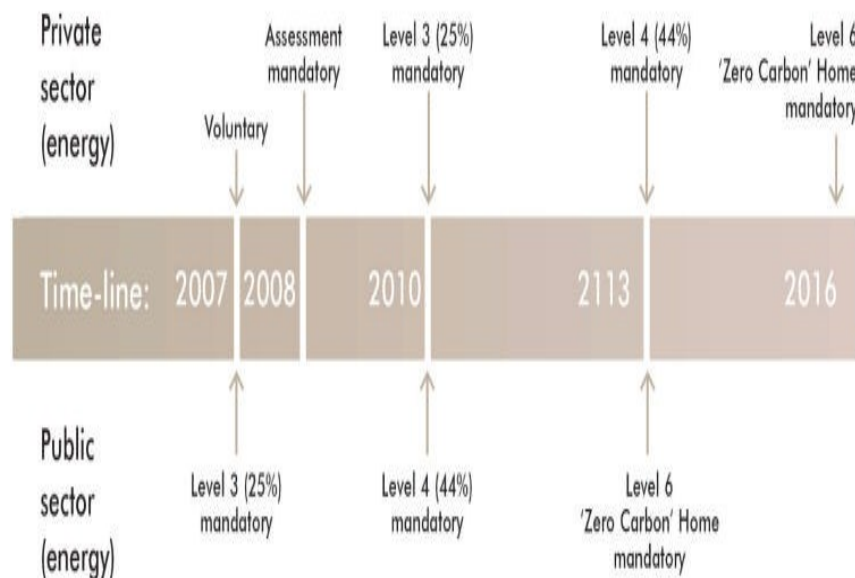


Figure 2.2: Code for Sustainable Homes

Source: (CLG, 2006)

It is reviewed every three years to align with Part L of the applicable building regulations. The current building regulation has been in use since October 2010, hence the next change to CSH will be October 2013, towards the original 2016 zero targets for all new homes in the UK. The CSH realises that as important as climate change is, housing causes other environmental problems. As such, it considers a number of different aspects in the design of new homes in the UK. It is supposed to make house building design and construction more sustainable, along with ensuring better quality housing for the future (Sustain, 2010).

The assessment of the CSH looks at nine categories, which are: Energy efficiency/ CO₂ emissions; Water efficiency; Surface water run-off; Waste; Materials; Pollution; Health and well-being; Management and Ecology (CLG, 2006). In each of these categories, the CSH looks to improve building

regulations where applicable, such as energy use to raise the standard of house building and reduce the impact of the dwelling on the environment. Other areas include improving waste management and using more sustainable construction materials. Each category has a number of issues to be assessed; each of the issues has specific assessment criteria, which must be met for credits to be awarded.

As emphasised by McManus *et al.*, (2010), the UK housing sector is dedicated to increase the number of social houses. The Department of Communities and Local Governments (DCLG) posit that the target is to provide three million more homes in England by 2020. Consequently, there arise demands for sustainable practices for new housing design in the UK to have the rating between Level 3 to Level 6 of the CSH.

2.3.3.1 CSH Implementation and Barriers towards ZERO Carbon Homes in UK

The CSH exceeds other international housing standards, such as the ‘R-2000’ in Canada and ‘PassivHaus’ in Germany, because it specifies that any domestic energy required must be generated by renewable sources in order to achieve a (Level 6) zero carbon home (Osmani and O’Reilly, 2009). This is because zero carbon homes targets, although not obtainable across board by the year 2016, has its maximum energy usage level surpassing that of PassivHaus standard, which is 15Kwh/m² per year for space heating and cooling. As such, when combined with other categories requirement of the CSH, such as waste, water usage and materials, the CSH can become one of the most challenging and demanding international housing standards (Osmani and O’Reilly, 2009).

It takes approximately 18-24 months to design and build a CSH (Baba *et al.*, 2012a). As a result, the first homes built to the Code standard were not awarded certificates until 2008 (CLG, 2011). Since then, there has been a steady increase in the number of new homes and certificates awarded (Table 2. 4). Code certificates are issued at two stages, the design stage (DSC) (early in the design and build process) and post construction stage certificate (PCSC), when the home is completed or nearing completion (Baba *et al.*, 2012a).

Table 2.4: Design of new houses to various level of the Code for Sustainable Homes

Source	Period	DSC	PCSC	Levels	Notes
CLG (2010)	April 2007 to June 2010	24,186	7,148	Level 3	10 per cent of homes with post construction certificates and 22 per cent of those with design stage certificates have been built by the private sector. 90 per cent of homes with post construction certificates and 78 per cent of those with design stage certificates have been built for the public sector. A total of 89 per cent of the certificates at design stage and 90 per cent of those at post-construction stage have been awarded at Code level 3 since April 2007.
		2656	828	Level 4 and 5	
		287	8	Level 6	
		27,129	7984	Total	
Horwitch-Smith (2011)	September 2010	Over 31,000	Over 11,000	Level 3	
		287	19	Level 6)	
CLG (2011)	April 2007 to September 2011	68,944	37913	Level 3	78per cent Design Stage Assessments for Social/Affordable Housing and 22per cent Private Housing for sale/rent The majority of the certificates issued since April 2007 at design stage (80 per cent) and at post construction stage (88 per cent) have been awarded at three star rating)
		17386	5091	Levels 4 and 5	
		329	34	Level 6	
		86,659	43038	Total	
CLG (2012)	April 2007 to March, 2012	86878	54976	Level 3	16per cent were built for the private sector and 84per cent for the public sector and 72per cent of those with design stage have been built for the public sector. Of the total number of Code level 6 homes at Design Stage, up to the end of March 2012, 60per cent were built by the private sector and 40per cent for the public sector. At Post Construction Stage, 8per cent were built by the private sector and 92per cent for the public sector. Majority of certificate issued since April 2007 at design stage (77per cent) and post construction stage (85per cent) have been awarded a three star rating.
		26004	9544	Level 4 and 5	
		354	142	Level 6	
		113236	64662	Total	

Source: CLG (2010; 2011; 2012); Horwitch-Smith (2011)

In relation to the zero carbon new homes target for 2016, the Core Strategy supporting technical paper posits that the most significant of the new regulations are the phased changes to Building Regulations designed to

implement 'zero carbon' homes by 2016 (Babergh District Council, 2011). Hence, the new concept of zero carbon is likely to impose a cap on the CO₂ emissions that can be emitted on site (carbon compliance) and an array of methodologies to reduce residual emissions (allowable solutions) (Babergh District Council, 2011). In actual fact, it is quite difficult to find a building that can be called the first Zero Energy/Emission Building (ZEB) (Marszal and Heiselberg, 2009). One reason could be that, ZEB is not a new concept for a building, but just a modern name for buildings before district heating and electricity came into being.

Osmani and O'Reilly (2009) investigated the feasibility of building zero carbon homes in UK and discovered a number of cultural, legislative, financial and technical barriers that stand in the way of the widespread zero carbon homes (level 6) by 2016. A consensus was reached to call for a joined up, holistic approach to the zero carbon targets. Nevertheless, the aim of CSH remains the same; to encourage a continuous improvement in sustainable home building.

Goodbun (2008) argues that there exists a lack of informed discussion around new policy, like the CSH. McManus *et al.*, (2010) evaluated the current situation, with a preliminary analysis of how the CSH may not be able to deliver its sustainable energy goals, due to the ways in which 'low and zero carbon technologies' are assessed and how they behave in real world situations. This was confirmed by Osmani and O'Reilly (2009) who argue that a high proportion of the existing information on CSH and its use are policy related, with sets of targets and lack of practical guidance on how to achieve the high level of the CSH rating. The challenges facing the construction industry to meet the requirements of the CSH and other standards introduced by UK government to reduce carbon emissions of buildings were further outlined, by Sodager and Fieldson (2008). They maintained tackling environmental sustainability alone is not enough; there is the need for a holistic approach to address the three principles of sustainable development.

2.3.3.2 Code for Sustainable Homes explained

So, why is the CSH needed if several assessments contributing to sustainable housing exist? At inception, the only difference was that higher levels of CSH applied to homes developed with direct funding support from any of the DCLG's growth areas. The significance lies in the aim of seeing the voluntary application of the CSH changed to a mandatory application for all new housing. Forbes (2007) states, the expectations were for local government to provide encouragement in this area.

Since 2010, Code Level 3 had become mandatory for public and private sector new-build residences, including flats and houses. This effectively made the use of code levels 1 and 2 redundant. The minimum standards are relatively modest, producing and implementing a site waste management plan to record materials used in the construction and to reduce water consumption by an average of eighteen per cent. However, the other three of the six minimum standards are already controlled by the building regulations. The CSH, however, does not raise standards in any real way above that of minimum compliance with current standards of energy efficiency, surface water disposal, or household waste management. The energy performance requirements in building regulations (2010) has been made equivalent to the existing Code Levels 3. The change to energy performance requirements will still be updated in 2013 and 2016 to meet code Level 4 and 5 respectively. Introducing new standards at a relatively low level has proved successful in raising standards in the medium term. It has also been used to increase the standards of energy efficiency demanded by the building regulations Part L and by the Housing Corporation to increase standards of sustainability to Eco-homes 'Very Good'.

CSH has two main advances over its predecessor 'the Eco-homes'. The first is the number of elements that are essential for compliance; whereas, it is possible to obtain an Eco-homes assessment without addressing the fundamental issues of energy or water efficiency. The second advance of the CSH is that it is assessed after completion, unlike Eco-homes, which only includes an option for a post completion assessment and, is generally awarded

on a design, which may or may not be amended during development and construction (Forbes, 2007).

Whilst the CSH builds on the framework already established by Eco-Homes, there are a number of key changes to how the assessment operates, and the options available to achieve a particular rating. The main difference between Eco-Homes and the CSH is in Table 2.5. The CSH is supposed to be better suited for delivering targeted reductions in CO₂ emissions and water use than Eco-Homes, but provides less flexibility (Forbes, 2007).

Table 2.5: Advantage of CSH over Eco-Homes

Eco-Homes	Code for Sustainable Homes	Comments
Overall rating built up from various elements (like location, ecology and amenities), to comprise total score	Rating built up from various building features (not location), each with a minimum threshold, to comprise total	Significant changes: (1) focus on building only – cannot ‘get away’ with a poor building in a great location (2) limited transfer between elements, so that poor features cannot be rescued by good performance in other areas
Covers new-build and refurbishment (Eco-Homes XB)	Initially covers new-build Only. Refurbishment to follow.	Initial change for new-build housing only
4 levels of compliance – ‘Pass’ to ‘Excellent’	6 levels of compliance, with minimum standards for 5 key issues	Classification change – Eco Homes ‘Very Good’ to be broadly similar to CSH Level 3
Overseen by BRE, with licensed assessors	Overseen by BRE, with licensed assessors	No change, but assessors to receive additional training. Concerns over the availability of assessors.

Source: Forbes (2007)

The main driver behind the CSH was the requirement of the Homes and Communities Agency (HCA) for all their funded projects to meet the level 3 as at 2010 and Level 4 from April 2010. The HCA is a merger of the former English Partnerships and Housing Corporation. Each of these former agencies published their own CSH guidance and until the HCA board issues its own direction, both of those guides remain valid. As such, former English

Partnerships sites require Code Level 4 from April 2010, under the National Affordable Housing Programme, while the HCA requires Code Level 4 from April 2011 as set out in the Housing Corporations Design and Quality Strategy.

2.3.4 Green Guide to Specification

The Green Guide to Specification provides designers with an easy-to-use guidance on how to make the best environmental choices when selecting construction materials and components. In the Green Guide, materials and components are assessed in terms of their environmental impacts, within comparable specifications, across their entire life cycles (Anderson *et al.*, 2009). This accessible and reliable information will help all those involved in the design, construction, and management of buildings to reduce the environmental impacts of their properties.

- **Functions of the Green Guide**

Environmental rankings: The guide presents information on the environmental impacts of building elements and specifications by ranking them on an A+ to E rating scale. These environmental rankings are based on life cycle assessment (LCA) using the green guide environmental profiles methodology. These are generic rankings that illustrate a range of typical materials; they can be used based on the building types or elements. (<http://www.bre.co.uk/greenguide>)

Building types: The guide examines the relative environmental impact of the construction materials commonly used in six generic building types, which are: commercial (offices); educational; healthcare; retail; domestic and industrial. They cover over 2000 specifications (<http://www.bre.co.uk/greenguide/>)

Building elements: Materials and components are arranged on a building element basis so that one can compare and select from comparable systems or materials as specification is being compiled. The elements covered are:

external walls; internal walls and partitions; roofs; ground floors; upper floors; floor finishes; windows; insulation and landscaping. This extensive catalogue is continually being updated with specifications covering the most common building materials (Anderson *et al.*, 2009).

In the Green Guide online (<http://www.bre.co.uk/>), building materials and components are assessed in terms of their environmental impact across their entire life cycle from 'cradle to grave', within comparable specifications. This accessible and reliable information will be of great assistance to all those involved in the design, construction and management of buildings, as they work to reduce the environmental impact of their properties.

2.4 Environmental Guidance

With the rising interest and demand from policy makers to achieve a sustainable society, the need for environmentally related information increases (Forsberga and Von Malmborgc, 2004). There has been extensive development of building environmental assessment methods since the 1990s. Many have subsequently gained considerable success, especially after the launch of Building Research Establishment Assessment Method (BREEAM) in the UK (which was the first real attempt), followed by other schemes such as Sustainable Building Tool (SBTool), Leadership in Energy and Environmental Design (LEED) and Comprehensive Assessment System for Building Environment Efficiency (CASBE) (Alyami and Rezgui, 2012). Many other assessment methods have also been developed around the world to undertake environmental building assessment.

International Energy Agency (IEA, 2001) summarised the old and new environmental building assessment methods used in different countries. Almost all the environmental assessment methods have been designed to suit a specific territory (Alyami and Rezgui, 2012). Some researchers (Cole, 1998; Crawley and Aho, 1999) had also suggested that the existing environmental assessment methods were developed for different, local purposes, though are not fully applicable to all regions (Alyami and Rezgui, 2012).

Consequently, there has been increasing interest in environmental assessment tools. Currently, there are a large number of these which focus on energy use in buildings. However, most of the tools are based on some form of life-cycle assessment database (Seo *et al.*, 2006). There had also been literature (Baumann and Cowell, 1999; Jonsson, 2000; Trusty, 2000; Todd *et al.*, 2001; Forsberga and Von Malmborgc, 2004; Lutzkendorf and Lorenz, 2006; Grace, 2006; Haapio and Viitaniemi, 2008) where the use of different tools had been compared. Hence, the focus in this section of the chapter is on the internationally building environmental assessment methods/framework/rating systems.

2.4.1 Environmental Assessment and Sustainable Buildings

The assessment tool typology, developed by the Athena Sustainable Materials Institute, classifies tools by end use (Trusty, 2000). However, environmental assessment tools from the International Energy Agency (IEA) (International Energy Agency, 2001) classify their own into five categories. These are:

- i. Energy modelling software.
- ii. Environmental Life Cycle Assessment (LCA) tools for buildings and building stock.
- iii. Environmental assessment frameworks and rating systems.
- iv. Environmental guidelines or checklists for design and management of buildings.
- v. Environmental product declarations, catalogues, reference information, certification, and labels.

Categories (iii) and (ii) were further categorised into qualitative tools (based on scores and criteria) and quantitative tools using a physical life cycle approach with quantitative input and output data on flows of matter and energy (Reijnders and Van Roekel, 1999; Forsberga and Von Malmborgc, 2004). In both groups, Reijnders and Van Roekel (1999) emphasised how there is a diverse variety of their concepts all over the world. Examples of widespread

and well-known qualitative tools at the international level include GB Tool, BREEAM, LEED and Eco-Profile (International Energy Agency, 2001).

Glavinich (2008) declared how rating systems differ in the order of reduction and in use of resources in the respective areas, without causing discomfort to the users of the space. This is to say that different rating systems may have similar categories, but can be quite diverse in their intent, criteria, emphasis and implementation. The ways categories are weighted, scaled and quantified in the various systems also differ, therefore, the same building may have two different ratings when judged by different systems.

Green building rating tools are also referred to (but not limited) as green building rating systems (Yudelson, 2008); building environmental assessment methods (Cole, 1998) and environmental assessment tools (Blom, 2006). They enhance the environmental awareness of building practices and provide a fundamental direction for the building industry to move toward environmental protection and the achievement of sustainability (Grace and Ding, 2008). They further provide a way of showing that a building has been successful in meeting an expected level of performance in various declared criteria. Their adoption and promotion has had a major contribution to creating market demand for green buildings and has significantly shifted the public's awareness and perceptions of what building quality is (Cole, 2005). This is confirmed by the increasing number of people demanding information on environmental aspects of buildings, such as whether or not a building is good for their health or if it fits into a sustainable society (Carlson and Lundgren, 2002).

Yudelson's (2008) definition of a typical green building in the US are those certified by a sustainable building rating such as, the Leadership in Energy and Environmental Design (LEED), developed by the US Green Building Council (USGBC) to establish a common standard of measurement. Yudelson (2008) emphasised that adhering to a standard is not the end of the process, but achieving some level of certification demonstrates that the project has attained the green measures set out by the standard.

Cole (1999) made the distinction between ‘green’ and ‘sustainable’ agendas and their implications for future development of building environmental assessment methods. He accentuated that this is essential in order to clarify the many roles and applications demanded of tools and the considerable practical overlap between the ‘green’ and ‘sustainable’ agendas, suggesting that they can indeed be reconciled within a single tool.

Fowler and Rauch (2007) look at rating systems with an emphasis on energy reduction, indoor air quality and the use of environmentally preferable products. They define a green/sustainable building rating system as a tool that examines the performance or expected performance of a ‘whole building.’ They further translate it as an overall assessment that allows for comparison against other buildings.

Lutzkendorf and Lorenz (2006) emphasised the shift from ‘green building’ to ‘sustainable building,’ and how it entails a number of great challenges and opportunities for the developers and users of planning and building assessment tools. The current assumption is that a new generation of building assessment tools are required to meet the current and forthcoming requirements associated with the description and assessment of each building’s contribution to sustainable development.

Existing design and assessment tools do not address the many economic, social and performance facets over the life span of a building, and do not provide building assessment results for all dimensions of sustainable development (Lutzkendorf and Lorenz, 2006). Table 2.6 presents three common qualitative green building rating tools. The developer, year of establishment, categories, and current versions are also listed. Globally, these tools have either been adapted to a specific country (the US LEED adapted for Canada, and Australian Green Star adapted for New Zealand and South Africa) or developed into a new tool, such as in the development of Green Star and SBAT influenced by BREEAM and LEED.

Table 2.6: Examples of existing green building rating tools

Name of rating tool	Developer, Year	Categories	Versions	Source
BREEAM	Building Research Establishment (BRE) in 1990	<ol style="list-style-type: none"> 1. Energy use 2. Transport 3. Water 4. Ecology 5. Land use 6. Materials 7. Pollution 8. Health and well-being 9. Management 	<ol style="list-style-type: none"> 1. Offices 2. Housing 3. Healthcare 4. Courts 5. Industrial Units 6. Prisons 7. Retail 8. Schools 9. Multi residential 10. Neighbourhoods 	http://www.breem.org
LEED	United States Green Building Council (USGBC) in 1993	<ol style="list-style-type: none"> 1. Energy and atmosphere 2. Water efficiency 3. Sustainable sites 4. Materials and resources 5. Indoor environmental quality (IEQ) 6. Innovation 	<ol style="list-style-type: none"> 1. Offices 2. Homes 3. Neighbourhood development 4. Retail 5. Healthcare 6. Schools 	http://www.usgbc.org/LEED
GREEN STAR	Green Building Council of Australia (GBCAUS) in 2003	<ol style="list-style-type: none"> 1. Energy 2. Transport 3. Water 4. Ecology and use 5. Emissions 6. Materials 7. IEQ 8. Management, 9. Innovation 	<ol style="list-style-type: none"> 1. Offices 2. Retail 3. Schools 4. Industrial building) 5. Mixed-use residential 6. Mixed use 7. Healthcare 	http://www.gbcas.org

Source: IEA (2001); Todd *et al.* (2001)

A majority of the existing green building rating tools are voluntary in their application (Cole, 1999). They can be used to assess the performance of existing buildings or the design of new buildings (Cole, 1998). However, sustainability as shown in Table 2.7 in the building domain is currently judged by rating systems, while design choices are usually validated by measuring against one rating system or the other (Biswas and Krishnamurti, 2009).

Table 2.7: Rating system by assessment area

Assessment Area	LEED	GreenGlobes	SBTool
Energy and Atmosphere	Energy and Atmosphere	Energy	Energy and Resource
Emissions to the environment		Emissions	Environmental
Sustainable sites	Sustainable sites	Site	Site Selection and Economic Aspects
Water Efficiency	Water Efficiency	Water	
Indoor Air Quality	Indoor Air Quality	Indoor Environment	Indoor Environmental Quality
Quality of Service			Service Quality
Materials and Resources	Materials and Resources	Resources	
Culture and Heritage			Cultural and Perceptual Aspects

Source: Biswas and Krishnamurti (2009)

2.4.2 Environmental Tools at Local and National level

There are national codes or regulations such as, French Energy Code (ASHRAE) and code for Life Cycle Assessment (LCA). Others are: Hong Kong (HK-BEAM); Germany (ECO-PRO); Canada (BREEAM); Norway (ECOPROFILE); France (ESCALE); Sweden (ECO-EFFECT); Netherlands (ECO-QUANTUM);US (LEEDS) and UK (BREEAM) (International Energy Agency, 2001).

Several other countries, especially the western ones, have also developed tools to measure environmental and energy impacts of buildings. The most concerned countries are Canada, United States, France, Germany, Denmark,

United Kingdom, and the Netherlands. However, the review done in this section of the thesis on most of the tools is accessed from Survey of LCA Tools, Assessment Frameworks, Rating Systems, Technical Guidelines, Catalogues, Checklists and Certificates (International Energy Agency, 2001). Some of the tools are based on, or linked to relevant codes of the particular country by which most are voluntary in application and require no legal precedent to be enforced.

- **BREEAM (UK and other Countries)**

Separate environmental indicators were developed for the needs of relevant interest groups. However, the first real attempt to establish a comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings, was the Building Research Establishment Environmental Assessment Method (BREEAM) (Crawley and Aho, 1999). BREEAM was launched and operated by the Building Research Establishment (BRE) in the UK. It came into prominence in 1990 (Prior, 1993; Grace, 2000) and since then, many different tools have been launched around the world (Reijnders and Van Roekel, 1999; International Energy Agency, 2001).

BREEAM is the first environmental building assessment method that still remains the most widely used (Larsson, 1998). A certificate of the assessment result is awarded to individual building, based on a single rating scheme of fair, good, very good or excellent. The purpose of this system is to set a list of environmental criteria against which building performances are checked and evaluated. Johnson (1993) draws attention to the fact that the assessment can be carried out as early as at the initial stages of a project. The results of the investigation can then be fed into the design development stage of buildings, through which changes can then be made accordingly to satisfy pre-designed criteria.

Larson (1998) acknowledges the particular benefits of 'BREEAM'. He states that it can readily adapt to local regulation and conditions. It has since been taken as a reference model when similar schemes were developed in Canada, New Zealand, Norway, Singapore and Hong Kong; specific versions of BREEAM are available for the UK, the Gulf and Europe. BREEAM schemes

can also be tailored for use for any specific country or region, and usually addresses the following issues.

- Categories of environmental issues.
- Environmental weightings.
- Details of the construction methods.
- Products and materials.
- References to local codes, standards and good practice guide.

However, other guidance with their different region of application includes:

- LEEDS (US);
- Minnesota Sustainable Design Guide (United States);
- SPeAR (UK);
- LCA Tools - Escal (France);
- HQE Rating System (Performance Guidelines for Green Building in France);
- EcoPro (Germany);
- Ecoquatum (Netherlands);
- Ekoprofile (Norway); and
- E2000 (Switzerland)

2.5 Existing Guidance and Tools in the UK

2.5.1 Planning and Early Design Requirements

Some local planning authorities have started to impose environmental standards on development projects. This includes requirements that a minimum percentage of the energy demand of a building must be met from renewable energy sources (Royal Institute of British Architects, 2009a). Several tools are accepted by planning authorities to demonstrate compliance with planning

requirements. The tools are usually to make initial estimates of the carbon dioxide emissions from energy use in the proposed developments and to demonstrate the reductions that can be achieved through new/renewable energy systems. These types of tools work essentially by first considering the energy efficiency (i.e. reducing fuel demand), followed by shared energy supply (e.g. district heating or communal boilers), then finally by considering the renewable energy systems. The following tools and guidance compiled by the RIBA are used to demonstrate carbon performance at the planning application stage.

- **Integrating Renewable Energy into New Developments (Toolkit for Planners, Developers and Consultants 2004)**

This is a paper-based tool to assess the feasibility of renewable energy systems and to assist developers and design teams in achieving Mayor of London and related borough planning policies. Where developments require proof of feasibility of achieving renewable energy targets (e.g. 20 per cent carbon dioxide emissions reduction as a result of using renewable), this tool may be used to identify appropriate routes to that target.

- **Low Carbon Designer**

This is a software tool following on from the Toolkit above. It offers a sequential, prescribed procedure for showing planning authorities the low carbon features that have been considered as part of a design, and the output report is suitable for inclusion with an application for planning permission. This tool is also to facilitate detailed studies to substantiate environmental performance claims at the planning stage.

- **Standard Assessment Procedure (SAP) and NHER Software**

Good quality SAP energy rating software such as NHER Plan Assessor is another tool, often used to support planning submissions and demonstrate compliance with minimum renewable energy contribution requirements. The software can be used to estimate annual fuel use, fuel costs, and carbon dioxide emissions of conventional building services, and then to identify the most cost effective renewable energy technologies and assess their potential

contributions to the overall energy demand. SAP energy rating assessments can include bio-fuel boilers (including communal boilers) and room heaters, solar water heating, photovoltaic, heat pumps and micro-CHP, but not wind power.

All NHER software delivers the SAP energy rating. NHER Plan Assessor, incorporating SAP 2005, is particularly useful as a design tool for new housing, as well as for assessing Building Regulations (Part L1A and the devolved nations' equivalents) compliance, Eco Homes (energy credits) and Code for sustainable homes (CSH) compliance, as well as performance.

2.5.2 Building Regulations Compliance Tools

Building regulations compliance tools simulate the performance of a building to demonstrate that predicted carbon dioxide emissions are within the targets embodied in the building regulations. Such tools use data on the final design and specification of the building, including the building fabric and services to generate reports and performance certificates that form part of the application for approval of the design under the Building Regulations.

Building regulations compliance tools usually predict the annual carbon dioxide emissions associated with energy use in the proposed building and compare them with the emissions of a 'notional building' of similar size, shape and use, with a standard specification (Royal Institute of Architects, 2009a). The proposed building must perform better than the notional building by a set factor. Predictions are made using 'standard' occupancy conditions and common databases of building fabric elements and building services. These tools must be approved and, in many cases, the person carrying out the assessment must be accredited.

2.5.3 Tools for Sustainability in the UK

- **Domestic Energy Rating (DER)**

The most useful low carbon design tool for housing projects, for both new and existing dwellings in the UK is the domestic energy rating (DER) software. It is the UK world leader in domestic energy rating. There is a wide range of simple and relatively accurate performance simulation software which both fulfils regulatory requirements and works well as design tools (Royal Institute of British Architects, 2009a). All of the UK's domestic energy ratings are based on estimated annual fuel costs. Fuel costs are used because consumers of housing understand costs better than energy use or carbon dioxide emissions, and because the fuel costs associated with a dwelling are a good proxy for its primary energy use.

- **Sustainable Works**

This is another important tool for sustainable housing; hence low carbon housing design in the UK. It is an online application developed by the Housing Corporation in co-operation with BRE, NHF (National Housing Federation), WWF (World Wildlife Federation and housing associations. It aims to bring sustainable development into the mainstream of social housing, whilst it embodies Eco-Homes and incorporates the CSH and (HQIs). It was launched in July 2002 and has over 1000 registered users (Sustainability Works, 2002).

Sustainability Works covers the full breadth of issues essential to a sustainable approach to housing by bringing together current research and best practice. Unlike the code and checklist, it does not just set overarching targets for CO₂ emissions. It provides the background information and recommendations for achieving those targets. Sustainability Works is a web based application, designed to provide framework for:

- Writing policies for sustainable housing development and implementing sustainable strategies on individual projects;
- Developing briefs for sustainable housing developments and for bidding for land and finance;

- Assisting Local Authority planning and housing departments to establish standards and targets;
 - Facilitating communication with consultants during design development and construction; and
 - Preparing an Eco-Homes prediction for projects.
- **Design Quality Indicator (DQI)**

This is a tool supported by the UK Construction Industry Council. It is a toolkit used throughout the development process to capture the opinions of all stakeholders. It is especially used at preparatory stage and aims at improving the design of buildings by providing feedback and capturing perceptions of design quality embodied in buildings. It assesses buildings in three main categories: functionality, build quality, and impact. It aims at assisting clients in defining their aspirations to which project's success will be measured against (Clements-Croome, 2004; Cole, 2005). The DQI process establishes a firm platform from which stakeholders can agree common goals, interrogate designs, and demand excellence from suppliers. It is in this way that DQI can really help people work together to achieve the best building possible. The Design Quality Indicator empowers a building's community by providing them with a structured way to talk about their new building. By encouraging effective communication between suppliers and the eventual users of the building, the process helps to ensure that suppliers deliver excellent buildings that meet users' needs.

- **Envest for Housing**

Energy Saving Trust Housing programme presents 'Envest for Housing' to help the industry keep abreast of the impact of embodied CO₂. By inputting basic design numbers such as, height of building, number of storey, window area and so on, together with choice of materials, such as roof covering and external walls, the impact of each element can be seen. It helps the industry keep abreast of the impact of embodied CO₂. As buildings become more energy-efficient, the ratio of embodied CO₂ (the environmental impacts throughout the life cycle of a building) to lifetime consumption rises.

- **Best Practice House**

This is also from the EST. It makes the designer to see at a glance what the components of an energy efficient house look like. Whether it is a new build or refurbishment project, this tool helps to identify the measures that can be implemented.

- **Checklists and Good Practice Guides**

These are commonly used to identify design considerations that will influence the eventual performance of the development. They help to identify conflicts between a specific development brief and low carbon good practice. The Housing Energy Best Practice Programme, managed by the Energy Saving Trust, and has published a large number of other guides and case studies. These are:

i. Best Practice in New Housing: A Practical Guide (CE95, 2005), intended to help designers and builders achieve best practice standards of energy efficiency.

ii. Meeting the 10per cent Target for Renewable Energy in Housing: A Guide for Developers and Planners (CE190, 2006), which provides developers, planners and specifies with guidance on meeting a 10per cent target for the use of renewable energy sources on new housing developments.

iii. Building your own Energy Efficient House (CE123, 2005), this demonstrates how homes that exceed the requirements of Building Regulations, in terms of their energy efficiency, can be built cost-effectively.

iv. Building Energy Efficient Buildings using Modern Methods of Construction (CE139, 2005): This demonstrates that homes that exceed the requirements of Building Regulations in terms of their energy efficiency, and use modern methods, can be built cost-effectively.

v. Renewable Energy Sources for Homes in Urban Environments (CE69, 2004), a non-technical guide giving clear and concise information on the integration of renewable into new and existing dwellings within the overall context of designing energy efficient homes.

vi. Renewable Energy Sources for Homes in Rural Environments (CE70, 2004): provides advice on the options and opportunities for specifying renewable energy technologies for new and refurbished rural homes. Many other technical guides deal with the building fabric and windows, heating, hot water, ventilation, and lighting systems.

2.6 Summary

This chapter focused on climate change, energy use, and sustainable housing towards defining ‘*Low Carbon Housing in the UK*’. It reviews various literatures on existing statutory and non-statutory regulations relating to the design and its delivery. Based on this review, building regulations, Part L1a and CSH were identified as being necessary and at the same time having notable influence on major information needed by architects for the design and delivery.

The chapter further appraises the environmental building assessment guidance at the local and national level as well as existing UK guidelines and checklists from the Royal Institute of British Architects (RIBA) and the Energy Savings Trusts (EST) towards the design delivery.

Chapter Three: Design and Decision Delivery Tools

3 Introduction

The preferred statutory and non-statutory regulations, policies, standards and environmental guidance relating to design, and delivery of low carbon housing were discussed and established in Chapter Two. This chapter is focussed upon achieving the second part of objective 1; to review design and decision support tools for architects to deliver the design.

The chapter identifies the role of architects and recognises the necessary tools in the form of design tools (Sketch-up, CAD) and decision support, such as, Building Performance Energy Simulation (BPES) tools for architects to deliver the design. The content of the chapter is thus:

- The Role of Architects;
- Design Tools and Building Information Modelling;
- Decision Support and Building Performance Simulation (BPS) Tools;
- Building Performance Energy Simulation (BPES) Tools; and
- Summary.

3.1 The Role of Architects

3.1.1 Architects' Role in the Traditional Building Delivery Process

The presence of architects has been documented since the third millennium before Christ (Pagani, 1999). The architect as a conceiver of buildings and supplier of images for new structures has existed from the time that buildings of any substantial scale were erected (Kostoff, 1977). In Western culture, the practice of architecture developed into a distinct professional activity in the late eighteenth century but subsequently established itself more solidly because of the development of specialties in buildings. With increasing technical innovation in the early twentieth century, more specialisation was necessary and engineers developed areas of expertise in structural,

mechanical and electrical engineering. Although engineers designed some early modern buildings, the architect took on the role of coordinator of the engineering specialties. By the late twentieth century, as a result of even greater technical development, specialisation has expanded further to the point where a complex building can employ the skills of up to thirty specialist sub-consultants and receive input from up to twenty regulatory or stakeholder bodies (Cuff, 1992).

Thus, architects have largely retained their role as coordinators of these special sub-disciplines but the emergence of the project manager as the coordinator and leader of a project team is increasingly challenging the profession. Beyond the coordinator's role, the architect's contribution to the project has been reduced to that of a provider of aesthetics or 'form' (conceived of in a sculptural sense). The scope of the architect's role has further been eroded by the rise of the urban planner since the mid-nineteenth century (Benevolo, 1977), the interior designer since the late eighteenth century (Rybczynski, 1986) and the architectural technologist.

While this outcome may have been inevitable given the tendency of many architects to focus exclusively on the aesthetic aspects of design, it has led to the situation where the major concerns of the project manager (scope, quality, risk, budget and schedule) often become the sole driving force of the project delivery process (Pagani, 1999). Hence, the traditional role of the architect as a member of a 'profession', interested in and standing up for the common good, became largely subsumed by the narrow requirements of the client.

Consequently, concerns related to community well-being or environmental impacts were seldom or enthusiastically considered. This led to controlling mechanisms such as building codes, health-planning legislation, and environmental protection legislation, all designed to protect the public interest. The role of the architect as the representative of the public interest then declined drastically since the early part of the century (Pagani, 1999). Schon (1985) noted the crisis of confidence within the professions. He states that accelerating technological change required

unprecedented professional adaptability, coupled with simultaneously expansion of both the body of professional knowledge and the expectations of society. Subsequently, the task facing the professions became one of managing complexity (Schon, 1985).

3.1.2 Architects' Role in Low Carbon Housing Design and Delivery

Construction is a major contributor to carbon emissions in modern society (Roaf *et al.*, 2004). The construction industry as the major consumer of energy undeniably also contributes considerably to the greenhouse gas emission (Bordass *et al.*, 2004). Adeyeye *et al.*, (2007) emphasised, emissions from the construction industry can be minimised through the role of architects. This is because most of the construction technologies and techniques involved in energy conservation, or efficiency of domestic buildings, can best be achieved when incorporated by the architects from the onset of the design. Better building designs would indeed reduce energy consumption by 50-75 per cent below the 2000 levels (Adeyeye *et al.*, 2007).

Architects are key players in the construction industry, whose services are needed from the conception stage of a project to its final handing over (Oyedele and Tham, 2007). They have the major responsibility to get the message across in the participatory decision making processes (Chen *et al.*, 2008). Banfill and Peacock (2007) suggest that, for new housing to become progressively more energy efficient, leading to net zero-carbon dioxide emissions by year 2016, it will involve some technological changes that will also entail architects' design knowledge' on how to design such buildings. Chen *et al.*, (2008) and Elforgani and Rahmat (2010) argue that architects as the first and an important point of contact in design, are the most involved during the whole design process, and especially, those involving green buildings. This is because the major environmental impacts of a building are determined at the conceptual design phase, by which architects should be the most involved in the process.

Architectural practice in particular, can take a leading role in driving the sustainability agenda forward through client education and an innovative approach to ‘designing in’ sustainable solutions and technologies (Hill and Bowen, 1997). This is because time and finances dictate the design choices made in the initial stages of a project, and since these are effectively fixed and cannot be ‘revisited’ or changed, it is crucially important that the correct choices are made at the outset (Boddy *et al.*, 2007a).

However, architects are not generally passive recipients of rules and regulations, but are active in their interpretation and outcomes (Imrie, 2004). Adeyeye *et al.*, (2007) maintain that architects like to consult simple, accessible, and easy to use documents, which offer practical information that can immediately be applied to design, without the need for further interpretation or consultation. Lawson (2010) concurs with this, emphasising that architects do not like to read and are more likely to consult or seek information from something that gives a pictorial view or sketchy illustration of explanation.

The design of a building or group of buildings is a complex process (IPCC, 2007). When designing a building the architect will consider aesthetics, technology, sociology, geography, history, philosophy, law and psychology, often moving iteratively between the disciplines. The majority of technical design process occurs after the client has ‘signed off’ the design and planning permission has been granted for the project. Historically, energy intensive technological solutions would be used to ‘solve’ problems arising from lack of environmental considerations at the design stage, for instance over/under heating or lack of day lighting. With low carbon, the consideration of significant technical detail will be required at a very early stage to overcome these energy penalties. It is estimated that the architect makes approximately 80 per cent of the decisions that influence a building’s energy performance in the early design stage (Sved, 2009). Traditionally, rules of thumb and simplified calculations have been used to design environmentally friendly buildings. The implementation of more rigorous standards will require frequent, measured, quantitative analysis to determine if the design is

sufficiently low carbon. Software, such as building simulation tools will have a significant part to play in how designers assimilate, handle, visualise and design with the extra information required at early design stages to achieve these proposed standards.

3.1.3 Low Carbon Housing Design Principles for UK Architects

Zero carbon (discussed in Section 2.3.3.1) is difficult, if not impossible to achieve, however low carbon is more feasible. In the *Mitigation* report the IPCC conclude that a major impediment to the construction of low carbon buildings is the lack of awareness amongst construction personnel, including architects and engineers of energy-saving methods (Intergovernmental Panel on Climate Change, 2007). This supports the need for information rich and interpretive software. Nevertheless, the following are the six major ‘RIBA’ principles to design of low carbon buildings in the UK (Royal Institute of British Architects, 2009c):

- **Understand energy use in the building type**

This is very important for architects, as they need to understand the breakdown of energy use for the building type, which in this case is the new housing type in the UK. The pattern of energy use is very important not just on annual basis but particularly when renewable technologies are to be considered.

- **Use the form and fabric of the building to do the work**

Architects should use this to do as much work of the environmental modification as much as possible. It can also be used to minimise the demand on services such as heating and lighting, and to exploit useful solar and internal heat gains from people and equipment, etc. to satisfy as much as possible some of the heat demand, with exclusion of unwanted solar gains when they may lead to overheating.

- **Focus on insulation and air tightness**

Low carbon design should seek to reduce unwanted heat loss and gains by adopting appropriate standards of insulation and air tightness. In order to identify these appropriate standards, it is necessary to understand the heating and cooling balance of the building. The design of a dwelling by architects should generally be in such a way as to keep heat in, thus making use of the heat gains in comparison to that of the office design that focuses on keeping the building cool, especially in the summer. Other principles from RIBA (2009c) include:

- Use high efficiency building services with low carbon fuel;
- Use renewable energy systems; and
- Manage energy within the building.

3.2 Design tools and BIM

3.2.1 Computer based drafting and design tools

In the conceptual phase of a project, designers do many sketches by which the immediacy and flexibility of traditional media are preferred over the possibilities that computer tools offer (Hoeben and Jan Stappers, 2001). Hence, most designers still consider hand sketches on paper as the most effective way to represent the first draft of a future ‘User Interface’ (UI) (Coyette *et al.*, 2007a). Sketching consists of a widely practiced activity during the early design phases and, in general, for the user interface development, in order to convey informal specifications before implementation. Designers, as well as end users, have abilities to sketch parts or whole of the final user interface they want, while discussing the advantages and shortcomings (Coyette *et al.*, 2007b).

Sketchpad images can be regarded as the first drawing system that used explicit constraints, defined by the user, which allows lines to be constrained by relationships with other lines (perpendicular, parallel, etc.) to form the beginning of a design. However, there are now different types of computer-

based drafting and design tools being promoted by different companies for architects use. This section describes just a few out of so many that falls within the scope of this research.

- **Sketch-UP**

This is a 3-D drawing program that offers the advanced visualization capabilities of more expensive computer-aided design (CAD) packages, but with a much simpler and more intuitive interface that facilitates the rapid Sketching of designs. Sketch -Up is available in free and professional versions for Microsoft Windows or Mac platforms. The plug-in works with either free or professional versions, but currently only on Windows. The hallmark of Sketch-Up is its easy-to-use Graphical User Interface (GUI). The program enables a user to easily manipulate and edit designs in 3-D and as with a CAD program, the user can still accurately measure distances and add dimension markings. The program also features a variety of rendering options, including bitmap textures, shadowing, x-ray mode, as well as traditional rendering modes such as black-and-white line drawings, or a rough “sketchy” style that imitates a hand-drawn architectural draft. By entering the longitude, latitude, date, and time, Sketch-Up can perform shadowing studies for a project. The shadowing feature can be useful for examining passive solar building designs.

Sketch-Up is widely used by architects during the conceptual phases of projects (Ellis *et al.*, 2008). An initial design proposal is rapidly ‘sketched’ with Sketch-Up to show the building form and massing, and then submitted to the client. The client provides feedback to the architect and requests the necessary changes. The architect and client might iterate over several Sketch-Up models until the client is fully satisfied with the design concept. The project then moves forward to design development, where the Sketch-Up model is exported to become a much more detailed CAD model. The conceptual phase of the design process, when the Sketch-Up models are being used by architect and client to make decisions about the building form and massing, is precisely when energy simulation should provide the most helpful feedback to influence the design. Sketch-Up is optimally positioned in the design process workflow for coupling to an energy simulation tool. Once the

project moves to the CAD model, it is usually too late or too expensive to revisit the design of the building form and massing (Ellis *et al.*, 2008)

Nevertheless, there has been some advancement towards integrating sketch up with energy analysis tools. This is exhibited in form of interoperability, where data can be transferred from architectural model to the simulation environment. Example includes the Open Studio, which is a free plugin for the Google Sketch Up 3D drawing program, which makes it easy to create and edit the building geometry in Energy Plus input files or launch Energy Plus simulations and view the results in Sketch Up. Other examples include the plug-in of IES, such as IES VE-Ware or the Revit Architecture plug-in IES (IES, 2012) and Autodesk AutoCAD plug-in to create and edit Energy Plus input files (Energy-Plus, 2013).

However, despite the proliferation of energy simulation tools with Sketch up described above, few connect to the actual analysis needs of the architects. Open Studio plug-in for Google's Sketch Up, use validated simulation tools, but are incomplete in a collaboration sense as the coupling link deals only with the translation of geometry between programs, and not material properties, building systems, or occupation (Toth *et al.*, 2011). Importing and exporting of building geometry is error-prone and tedious, especially as geometry models established in CAD-software are often not suitable as simulation models. The simulation results and possible conclusions remain in the simulation software; a feedback into the design software is not possible. Changes in design due to performance criteria have to be done manually in the design software, the model has to be exported and simulated again. These steps have to be repeated after every change in the design (Schlueter and Thesseling, 2009).

- **SketchiXML**

As related to design, SketchiXML consists of a multi-platform and multi-agent interactive application that enables designers, developers, or even end users, to sketch user interfaces with different levels of details and support for different contexts of use. The results of the sketching are then analysed to produce interface specifications independently of any context. These specifications are

exploited to progressively produce one or several interfaces, for one or many users, platforms, and environments (Coyette *et al.*, 2007b).

- ***SILK (Sketching Interfaces Like Crazy)***

James Landay developed SILK, at the Human-Computer Interaction institute, Carnegie Mellon University. *SILK* is an informal sketching tool for graphical user interface design that combines advantages of paper-based sketching with electronic tools. Using ***SILK***, a user can quickly sketch an interface using a digital table and pen. The system attempts to recognise the drawn interface elements and adds functionality to the recognised interface elements (Landay and Myers, 1995). This permits exploration of the behaviour of the drawn interface elements while they are still in the ‘sketch’ state. When the designer is satisfied with a result, SILK can convert drawn interface elements into real widgets and graphical elements.

- ***Smart sketch***

This is a tool, which provides beautification in design (Pranovich and Van Wijk, 2003). The designer can sketch free hand, the system then attempts to recognise common graphic elements from this input. Systems such as Pegasus, introduces predictive drawing that predicts the user's next drawing operation based on the existing drawing (Pranovich and Van Wijk, 2003). However, and in general, systems supporting freehand Sketching with beautification techniques still suffer from plenty of limitations (Plimmer and Apperley, 2002).

- **Computer Aided Design (AutoCAD, ArChi-CAD)**

The application of computer-based tools in the building design can be broadly divided into two groups, namely, computer-aided documentation design (CADD) and drafting tools, and computer-based simulation tools (Hong *et al.*, 2000). The first application often uses personal computers to produce technical documents and drawings. It is popular with building designers and helps to improve the productivity of the building, but has little influence on efficient building performance. The latter application often entails the use of

engineering tools to calculate envelope heat gains, space heat loads and predict the energy performance of the building (Hong *et al.*, 2000).

Auto-CAD is a software application for computer-aided design (CAD) and drafting supports, in both 2D and 3D formats. It was developed and sold by Auto desk (Autodesk, 2012) and was first released in December 1982 in the first form of software by the Autodesk founder; John Walker. AutoCAD is Autodesk's flagship product and by March 1986 had become the most omnipresent micro computer design program in the world, utilising functions such as poly lines and curve (Computer Graphics World, 2011). Subsequently, the introduction of 3D-CAD has allowed the development of the 3D models. However, a 3D modeller on its own does not offer a significant advantage to the design process other than as a visual aid; neither does a CAD system that only produces 3D models.

3.2.2 Revit Architecture Suite and BIM

Revit was defined from the ground up as a Building Information Modelling (BIM) tool to specifically address problem area of architecture, engineering and construction (AEC) industry; communication, coordination and change management (Krygiel, *et al.* 2009). It is a technological platform that supports architectural, structural and mechanical disciplines.

A BIM application is not only used to create the elements, but also as a manager of all the designs, uncovering construction errors when merging the different specialities. Thus, applications such as Autodesk's AutoCAD Revit Architecture Suite, AutoCAD Revit Structure Suite and AutoCAD Revit MEP Suite offer the possibility of different specialist working on the same project in different files and then combining them efficiently (Autodesk, 2010; Sampalo and Santos, 2011). However, Sampalo and Santos (2011) stated that, one drawback of these 4D models is the amount of time needed to create them, as well as the lack of trained personnel .

- **BIM (Building Information Modelling)**

In recent times, substantive progress has come from software developers in the design and construction area. This is known by various terms such as ‘Virtual Building Environment’, ‘Single Project Model’, ‘Building Information Modelling’, and ‘Virtual Product Modelling’ by the vendors of alternate design systems such as Archi-CAD, Bentley, Autodesk, and CATIA. Thus, the present generation of software provides building information modelling in place of building graphic modelling. Eastman (1999) emphasised how some early efforts in building modelling were a precursor to this current effort. He states that several systems in both the UK and United States (US) developed in the 1970s and early 1980s had similar ambitions to the goal of current generated intelligent CAD systems, with the development of an integrated environment to support design and construction.

Building information modelling (BIM) seeks to integrate processes throughout the entire lifecycle (Aouad and Arayici, 2010). It is the latest trend in the Architecture, Engineering, and Construction (AEC) industry. With the increase call for use of BIM, the building industry has become more competitive for all participants. The main advantage of BIM comes from the new concept of creating central ‘virtual building information’ to retrieve information and to generate associative documentation from the model. Building Information Modelling as a process, involves the generation and management of digital representation of physical and functional characteristics of a facility. The resulting building information model becomes a shared knowledge resource to support decision making about a facility from the earliest conceptual stages, through design and construction, then through its operational life before its eventual demolition (Eastman *et al.*, 2011). The mass models used in the early design stages can be considered as the foundation for the development of the BIM. It is a computer model database of building design information, which may also contain information about the building’s construction, management, operations, and maintenance.

From the central database, different views of the information can be generated automatically, views which correspond to traditional building design documents, such as plans, sections, elevations, quantity take-offs, door and

window schedules, 3D model views, renderings and animations. Since the resulting documents are derived from the same database, they are all coordinated and accurate. Any design changes made in the central model will automatically reflect in the resultant drawings, ensuring a complete and consistent set of documentation. Unlike traditional 2D CAD systems in which the building design is represented in multiple drawing files made up of lines, arcs and circles, the BIM is a single database or fully integrated, fully associative building model, that is constructed with intelligent “objects” which represent building elements like walls, slabs, roofs, doors and windows.

BIM provides a technology by which the building project team can improve the building design, documentation and construction process, providing a powerful digital framework for downstream facilities management, operations, and maintenance. It enables the architect, the contractor and the building owner to simulate the performance of the building before it is built. This simulation may include energy use analysis, construction cost estimation, construction sequencing, building code compliance, and space utilization. This kind of analysis gives the architect an unprecedented opportunity to improve the design based on the results received. The contractors can also predict with greater reliability the cost and schedule of construction. For the building owner, BIM provides the tools for understanding and managing the total cost of ownership of the completed facility.

There is evidence to suggest that the architectural profession is beginning to come under pressure to adopt BIM (Coates *et al.*, 2010). Although it has been in existence for over twenty years, it is only over the last few years that building owners are becoming aware that BIM promises to make the design, construction and operation of buildings much more streamlined and efficient (Coates *et al.*, 2010). Owners are starting to insist that architects and other design professionals, construction managers and construction companies, adopt BIM (Mihindu and Arayici, 2008).

However, there are challenges in implementing BIM within the UK construction practice. These include: overcoming the resistance to change and getting people to understand the potential and the value of BIM over 2D

drafting; adapting existing workflows to lean oriented processes; training people in BIM, or finding employees who understand BIM. The other challenges include: understanding of the required high-end hardware resources and networking facilities to run BIM applications and tools efficiently; the required collaboration, integration and interoperability between the structural, designers/engineers and developing a clear understanding of the responsibilities of different stakeholders in the new process by construction lawyers and insurers (Arayici *et al.*, 2011).

3.3 Decision Support and Building Performance Simulation (BPS) Tools

3.3.1 Decision Support Tools

Decision Support Tools (DSTs) are any tool(s) used as part of a formal or informal decision process (Kapelán *et al.*, 2005) or that, which informs the decision-making process by helping them understand the consequences of different choices (Canada Mortgage and Housing Corporation, 2004). While there is no shortage of DSTs to aid the building professions in meeting new green building requirements, Keysar and Pearce (2007) state that there is knowledge deficit regarding what tools are available and the potential benefits associated with their use. Decision makers, such as architects, need the right tools and data at the right time to identify and assess potential low energy design solutions (Dunsdon *et al.*, 2006). In the traditional design process, however, it is the energy engineer who uses simulation tools for equipment sizing and code compliance, only after the architect has completed the architectural design (Ellis *et al.*, 2008).

From the RIBA Climate Change Toolkit 05, all design tools, from simple calculation procedures to complex simulation models, are means of estimating the approximate performance of a given design. Hence, tools such as BPES tools for architects ‘decision making should complement the designer’s own knowledge by quickly confirming whether proposed changes to a design are likely to make the performance of the design better or worse, and by indicating the relative effects on performance of different design features (Royal Institute

of British Architects, 2009b). Tools should provide different degrees of confidence, depending on the quality and amount of the input data, the complexity of the calculations and the skill of the user (Royal Institute of British Architects, 2009a).

Thus, when using simulation tools to support the decision of a LIB, a staged approach should be adopted with complexity of simulation, increasing in proportion to the complexity of the design. Outputs from each modelling stage are bound to involve some approximation, hence the need to be careful about the level of confidence with which the predictions are also interpreted. Tools are required to help designers predict how buildings will perform in use, and to support the construction and operation of buildings. Many tools have been and will continue to be developed by specialists, software developers, and suppliers of materials and components to support specific aspects of building design and the selection of materials and components.

However, to support architects in decision making, the current energy models, which describe the building design, is time-consuming and requires skilled specialists. Thus, design and decision support tools for architects as a research focus has been characterised by barriers between disciplines and between successive design phases (Technology Strategy Board, 2009). Ideally, the architectural design team should use building energy simulations to guide the architectural design from the earliest phases of the project.

Torcellini *et al.*, (2011) argue that low-energy design is not intuitive, and simulation should be an integral part of the design process. Elforgani and Rahmat (2010) posit that tools' provision should be from the early stage of the design process so that the environmental implications of different iterations of the design can be monitored progressively. Dunsdon *et al.*, (2006) concede that the most cost effective carbon reduction measures are those introduced at the early design stage. Failure to embed low carbon considerations from this stage is likely to result in a building with higher carbon emissions.

Hence, to deliver LIB in the UK, the loop between building design must be closed (Technology Strategy Board, 2009). This can be achieved by creating new generation of tools that will aid architects' decision making. This will be

especially important and useful at the early stage of the design process, where major decisions that affect the building usually take place (Dunsdon *et al.*, 2006; Beadle, 2008; Elforgani and Rahmat, 2010). This is because; there is lack of integration between the design tools such as CAAD and Sketch up, explored in Section 3.2.1 and the current simulation tools, which do not fit with the architects intrinsic way of design and decision making neither interpret the representations effectively.

3.3.2 Background to BPS Tools

Since the inception of building simulation discipline, it has been evolved as a vibrant discipline that produced a variety of Building Performance Simulation (BPS) tools that are scientifically and internationally validated (Attia, 2010). Foundation work for building simulation was pioneered in the 1960s and 1970s (Clarke, 1985). It focused on building thermal performance, load calculation and energy analysis (Kusuda, 1999; Clarke, 2005; Attia 2010). The beginning of the 1990s, however, manifested a shift from an energy consumption focus to many other building performance characteristics (Augenbroe, 1992; Attia, 2010). Hensen and Radosevic (2004) states, building simulation discipline reached a certain level of maturation to offer a range of tools for building performance evaluation in the 1990s. By the end of the 90s, a range of simulation applications spanned out from the research community to professional practice, allowing a diverse tool landscape for a variety of users (Papamichael and LaPorta, 1996; Tianzhen and Jinqian, 1996). This maturation had a major influence on the building design profession and resulted into four major changes defined in Attia (2009) as:

- Diversifying tools users and addressing more of the whole design team;
- Modifying the tools to suite early and late design phases;
- Increasing the number of tools and developing a large range of function complete tools;
- Localising the tools capabilities.

The first major change was the trend to encourage the whole design team to use BPS tools. The increased complexity of building delivery process led to a broader view of BPS, which resulted in a broader user base. Simulation tools moved progressively towards all professions involved in design of buildings, including architects, who have been regularly described in literature as non-specialist, non-professional, non-experts, novice or generalist (Hand and Crawley, 1997; Morbitzer *et al.*, 2001; Augenbroe, 2002; Schlueter and Thesseling, 2009). The implications of engaging all design team members in making design decisions about energy and environmental performance of the buildings, made simulation tools to be recognised as design support tools within the Architecture-Engineering-Construction(AEC) industry. Simulation thus became an integrated element of the design process (Augenbroe, 1992; Mahdavi, 1998), involving the whole design team.

The second major change was supposed to modify tools to suite early and late design phases. The trend was to progress particularly towards the early design phases, due to the increasing importance of the decisions made early in the design process and their impact on energy performance and cost. Hensen (2004) states, BPS tools were developed to help architects perform early energy analysis, as well as to create more energy efficient and sustainable buildings.

The third change was the rapid extension of BPS tools. This brought about a diverse tool setting for all building design professionals, especially in the U.S. The Department of Energy (DOE) maintains an up-to date listing of BPS tools on the Building Energy Software Tools Directory (BESTD) website. The range is from research software to commercial products, with thousands of users (Crawley *et al.*, 2005). By 2010, there were more than 378 tools (US-DOE, 2010), hence they had quadrupled between 1997 and 2010.

The fourth major change was the localisation of BPS tools 'capabilities, incorporating local weather data, provision of local building materials, construction and codes. The number of tools users grew enormously. High quality thermal models were uploaded on earth viewer software (Google Earth)

and positioned on 2D and 3D satellite images of terrain and cities (Attia, 2010).

3.3.3 Application of BPS Tools

For construction professionals, the initial surge of enthusiasm for computer applications started in the early 1960s. There was an optimistic view of the computer's potential as a supporting tool for design and construction, along with the time needed to develop this potential (Sun and Aouad, 2000). According to a computer survey conducted by the Construction Industry Computing Association (CICA) in the UK, computers are used in up to 85 per cent of building services design work. Software is used for technical and design applications covering: energy consumption (U-value calculation and envelope analysis, analysis of domestic fuel use, thermal and comfort analysis and analysis of energy consumption and cost); pipe-work design (hot and cold services, pipe work sizing, fluid dynamics, and heat emissions); drainage (design of drainage systems, soak away design, storm water flow, manhole and pipeline schedules) and other pipe work (sprinkler systems and rainwater gutter sizing) (Hong *et al.*, 2000). Thus, major applications of BPS tools within the construction industry include the following:

- ***Simulation tools for building heating/cooling load calculation.***

This type of BPS tools calculates the peak values and load profiles of heating/cooling loads of buildings. They are the basis for the sizing and selection of heating, ventilation, and air conditioning (HVAC) equipment, systems, and plants (Hui and Cheung, 1998)

- ***Simulation tools for energy performance analysis for design and retrofitting***

It analyses the annual building energy demand profile and part-load performance of major energy-consuming equipment to realise energy-efficient building design. The energy budget of the building can also be accurately estimated for energy planning and management (Hui and Cheung, 1998). It further provides innovative strategies such as reflective roof, day lighting, free-

cooling, solar hot-water heating, heat recovery, and thermal storage for energy savings, and thus, can be evaluated before implementation (Hong *et al.*, 2000).

- ***Simulation tools for Building Energy Management and Control System (EMCS) design***

EMCS plays the role of monitoring, controlling and reporting the operation of the building systems and plants so as to ensure that thermal comfort and energy efficiency is maintained (Hong, *et al.* 2000)

- ***Simulation tools for complying with building regulations, codes, and standards checking simulation tools***

Building simulation can be employed to design the building to the requirements of local building regulations, codes, or standards. Subsequently, building simulation can supplement energy auditing to check the energy performance of the as built building (Curcija *et al.*2012)

- ***Simulation tools for Life Cycle Cost analysis***

Some BSPs are able to perform a cost analysis of the various options being simulated, thus presenting the designer with cost-effective energy-saving alternatives. BSPs of this type are best used in conjunction with codes of practice and energy standards (Curcija *et al.*2012).

- ***Simulation tools for studying passive energy saving options***

BSPs can be used to investigate the technical and economic feasibility of passive design options such as sun shading, day lighting, evaporative and earth cooling, night ventilation, radiative cooling, movable insulation, roof ponds, reflective roof, and various heat storage, release and buffer systems (Hong *et al.*, 2000).

- ***Simulation tools apply in Computational Fluid Dynamics (CFD)***

Computational Fluid Dynamics (CFD) tools are widely used in the study of global warming, urban climate, microclimate, building ventilation, indoor air quality, indoor and outdoor thermal comfort, fire safety, and smoke extraction.

Building simulation using CFD software is gaining popularity due to new standards on health and comfort in the built environment and the need to design internal spaces and HVAC systems that meet the required standards criteria (Hong *et al.*, 2000).

3.3.4 Choice of Building Performance Simulation

Computer software is a complex product, more so for those in the domain of building simulation. For any given problem, there is usually more than one building simulation programme (BSP) that can meet the requirements. On the other hand, there is no single BSP that can perform all kinds of building simulation (Hetherington *et al.*, 2010). Hence, potential users are faced with the difficulty of choosing a suitable program from those available along with which BSP to select.

The choice should be made after carefully assessing the requirements of the user and matching them with the capabilities of the BSP. There are three vital factors to consider from the user's side. The first concern is the need or purpose. Understanding the nature of the problem that the user expects to solve with the use of a BSP is an important criterion. Choosing an 'overpowered' BSP is not only unnecessary and expensive but can be costly when mistakes are made due to the complexity of the software. The second relates to budget. The budget to purchase and use a BSP includes software cost, maintenance, if necessary, and the cost of the computer platform to run the BSP in addition to provision for user training.

The third is the availability of facilities. The user should select a BSP that can be run on existing computer facilities, or when anticipated, investment in new computer resource is bearable. It is difficult to compare BSPs in absolute ways, because each BSP has its advantages and disadvantages (Hong *et al.*, 2000). However, BSPs can be evaluated on their cost and performance. The cost includes not only the purchase cost but also the use cost. The cost components consists the following:

- Software cost, covering the license fee, after sales service, and software upgrading fee;
- Training cost, which is the fee that software vendors charge to train the user to use the software;
- Users' cost, which includes the labour and computer resources consumed during the use of a BSP.

Currently, more and more BSPs can run on PCs, so the use cost of computer facilities is relatively small. But labour can be quite expensive, especially when a BSP requires a user to spend long hours preparing the input data files and waiting for simulation results. With increased complexity of BSPs, the training cost can rise. The user cost is often the highest followed by training cost and software costs (Hong *et al.*, 2000). A tool's performance can be evaluated on various aspects, such as: computing capability; usability; data exchange capability and database support. The performance of a BSP depends on how well domain knowledge, software engineering, software quality assurance, and human computer inter-face (HCI) technology are applied during the development of the BSP.

However, towards achieving LIB design in UK, there is no BSP that fits into the intrinsic process of architects' design decision making. This is because the existing BPS tools are too complicated, especially at the early design stage. Despite the availability of sufficient technology, energy simulation tools have proven to be incompatible with the design process (Lowe, 2000; Morbitzer, 2003; Hensen, 2004). Energy simulation tools are often complicated to use and decisions regarding energy performance are often outsourced (Hensen, 2004; Attia *et al.*, 2009). Conventional design tools do not effectively communicate environmental impact of design decisions between concerned parties (TSB, 2009). Hence, this limitation inhibits designers in evaluating energy performance of building design, when it matters most.

3.4 Building Performance Energy Simulation (BPES) Tools

Energy efficiency and thermal comfort are of concern in building design. Since, one third of national total annual energy consumption is consumed in buildings, it is estimated that substantial energy savings can be achieved through careful planning of energy efficiency (Hong *et al.*, 2000; Hetherington *et al.*, 2010). According to the World Business Council for Sustainable Development (WBCSD), with immediate action, the energy use in buildings can be reduced by up to 80 per cent by 2050. Buildings use more energy than any other sector and as such are a major contributor to climate change (discussed in section 2.1). In numerous countries, building regulations (discussed in section 2.3.1) and environmental guidance (discussed in section 2.4) exist to ensure that building designer considers building energy performance improvement measures.

However, for decision making, BPES tools, with the aid of computer-based models, cover performance aspects such as energy consumption and thermal comfort in buildings. Crawley (2003) describes BPES tools as powerful tools, which emulates the dynamic interaction of heat, light, mass (air and moisture) and sounds within the building. They predict the energy and environmental performance exposure to climate, occupants, conditioning systems, and noise sources. Although, there are large number of BPES tools, Hopfe (2009) emphasised that most use the same modelling principles and are used in a similar manner. They are also primarily used for code compliance checking and thermal load calculations for sizing of HVAC systems.

3.4.1 BPES Tools Functions

Before the advent of computer-aided building simulation, architects and building services engineers relied heavily on manual calculations using pre-selected design conditions. This often resorted to the 'rule-of-thumb' method and extrapolations in extending beyond conventional design concepts. The approach had frequently led to oversized plant and system capacities, as well as poor energy performance, due to excessive part-load operations (Hong *et al.*, 2000). However, the use of computer simulation by building professionals

is now considered common. Building simulation can be applied in the life cycle analysis of a building, including design, construction, operation, maintenance, and management (Hopfe, 2009; Attia, 2010).

The advantages of BPES tools include the following:

- To answer “*What If*” questions;
- An inexpensive means for exploring plethora of different design decisions, options and HVAC systems;
- To aid in the analysis of energy usage in building such as, energy conservation studies and building design studies;
- For energy saving potential: energy efficient design and operation;
- For building performance which involves complex interactions, hence, designer can experiment with different strategies quickly;
- To help in designing the buildings to conform to building codes (Hong *et al.*,2000)

3.4.2 Critique of BPES Tools

An effective way to ensure that low carbon considerations influence a building design is to empower designers with tools for building performance analysis, especially on energy and whole life costing, to reveal the implications of design decisions. However, from deeper examination of the changes within the four phases in the background study of BPS tools in section 3.3.2, it can be observed that the phases happened so quickly and resulted in growing scenery of tools that has now been considered more of a barrier than an advantage.

The increasing numbers of BPES tools reflect a broader variety of their abilities, but do not necessarily reflect wider penetrations within the building design community, especially for architects’ decision making to achieve LIB. Balcomb (1997) states that the major barrier to using the energy simulation tools during the design process of a building have been the difficulty of using the available programs. Hence, BPES tools are not routinely applied in building design practice. Currently, there is replication of many tools with striking similarities between them. There has been no attempt to develop

design team friendly, effective and efficient design and decision support applications for the architects. Most BPES tools are difficult and cumbersome to use, and cater more for engineers (Morbiter, 2003; Attia, 2010). The existing tools are mainly oriented towards final design stages because most tool developers use engineers' feedback to develop architect friendly tools (Attia, 2010). Thus, the rapid changes discussed in Section 3.3.2 could not bridge the mono-disciplinary of the tools, used by the engineers.

This is because most of the existing BPES tools are lacking from the architects' viewpoint, in terms of approximation, flexibility and accuracy. Hence, they are not suitable for purpose of architectural design (Attia *et al.*, 2009; Attia, 2010). Attempts to address the architects' and engineers' use of BPES tools have been proposed separately by many researchers (Attia, 2010). Very little effort has been carried out to develop BPES tools with adaptive interfaces that cater for architects, especially at the conceptual design stage where many decisions are taken. Nevertheless, Mahdavi (1993) stated that if the current crop of energy analysis tools is not being used to support critical early design decisions, then the solution may be found in the use of tools which follow the design process.

3.5 Summary

The chapter has recognised architects' role in the traditional design process, as well as in the delivery of low carbon housing design in the UK. It reviews relevant design tools in the form of computer-aided drafting and design tools, followed by computer-based decision support tools in form of BPES tools.

The chapter has established how BPES tools are characterised by barriers between successive design phases. Hence, there is a gap in such tools to support architects in the UK, in making decisions about how to achieve low carbon housing design and delivery, especially during the early phase of the design process.

Chapter Four: Design Process and Decision Making Framework

4 Introduction

A broad, but focussed literature review on design and decision support tools was carried out in Chapter three. The observed gap in research, in the form of the critique on the use of BPES tools by architects to achieve low impact housing design was established. The established critique was that most architects do not use BPES tools because the tools are established on the case-based reasoning of engineers. They also reflect little of the iterative way of architects' decision making at the various stages of the design process, especially at the early design stage.

This chapter reviews the Royal Institute of British Architects (RIBA) plan of work stages, as a familiar design process for UK architects (RIBA, 2013). It further reviews other processes, such as: theoretical (Hamel, 1994; Lawson, 1994 and Pagani, 1999); rational (Hakkinen and Belloni, 2011); traditional (Reed and Gordon, 2000; Lohnert *et al.*, 2003 and Larsson, 2004) and integrated design processes (Reed and Gordon, 2000; Pearl, 2004). The strengths and weaknesses of the processes were identified and analysed, towards justification of an appropriate design process that will enable architects in the UK to deliver the low impact housing design. Finally, the act of decision making in the design process were reviewed to conclude the chapter. The scope of the chapter can thus be summarised as:

- Design and RIBA Plan of Works Stages of Design Process;
- Conventional Design process;
- Integrated Building Design Process;
- Decision Making;
- Past Models and Frameworks; and
- Summary.

4.1 Design and RIBA Outline Plan of Works

4.1.1 Design and its Process

Having established that the plethora of policies, legislation, regulations and environmental guidance from different sources and formats in Chapter two are not achieving the LIB design, and the plethora of design and decision support tools reviewed in Chapter three are not well adapted to the way architects work, this chapter reviews various design processes. The aim of this is to map a suitable framework for architects' iterative way of design and decision making. However, before attempting to design and develop the features and functionality of the framework, it is practical to examine the background study of the design process itself, along with the act of making decision towards development of the design information requirements for sustainability activities within the process.

The word 'Design' is a noun which the Cambridge Dictionary of American English informally refers to a plan, or convention construction, of an object or a system (as in architectural blueprints, engineering drawing, business process, circuit diagrams and sewing patterns). The term 'to design' is a verb which refers to making of the plan. Design as both a noun and verb refer to either the product or the process, by which relatively and recently the word '*designer*' has become an adjective rather than a noun (Lawson, 2010).

Ralph and Wand (2009) state, there is no general accepted definition of 'design' because of the dissimilar connotations of the term in different fields. In formal terms, 'design' is the specification of an object, manifested by an agent, intended to accomplish goals, in the environment, where the designer operates (Ralph and Wand, 2009). Kumaragamage (2011) defines 'design' as a road map or strategic approach for someone to achieve a unique expectation or objective. He further characterised: specifications; plans; parameters; costs; activities; processes, how and what to do within legal, political, social, environmental, safety and economic constraints, in achieving the objective.

Architectural design, defined by Schon (1985), is the very prototype of design activity, generally considered to apply to the class of problems called 'wicked' by Horst Rittel. This class of problems defies complete

description and lacks the clarity of formulation found in scientific problems. The information needed to understand these problems depends upon ideas for solving them and there are no 'correct' or even optimal answers (Lawson, 1994). Design takes place when a person makes plans about the future environment. It is in the context of all the participants' interactions that a building emerges (Cuff, 1992). Pagani (1999) states that design is an individual activity and further recognised and discussed design as a collaborative activity involving teamwork in the building delivery process.

With this broad denotation, it is clear that there is no universal language or unifying institution for designers of all disciplines. This allows many differing philosophies of 'design'. This is because, it is also used for people who work professionally in one of the various design areas, such as fashion designers, concept designers and web designers (Lawson, 2010). A designer's sequence of activities is called the design process (Simon, 1996), and it is an approach toward the subject 'a designer'.

The early models of design process varied, but in general, agreed on a basic flow of: problem statement; analysis of the problem; synthesis of a solution; evaluation of the solution and communication of the solution. This process was described as linear, with a recycling loop back to synthesis if the evaluation was negative (Mackinder and Marvin, 1982). Lawson (1994) questions this basic model and denies that the process in reality is not as neatly categorised. He suggests that designers come to understand their problems through their attempts to solve them; that is, 'analysis through synthesis'.

4.1.2 RIBA Outline Plan of Works

The RIBA Outline Plan of Work was established over fifty years ago in the form of Plan of Work for Design Team Operation (Royal Institute of British Architects, 1963). It is widely used by those in the building industry (Royal Institute of British Architects, 1998) and has been referred to by several

publications (Mackinder and Marvin,1982; Imrie, 2007; Adeyeye *et al.*, 2007; Beadle, 2008 and Lawson, 2010) within the scope of this study.

The RIBA Outline Plan of Work stages of the design process, is used in this study because of its familiarity to architects and recognition by the general construction industry in the UK. The associated professionals in the field also recognise it, as a model with set of procedures for building project administration. The Plan of Work is usually used when the architect is appointed at an early stage of a design project, or where members of the architectural practice led the design team (Royal Institute of British Architects, 1998; Royal Institute of British Architects, 2008).

The use of RIBA Outline Plan of work stages of design process is very familiar to UK architects. Hence, it will make it easier to accommodate the idea of using the proposed framework developed in this study, not just as a support, but a support with familiar design process to achieve low-impact housing design up to Level 5 of the energy criteria in the Code for Sustainable Homes. The intention is not to replace the existing Outline, but can be used as an addendum towards the development of the proposed 2012/2013 version of the Outline.

4.1.3 RIBA Outline Plan of Work as the Base Line Model

The RIBA model was created as a guide to the design process (Royal Institute of British Architects, 1965) and was influenced by theoretical models used by members of RIBA. It has been updated a number of times after the original version, by which the most recent model consists of eleven linear stages, split into design phases represented in Table 4.1. The RIBA Outline Plan of Work (2007) version was amended in January 2009 with the publication of simple Corrigenda. The corrigendum was to include the amendment affecting the wording under Stages F1 and F2 (issued November 2008) and the Corrigenda issued in January 2009.

Table 4.1: Design Process stages split into phases

Plan of work Stages (1998)	Plan of Work Stages (2009)	Plan of work stages split into phases
Pre-Design	Preparation	A*B
Design	Design	C* D*E
Prepare to Build	Pre-Construction	F* G* H
Construction	Construction	J* K* L
Post Construction	Use	M.

Source: Adopted after Morbitzer (2003)

However, with the introduction of the Green Overlay (Royal Institute of British Architects, 2011), the latest RIBA Outline Plan of Work as at the time of this thesis aimed to provide a framework for better embedment of sustainability into the appraisal, briefing, design and construction process of the outline. The RIBA president, Angela Brady states, ‘*The RIBA Outline Plan of Work is the most widely recognised and used framework for design and construction. It therefore offers an appropriate and accessible vehicle for mapping the ways in which sustainable design activities can be integrated into the building design and construction process*’ (RIBA, 2011, pp1).

The Green Overlay takes the familiar, succinct format of the existing Outline Plan as its starting point. It simply adds a few carefully chosen words to the current descriptions of the key tasks for each work stage to highlight some additional actions necessary to promote the construction of more sustainable buildings. Sustainability checkpoints and guidance notes have also been added to illustrate behaviours and activities to support a more sustainable approach to each work stage.

The latest addition to the RIBA plan of work stages is the BIM Overlay (Royal Institute of British Architects, 2012a). It builds on the Green Overlay and forms part of the response from the construction industry, and in particular

RIBA, to the Government's commitment to have all its projects utilising BIM from the summer of 2012. This document provides an Overlay that simplifies the BIM processes and clarifies terms, which have caused confusion in the industry. Core BIM activities are considered in the guidance for each stage of the plan. The BIM Overlay is not a fundamental review of the Plan of Work, but does provide guidance on the use of BIM in the context of the current Plan of Work. These two documents (Green and BIM overlays) are part of the preparatory work being undertaken prior to a fundamental review of the RIBA Plan of Work that will take place in 2012-13 (Royal Institute of British Architects, 2012a).

4.1.4 The RIBA Design Model and Sustainability

The design of buildings is a complex process by which architects are centrally involved in a sector of the national economy that is responsible for between forty to fifty percentage of UK national emissions (Pritchard and Willars, 2007; Hetherington *et al.* 2010). Hence, RIBA and its members have a part to play and an opportunity to work with others to influence the future. The latest version of the RIBA Outline plan of work comprises of five stages (Table 4.1) and eleven activities (Table 4.2 and 4.3). In the former version of the model before the introduction of the green overlay to the RIBA Outline Plan of Work in 2011, the technical design is scheduled to occur after the client has "signed off" the design, and planning permission has been granted for the project. Traditionally, energy intensive technological solutions are used at this stage by architects to solve problems arising from lack of environmental considerations at the early design stage such as over/under heating or lack of day lighting (Hetherington *et al.*, 2010) .

The argument in this research is that for a housing design in the UK, to overcome energy penalties and move towards low impact housing design and delivery, the consideration of significant sustainability and environmental design information requirements should be with the use of BPES tools, from the very early stage of the design process. The sustainability consideration is partly reflected in Tables 4.2 and 4.3 (Royal Institute of British Architects,

2011) compared to the former RIBA plan of work (2007) and the conventional design process in section 4.2.

Table 4.2: Green Overlay to the RIBA Plan of Works-1

RIBA Design Stages		Description of Key Tasks
A and B	Appraisal	<p>Identification of client’s needs and objectives, business case, sustainability aspirations and possible constraints on development</p> <p>Preparation of feasibility studies and assessment of options to enable the client to decide whether to proceed.</p>
	Design Brief	<p>Development of initial statement of requirements into the Design Brief by or on behalf of the client confirming key requirements and constraints</p> <p>Identification of procurement method, project and sustainability procedures, building design lifetime, organisational structure and range of consultants and others to be engaged for the project</p>
C, D and E	Concept	<p>Implementation of Design Brief and preparation of additional data.</p> <p>Preparation of Concept Design including outline proposals for structural and environmental strategies and systems, site landscape and ecology, outline specifications, preliminary cost and energy plans</p> <p>Review of procurement route.</p>
	Design Development	<p>Development of concept design to include structural and environmental strategies and services systems, site landscape and ecology, updated outline specifications and cost and energy plans.</p> <p>Completion of Project Brief., Application for detailed planning permission</p>
	Technical Design	<p>Preparation of technical design(s) and specifications, sufficient to co-ordinate components and elements of the project and information for statutory standards, sustainability assessment and construction safety</p>

Source: RIBA (2011)

Table 4.3: Green Overlay to the RIBA Plan of Works-2

RIBA Design Stages		Description of Key Tasks
F,G and H	Production Information	<p>F1: Preparation of production information in sufficient detail to enable a tender or tenders to be obtained.</p> <p>Application for statutory approvals.</p> <p>F2: Preparation of further information for construction required under the building contract</p>
	Tender Documentation	Preparation and/or collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the project.
	Tender Action	<p>Identification and evaluation of potential contractors and/or specialists for the project.</p> <p>Obtaining and appraising tenders; submission of recommendations to the client.</p>
J and K	Mobilisation	<p>Letting the building contract, appointing the contractor.</p> <p>Issuing of information to the contractor.;</p> <p>Arranging site hand over to the contractor.</p>
	Construction to Practical Completion	<p>Administration of the building contract to Practical Completion.</p> <p>Provision to the contractor of further Information as and when reasonably required.</p> <p>Review of information provided by contractors and specialists.</p> <p>Assist with preparation for commissioning, training, handover, future monitoring, and maintenance.</p>
L	Post practical completion	<p>L1: Administration of the building contract after Practical Completion and making final inspections.</p> <p>L2: Assisting building user during initial occupation period.</p> <p>L3: Review of project performance in use.</p>

Source: RIBA (2011)

In the Green Overlay (2011), the design stages has more lists of sustainability to do supplementary guidance process than the other stages within the framework., Angela Brady states that the Green Overlay is a very significant RIBA initiative, which is part of a continuing commitment to tackle the most urgent priority to deliver low-carbon buildings. The RIBA felt that the time

had come to review the current version in order to reflect the changing agenda in the RIBA Outline Plan of Work. The result was this 'Green Overlay'. It amends the succinct wording of the Outline Plan of Work (2007) edition, amended in November 2008 to clarify the issues, and their timing, in response to the growing imperative that sustainability should be actively considered from the early stage of the design and construction of buildings

The Green Overlay was not intended as a fundamental review of the RIBA Outline Plan of Work. However, it is to inform any future review of this and related documentation, such as the Architect's Job Book, RIBA Agreements, RIBA Architect's Handbook of Practice Management, and so on. Low carbon housing design in the UK will specifically require a paradigm shift, as stated by Angela Brady. This is because the current policies, standards, design and many more identified in Chapter two, and the existing decision support tools in Chapter three, seems not to be sufficient towards the realisation.

Architects in the UK have the major role to play by assimilating, handling, and designing. Hence, there is need for new generation of tools that fit into their working practice. This is line with the Carbon Homes Programme Delivery Timeline, which states that it is critical that seventy-five per cent of all architects are trained in low and zero carbon homes concepts between 2010 and 2013.

4.1.5 RIBA Design Stages and Sustainability Assessment

4.1.5.1 Preparation Stages A and B

At the beginning of the preparation stage, the client's requirements and objectives, including timescale, possible constraints, and financial limits, are assessed to give general advice on how to proceed. This is followed by the feasibility study, usually undertaken, before a building is initiated. It matches the goal of the proposed building projects against resources and identifies those special issues requiring response. Real estate investment specialists, or corporate planner, may generate the feasibility study. Alternatively, a family may plan what quality or quantity of housing it can afford (Eastman, 1999).

This is followed by the strategic sustainability review of client needs and potential sites, including re-use of existing facilities, building components or materials (Royal Institute of British Architects, 2011). In addition to early stage consultation, survey and monitoring, undertaken to meet sustainability criteria and assessment procedures, internal environmental conditions, formal sustainability targets, building lifespan and future climate parameters are also stated at this stage of the design process. Involvement of design teams from the beginning to after practical completion should be defined and Site Waste Management Plan (SWMP) started at this stage.

Morbitzer (2003) analysed the feasibility stage as the stage at which the designer does not design the building but determines the objectives and constraints that may influence the decision. According to him, this usually includes the planning permission issues, health and safety, site visits, financial considerations and any other aspect that may be relevant to the particular project. In line with this study's argument, the most cost-effective carbon reduction measures are those introduced at the early stage of the design process. Failure to embed low carbon considerations from this stage is likely to result in a building with higher carbon emissions (Dunsdon *et al.*, 2006).

4.1.5.2 Concept Design Stage 'C'

This is the second phase of the early design stage after the preparation stages A and B. Morbitzer (2003) in his definition of this stage refers to it as the inception stage. He states that it is at this stage that designer produces a range of options for the client, which in the first instance is the response to factors such as site conditions, views, orientation, and size.

From the Green Overlay to the RIBA Outline Plan of Work (2011), it is at this stage that: key design team members are appointed; formal sustainability pre-assessment and identification of key areas of design focus carried out; deviation from aspirations reported; initial Part L assessment are undertaken; description of internal environmental conditions are made; seasonal control strategy and systems prepared. The environmental impact of key materials and

construction strategy should also be checked at this stage and resilience to future changes in climate considered. All of these options should be analysed before presenting it to the client as a form of feasibility study, to show the design analysis and all options considered (Morbiter, 2003).

The study at this stage should be detailed enough to establish the preferred outline proposal to the client. From the perspective of this research, the BPES tools for this stage of the design process, as well as the proposed DIR, should make architects understand how any design decision made may eventually affect the performance of the building. The BPES tool at this stage should approximately determine the energy and environmental implications of decision taken by architects.

4.1.5.3 Design development Stage ‘D’

This is otherwise referred to as the schematic design stage in the earlier version of RIBA Outline Plan of Work. It is at this stage that the outline proposal approved by the client is taken to a more detailed level. The designer should ensure at this stage that all the clients’ needs and desires are integrated into the design proposal. Additionally, full formal sustainability assessment; Interim Part L assessment and design stage carbon/energy declaration (such as the Carbon Buzz) should be done. At this stage, from the Green Overlay (2011) design should be reviewed to identify opportunities, reduce resource use and waste, which should be recorded in the SWMP. Architects should use BPES tool at this stage, in greater accuracy and result output, to investigate the problem areas that have been identified earlier, on how best to improve the energy and environmental performance of the design. Hence, the tools should help in decision making and not verification.

4.1.5.4 Technical Design Stage ‘E’

This stage is referred to as the Detailed Design Stage in the earlier version of the RIBA framework. It is at this stage that the approved schematic design solution is worked through into details. Formal sustainability assessments

should be substantially complete, with minor technical and contractor items only outstanding. Principles of handover process and post completion service should be agreed, details audited for air tightness, continuity of insulation and subcontractor package coordination are carried out (Royal Institute of British Architects, 2011). Design drawings are produced at this stage for coordinating structure, services, and specialist installation. Internal spaces should also have reached the stage to include fittings, equipment, and finishes (Morbitzer, 2003). It is also wise to consider the various technologies at this stage in order to avoid difficulties later on. The type of construction will need to be considered, whether timber frame, concrete, externally insulated masonry, insulated concrete formwork, straw bale, as well as the space required for services such as solar panels, large domestic hot water tank, mechanical ventilation equipment with supply and exhaust ducting.

Here, the building itself should have progressed in detail toward specification of materials and the detailed technology needed for the production information phase of the pre-construction stage. A large number of parameters would also need to be taken into consideration and finalised with any significant uncertainty in specification of materials to have been removed (Morbitzer, 2003). The argument in this research as stated earlier is that if energy sustainability and environmental aspects are addressed right from the beginning of the design process, it will aid architects in taking the right decision from the onset. It will also enable the clients to understand the lifetime benefits/ savings of investing in environmental design strategy right from the start, especially when the budget for the building is being determined or established.

4.1.6 Critique of the RIBA Outline Plan of Work

The recently published Green and BIM overlays to the RIBA Outline Plan of Work have already begun the process of examining the implications of developments in sustainable design and BIM for the RIBA Outline Plan of Work. However, to deliver the sustainability agenda through building design, from the early design stage, this study posits the integration and use of

simulation tools by architects in to the RIBA Outline plan of work stages. The existing RIBA plan of work provides a long list of sustainability activities but not how they can be achieved through the design and decision making by the architects.

Hence, the need for new generation of tools, fit for design and decision making of architects at every stage of the process towards delivery of the low impact buildings and the sustainability agenda. This accords with Mendler *et al* (2006) and De-Wilde and Prickett (2009), who argued that tools should be centric to the design process. With the growing importance in bridging this gap, through integration of simulation tools into the whole building design process for architects to achieve the low impact housing design, it should also be used as an integrated element (Augenbroe 1992; Mahdavi, 1998).

4.2 Conventional Design Process

In the conventional design process, many architects usually address different categories of sustainability. Their capacity to influence decisions beyond the building is constrained because they do not control the full design process and significant steps often occur before the architect is brought on as a consultant (Reed and Gordon, 2000). The owner (client) usually identifies the building concept, by which the site would have been selected and analysed by non-design professionals. As a result, sustainable objectives, alternative transit options, and building orientation are usually scheduled, by which, this should only be on a temporary arrangement before the architects' consultation. Furthermore, ecological design objectives would not have been identified, developed, and incorporated early enough in the planning process. System-wide innovations (i.e. beyond the building) cannot, also be considered because of the limited and after the involvement of design expertise (Reed and Gordon, 2000).

In the conventional design process, both the architect and the client agree on a design concept consisting of a general massing scheme, orientation, fenestration, and the general exterior appearance of the building (Larsson,

2004). The mechanical, electrical, and structural engineers then implement the design in order to suggest appropriate systems.

However, the problem identified with the process has been that the project is too quick and simple often resulting in high operating costs, poor comfort performance and few sustainable gestures that fall within the client's restrained budget (Pearl, 2004). This has frequently come as a surprise to the owners, operators, and users, since the design process does not usually involve computer simulations of predicted energy performance and cost (Larsson,2004). In fact, engineers have had little or no enthusiasm in this context as their role is limited to applying code requirements, cost-benefit analysis and, at times, satisfying the whimsical desires of traditional designers (Pearl, 2004).The various phases of the conventional architectural design process include, programming, schematic, design development and construction.

4.2.1 Activities in the Conventional Design Process

The conventional (traditional) design process can be understood as a linear process, with sequential work routines which are usually unable to support any adequate design optimisation efforts during individual decoupled phases, which of course leads to higher expenditure (Lohnert *et al.*, 2003).

The conventional building delivery process involves many people, who interact in predictable ways according to well-established procedures. First, a need is identified. This can occur at an individual level, an institutional level, or a community level. The need can be for a dwelling, a place of work, a hospital, a school, a subdivision or a commercial development (Pagani, 1999). The party that has the need can turn the need into a project or by a third party (a developer) who determines that an opportunity for profit exists in fulfilling the need. These two basic approaches give rise to different imperatives on the part of the 'client'. In the former case, the client is directly interested in the end-product as a means of meeting the

need. In the latter case, the client is interested in the end-product, primarily as a means of making profit.

However, in both cases the objectives are essentially confined to the provision of a facility that meets a need; the statement of need is usually confined to the immediate imperatives of the client. While some of the larger concerns related to the needs of the community (such as zoning and public safety) are addressed by building regulations and design guides, other concerns (such as public security), are either not made explicit or not addressed. Similarly, while certain undesirable environmental effects of the building (such as emissions, energy use or sewage effluent) are controlled by legislation such as CSH, others are either unregulated or not able to be addressed within the parameters of the project (Pagani, 1999).

Once the statement of need is clear and the financial resources to address it are available, a client will contract directly with a professional or a series of professionals to develop a design for the building to meet the need and responds to the legislative requirements of the community (Royal Institute of British Architects, 2008). This prime contract is usually either with a project manager, an architect, or an engineer. Recently alternative design/build contracting arrangements have been developed where the prime contract might be with a construction manager or a contractor (Pagani, 1999).

In either case, the prime consultant will then engage sub-consultants to provide the necessary range of professional expertise for the design of the particular facility being developed. Upon completion of the design and all the technical details and specifications necessary for the construction of the building, the project will be priced and constructed. In these arrangements, the client is seeking expert knowledge and advice as well as accountability and responsibility for an end-product which meets the stated need in terms of quality, cost and time (Pagani, 1999).

4.2.2 Critique of the Conventional Design Process

The process outlined above, has developed over a relatively short period of time. Developments have occurred in response to: increasingly sophisticated societal demands for more refined products; relatively conservative demands of financial institutions who lend capital for development; more complex and readily available technical systems, and public demand for more accountability from project developers. Just as clients have become more demanding in their requirements for fast, efficient, and cost effective services, Pagani (1999) states that society has become increasingly concerned and vocal about responsible development. Communities want development that respects existing contexts and fits within their cultural and social needs.

At the same time, it is evident that pollution levels, energy and resource conservation, and waste management are becoming critical to the health of global ecological systems (Brown, 1995). This presents a paradox for designers who increasingly find themselves, having to do more for less. Whatever the cause, the reduction of ethical concerns in the traditional design process has resulted in the design and construction of buildings which respond to the narrow, specific needs of the owner and the artistic desires of the designer. However, the larger requirements of the community and the ecosystem of which they are a part are largely ignored (Brolin, 1976; Brown *et al.*, 1996).

Decision-making on a project tends to proceed according to a linear model. Handbooks of practice, such as RIBA job book outline the steps. Usually, the site is selected first, and then a specialist programming consultant develops the building program before the prime consultant, usually an architect, is engaged. The architect retains sub-consultants: landscape, structural, mechanical and electrical, but then analyses the site and the program and develops schematic designs without sub-consultant involvement (Royal Institute of British Architects, 2008).

Development permits are applied for before the design is checked by a municipal planner for conformance with planning and zoning regulations and other technical requirements. The sub consultants are then given the schematic architectural designs and asked to design their engineering subsystems to conform to it. Architectural, structural, mechanical and electrical working drawings and specifications are usually developed with the various disciplines working in isolation (Lohnert *et al.*, 2003).

The architect coordinates the specialist documents towards the end of the working drawings to ensure there are no conflicts. The building represented by working drawings and specifications is then priced competitively in a short period of time by general contractors, who call upon sub-contractors (up to twenty, or occasionally more) to price their specialised sub-component of the work. The general contractor tendering the lowest price is awarded a contract and then co-ordinates construction of the work of all the sub-contractors within the terms of the sub-contracts. A building permit is then applied for and a building inspector checks that the design conforms to the building regulations, with subsequent checks during construction to ensure that the building further complies with design guides, regulations, and legislation (Pagani, 1999).

The critique in this model is that delivery of the project takes place in the context of the many parties involved all pressing for the maximisation of their own interests (incurring financial profit), while minimising the risk of negative consequences (incurring financial loss (Reed and Gordon,2000)). This basic process can sometimes be further complicated by the addition of cost consultants; interior design consultants; code consultants; elevator consultants; acoustic consultants; building management system consultants; disabled access consultants; scheduling consultants and landscape architects. The specialist consultants continue to grow in number as the process becomes more specific. These specialist sub consultants are normally unaware of the basic parameters of a project. They are called in by the architect at certain points in the process to provide their own particular expertise, but have nothing more to do with the project (Pagani, 1999).

Moreover, there is little emphasis placed on the specialists as a team and this attitude is perpetuated through the education of architects, who are largely taught that they have sole control of the design decisions related to form. Thus, the form arises from an impoverished set of constraints, made up of the client's imperatives, the personal interests of the architect, and zoning and building permit regulations. The larger constraints of the ecology of the site, energy and water flows and the cultural, community context and neighbourhood contexts, are rarely allowed to become part of the forces affecting 'form-making'. The narrowness of the constraints that the architect responds to leads to buildings that lack 'fit' and are not well adapted to their real environment (Pagani, 1999; Reed and Gordon, 2000)

Not surprisingly, this process results in a lack of shared objectives, contradiction, confusion, hasty decision making made in isolation from the complete project parameters, and an atmosphere of distrust. However, in certain ways the process works within the narrow confines of the objectives of the individual participants. In the end the client has a building which more or less meets his needs, his budget and his schedule. The consultants are paid for their work and occasionally derive professional satisfaction and community recognition from it.

The contractors and their employees also get paid for their work and occasionally derive satisfaction from their accomplishment (Pagani, 1999). There are three major external constraints on the conventional design process which end up as peripheral to the designer. First, the users of the building usually have no input into the development of comfort standards. Secondly, the community into which the building is inserted. Third is the ecosystem, which provides the resources for the building materials, the inputs for their continued operations and the sinks for their by-products (Pagani, 1999).

4.3 Integrated Building Design Process

Literature reviews within the scope of this research, which presented an integrated model of the design process are: Lohnert *et al.*, (2003); Pearl (2004); Larsson (2004); Hansen and Knudstrup (2005). Lohnert *et al.*, (2003) developed an integrated design process for Integrated Energy Agency (IEA) Task 23. It was based on analysis of principal working methodologies used by architects and engineers and the examination of existing guidelines, related to an integrated design process, analysis of traditional design phasing and related fee structures in nine different countries participating in the Task 23.

Pearl (2004) combines stages to create a circular model to present an integrated design process, whereby the client takes a more active role than usual and the architect becomes a team leader rather than the sole designer or form-giver (Lohnert *et al.*, 2003; Larsson,2004; Pearl, 2004). The structural, mechanical, and electrical engineers also take on active roles at the early stage of Pearl's and Larsson's integrated design process (IDP) just as in the IEA Task 23 process from Lohnert *et al.*, (2003). Knowledge and understanding by the project team were suggested as key to the successful implementation of the model. The methodology for developing this model was not explained by Pearl (2004). However, it is highly relevant to the present research since it relates to environmental standards and sustainability requirements.

Hansen and Knudstrup (2005) focused on the ability to integrate knowledge from engineering and architecture; thus, interacting to solve the often complicated problems connected to the design of sustainable buildings. Some of the aspects of their integrated design process were tested on a virtual design project in order to evaluate if the IDP can help achieve sustainable architecture. Hansen and Knudstrup (2005) and Pearl (2004) documents on IDP as related to this research are further analysed in Chapter Five towards development of the theoretical model of design information requirements, required of objective two in this study.

4.4 Other Type of Design Processes

According to Finger and Dixon (1989), a prescriptive model shows how design must be done, and a computable model expresses a method by which a computer can accomplish the task. However, Takeda *et al.*, (1990) argue that design theory for intelligent CAD is not useful when it is merely prescriptive or cognitive; for it must also be computable.

Much of the literature addressing other models of the design process, originates from both academic and non-academic sources. Watson (2004) developed a theoretical model of the design process for low-energy housing. His model was complex, making it difficult to translate into practical guidance. Additionally, it did not address the real life design process, focussing only on the design brief. Lowe *et al.* (2003a; b; c), explored the incorporation of environmental standards into the design of a small-scale, timber, social housing development. Roberts *et al.* (2005) in continuation of Lowe *et al.* (2003a-c) looked into how environmental standards can be included into the design of a masonry, large-scale, private-sector housing development. However, these studies are not directly used in this thesis since they do not identify integration within the design process.

However, the other types of design processes (apart from the RIBA in section 4.1, conventional and integrated design processes respectively in sections 4.2 and 4.3) can be categorically grouped into: purely theoretical; rational and reflex -in- action models.

4.4.1 Purely Theoretical Models

Purely theoretical models of the design process, based solely on theory, were presented in three publications (Hamel, 1994; Lawson, 1994; Pagani, 1999) Pagani (1999) recognises design as a collaborative activity involving teamwork and the input of many of those involved in the building delivery process. Pagani (1999) emphasised that many architects have disassociated themselves from economics, politics, and the social forces that shape buildings. Lawson (1994) questioned the process of a linear model with a

recycling loop back to synthesis if the evaluation was negative. This is similar to Mackinder and Marvin (1982), who argue that the basic model of the design process in reality is not as neatly categorised. However, these publications are not directly relevant to this study, as they do not address issues relating to environmental and sustainability design information requirements of architects.

4.4.2 Rational and Reflex -in -Action Process Model

Substantial disagreement exists about how designers in many fields, whether amateur or professional working either alone or in teams, produce their designs. Dorst and Dijkhuis (1995) contend that there are many ways of describing the design processes. They discussed two basic, though fundamentally different ways, both of which have several names. The prevailing view is referred to as: *Rational Model* (Hakkinen and Belloni, 2011); *Technical Problem Solving* (Schön, 1983) and *Reason-Centric Perspective* (Ralph, 2010). The alternative view is referred to as: *Reflection-in-Action* (Schön, 1983); *Co-evolution* (Babergh District Council, 2011) and *Action-Centric Perspective* (Ralph, 2010).

Pahl and Beitz (1996) developed a rational model, adopted after Newell and Simon (1972). They conclude that the design process is plan-driven and understood as a discrete sequence of stages. Typical stages consistent in the Rational Model, as related to architectural design process, and further recognised in Hakkinen and Belloni (2011) include:

a. Pre design

- Design brief- an early (often the beginning) statement of design goals;
- Analysis-analysis of current design goals;
- Research-investigating similar design solutions in the field of related topics;

- Specification-specifying requirements of a design solution for a product(product design specification) or service;
- Problem solving- conceptualizing and documenting design solutions;
- Presentation-presenting design solutions.

b. Design production/Development

- Development: continuation and improvement of a designed solution;
- Testing: in situ testing a designed solution.

c. Post-production design feedback for future designs

- Implementation: introducing the designed solution into the environment;
- Evaluation and conclusion: summary of process and results, including constructive criticism and suggestions for future improvements;
- Redesign: any or all stages in the design process repeated (with corrections made) at any time before, during, or after production.

However, the Rational Model has been widely criticised on two primary grounds. Ullman (2009) argues that designers do not work this way; extensive empirical evidence has demonstrated that designers do not act as the rational model suggests. The second primary grounds for the criticism was that, there are unrealistic assumptions, that is, goals are often unknown when a design project begins, because requirements and constraints continue to change (Schon, 1983; Marszal and Heiselberg, 2009; Ralph, 2010). The Action-Centric Perspective (ACP) is a label given to a collection of interrelated concepts, which are adversative to the rational model (Schön, 1983). Designers use creativity and emotion to generate design candidates, the design process is improvised, no universal sequence of stages is apparent, analysis, design and implementation are contemporary and inextricably linked (Schön, 1983). However, these two models were also not directly relevant to the present research, as they also do not address the issue relating to sustainability and environmental design information requirements for architects.

4.5 Decision Making

4.5.1 Decision Making in the Design Process and Sustainability

Lawson (2010) acknowledges ‘design’, as that which requires the use of experience, judgement and intuition. Hence, it becomes extremely difficult to apply conventional computing programs to model the process, especially at the early design stage. In the design process, the use of human intelligence plays a very important role (Mukherjee, 1995). This is because the major part of it makes the decision.

The popular view of problem solving in a design process is the assumption that progress occurs through methodical collection of data and careful inferences from observations. Harty (1994) in recognition of the traditional design process states that internal mechanisms that generate design solutions are considered to be mystical forces within a black box. That is, design creativity is something mystical and inexplicable. His view is that this has been a major deterrent to scientific studies of design.

Boddy *et al.*, (2007b) posits that critical decisions influencing the sustainability of a construction project, are made in a pressurised, time-critical environments. These decisions must be supported and informed by knowledge resources, with the reasons for these decisions feeding back into the body of knowledge (Boddy *et al.*, 2007b). Sandahl, *et al.*, (1994) state that the information on sustainability needs should be distributed to architects and the other project team members in easy to use formats, such as case studies, rules of thumb, checklists, handbooks and worksheets.

If people can draw on accurate knowledge, they will react differently to information and data, than if they have no prior experience and learning to guide them (Boddy *et al.*, 2005). This has been the basis for the existing environmental and energy-related tools predominantly developed at universities and research establishments. They do not, however, fit into the working practice of architects, nor serve today’s decision-makers’ information demands. Although architects, construction industry representatives and marketing experts, did participate in the development and testing of these assessment tools, the tools’ application leads to a mismatch of information

supply and demand. This is because the end users of information such as architects, investors and property valuation professionals, have neither fully recognized, nor appropriately formulated, their particular requirements for assessment results associated with their field (Boddy *et al.*, 2005)

The majority of designers interviewed for a survey carried out on behalf of the Building Research Establishment (BRE) by Gangemi *et al.*, (2000), claims that the main sources of information on environmental issues, as at the time of their research, were represented only in specialised journals and publications. This included architects' journal and various reports published by BRE and other research institutions. Yang *et al.* (2008), however, proposed a matrix-based decision-making method (Quality Function Deployment; QFD) that enables design teams to clearly specify the integrated requirements of designers' upstream customers, the clients, their downstream customers and construction professionals. There is also a need to systematically evaluate each proposed design alternative in terms of their impact on meeting the requirements (Yang *et al.*, 2008).

4.5.1.1 Communication and Collaboration in Decision Making

Wallace (1987) and Gorse *et al.*, (2001) discussed communication between project team members within the construction industry. Wallace (1987) investigated the communication pattern of architects during the decision-making process. He used a longitudinal and fourteen cross sectional case studies, as well as interviews and content analysis of design team meetings. Wallace (1987) showed that architects' involvement in decision-making were much less apparent in the middle stages of the design process when cost became an increasingly important influence throughout, often at the expense of aesthetics.

Gorse *et al.* (2001) examined the social interactions of the project team using four case studies of building projects. They used interaction process analysis of three design meetings and a form of content analysis to interpret social interactions in small face-to-face groups. Their analysis revealed that both

architects and contractors are important to the design and management of building projects, as the two are heavily involved in decision-making.

Collaborating as an integrated and co-ordinated team to achieve common objectives and shared benefits, is an agreed method of working together (Constructing Excellence, 2006). Weingardt (1996) investigated the role of collaboration between architects and consulting engineers, using case studies to provide evidence of successful collaboration. He concluded that collaboration enabled better decisions to be made and better budgets to be achieved. Weingardt (1996) further suggested that collaboration should be encouraged right from the beginning of the project, with everyone involved in the process being invited to take part. Lowe *et al.* (2003) support design and project teams using collaborative approach. They posit that the approach should incorporate enough flexibility to deal with communication issues; such an approach is likely to produce satisfactory solutions.

At the project level, there are many decisions taken in the initial stages of the design, which will have a direct impact on the sustainability of the project (Boddy *et al.*, 2007b). To effectively promote sustainability, these decisions must be informed by sustainability- related knowledge and experience, as well as integration of BPES tools into the architectural practice. Moreover, time and finances dictate that design choices and decisions made in the initial stages of a project are effectively fixed and cannot be 'revisited' or changed; hence it is crucially important that the correct choices are made from the onset (Boddy *et al.*, 2007b).

4.5.2 Decision Making at the Early Design Stage

The design process from the RIBA Outline plan of work stages consist of four main phases preparation stages A and B; conceptual design stage C, design development stage D and technical design stage E. The preparation and conceptual design stages A to C form the basis for the remainder of the design process. During this stage, designers make various decisions suitable for the building project from a number of possible choices and schemes.

The conceptual design, within the early design stage, involves activities and decisions that are heuristic in nature and rely more on experience and judgement than on computation (Harty and Danaher, 1994; Lawson, 2010). At the conceptual stage of the design process, decisions are made about the most appropriate schemes for the project at hand. Ballal *et al.*, (1996) argue that designers at this stage should ideally consider a number of alternative schemes, thoroughly evaluate each scheme, and choose a suitable structure. However, this has rarely been the case, despite modern buildings becoming increasingly complex, and choosing a suitable scheme is becoming more important.

De-Groot and Mallory Hill (1999) acknowledge that the conceptual stage of the design process is the point where a small number of people make decisions that have far-reaching implications on both the efficiency and effectiveness of projects. Decisions made during conceptual design are considered to have the greatest influence on project performance and have the least associated cost (Beadle, 2008). This is in agreement with Evbuomwan and Anumba (1996), who emphasise that decisions made at this stage have a significant influence on costs. According to Bishop (1996), eighty per cent of the overall cost of a project is determined by the first twenty per cent of decisions, taken at this stage.

Improving the quality of conceptual design is therefore crucial to the whole design process. The concept design stage is the stage of the design and construction process when designers work on the proposal for the selected site. In most cases they do this with limited information, apart from some key factors deduced from the preparation stage. Information at this stage is largely approximate and not exactly defined. Most of the time, this is reflected in the information gained from verbal descriptions, sketches and drawings, both digital and on paper.

However, more often than not, computers cannot interpret representations automatically, since the semantics of the content often requires human interpretation (Rudy and Jaksch, 2004). Consequently, there is desire to reuse existing design knowledge from previous design solutions. This calls for new methods to record the decision-making process. With the additional methods in

the form of BPES tools that fit into each stage of decision making by architects, it should be possible to develop a greater variety of concepts and possibly gain more time for the investigation of innovative design ideas.

Akin (1986) presents a picture of the psychology of designers at the initial stage of the design process and illuminates architects' design exploration processes by studying their behaviour. He stresses, creativity is a complex process of the interaction between many mental operations. By clarifying the scope of design knowledge, he designed an information-processing model that account for such behaviour.

For Bass *et al.*, (1998), 'architecture' as means of capturing early design decisions, touches upon both functional as well as non-functional aspects of cognitive operations. According to Bass *et al.* (1998), the early design decisions are important since their ramifications are felt in all subsequent phases. In this sense, architecture forms a bridge between a system's definition and a system's design. It has therefore become prudent for building development teams to spend sufficient time and effort during the early stage of the design process to get the design right.

Kartam (1996) argues that majority of design professionals rarely seek constructors' opinions at the early stage of the design process. He emphasises, the lack of practical construction knowledge required to make prudent construction-driven decisions. As a result, opportunities are missed in making use of knowledge of the construction process, which later leads to impractical, complex, and costly designs, and poor overall quality of the project.

The key factors usually determined at the early design stage are issues such as the proposed occupancy types (residential, office, commercial, or retail and car parking), the anticipated amount of area or space required for each occupancy type, as well as the extent, shape and orientation of the site. These are carried out at this stage, because the designer is looking to recommend the selection of key building system and complete an initial configuration to obtain better or more accurate information about the proposed building project. However, at this stage, the designer avoids obligation to undertake the work entailed in producing a detailed design along with accompanying documentation. The

consensus of the industry representatives is that this type of operation results in each professional tending to optimise within their own specialisation (CRC, 2005).

However, overall optimisation or balance was believed critical to specify the absolute 'best' design that will allow the architects, engineers and other design team members work in harmony to achieve a balanced outcome. The early design has been known to usually be undertaken by working with what are commonly called the "massing models" where blocks or prisms with little details other than size and shape are used to represent parts or the envelope of the proposed building (CRC,2005).

The complexity of modern buildings also means that the successful completion of the initial design has now become more important and the choice of economic framework has become more difficult. Mackinder and Marvin (1982) state that pressure of time had forced designers, especially architects, to get projects committed to paper in order to produce relevant information, rather than ponder on the actual quality of the design. In such circumstances, there is little time, or no time at all, for designers to scrutinise alternative design solutions and thoroughly evaluate them. Maher (1987) acknowledges designers opting for the most obvious or apparent choice regarding the concept, sustainability and environmental decision of the design. This is because designers do not have the time or the resources, such as the BPES tools, that fit the nature of their decision making for each stage. Thus, they cannot thoroughly investigate all possible choices and schemes, nor can they develop multiple configurations (De-Groot and Mallory Hill, 1999).

Other researchers (Weytjens and Verbeeck, 2009; Lawson 2010) also recognise that time pressure contributes to designers relying on their own experience in making decisions. Ballal *et al.*, (1996) argue that such practice is insufficient to produce buildable designs that satisfy clients' needs. According to Ballal *et al.*, (1996), appropriate information at the right time and especially at early design stage is vital to ensure the desired quality of construction projects. This will ultimately contribute to a reduction of negative impact of buildings on the environment.

A number of studies, such as Neuckermans (1992); Reed and Gordon (2000); Ellis *et al.* (2001); Pearl (2004); Zhu *et al.* (2007); Sodager and Fieldson (2008) and Fieldson *et al.*, (2010) had further demonstrated that indeed, early decisions in the design process have the largest impact on the sustainability of the final design. Decision-making at this early phase of design relies on available information that may be incomplete, such as maintenance costs (De-Groot and Mallory Hill, 1999), or overly complex, such as the code requirements of the Code for Sustainable Homes (CSH).

Nevertheless, Verghese and Hes (2007) recognise the need for growth in the tools and approaches that will assist in supplying stakeholders with information such as, green gas emissions, embodied energy, waste, recycling quantities and material selection. Elforgani and Rahmat (2010) state that the major environmental impact of a building is determined at the conceptual design phase.

However, Aliakseyeu *et al.* (2006) addresses the potential of artificial neural networks in improving the quality of the conceptual structural design. They investigated the development of artificial neural networks to act as decision support techniques to aid structural designers in finding the most appropriate structural frame of a building, given its constraints and requirements. They propose a structure for a neural network mode and present possible parameters for the model.

Dunsdon *et al.*, (2006) also described the findings of their project, which aimed to integrate the range of activities, tools and information that constitute the low carbon building design process. They argued that it should combine them into a conceptual framework that can be used by developers, planners and architects at the critical early decision making stages of the procurement and design process. Conclusively and towards making the right decisions, the designers should incorporate environmental, sustainability and construction issues in their designs right from the onset.

4.5.3 Human Decision-Making Process

Human problem solvers appear to rely heavily on heuristic search methods. Simon (1982) proposed a theory that combines models of human memory with information-processing models to explain human problem solving mechanisms. He argues, ‘chunks’ are related to a higher level-structure containing detailed domain specific knowledge. ‘Chunks’ are necessary for creative problem-solving activities that may allow one to move directly to the goal (Simon, 1982).

Turban (1993) contends that in order to automate assisting humans in decision making, one should keep in mind that people are not entirely rational. The way that people react to problems, the way they perceive problems, their values and beliefs, may all cause people to make decisions differently. Different psychological personality types also exist which play an important role in the decision- making process. The ways that people approach decisions are usually influenced by preference, as determined by their personality type. For Mallach (1994), knowing the personality type of the decision-maker will help in designing appropriate tools to support that person. Huitt (1992), referenced in Mallach (1994) summarises the preferred decision-making techniques to be of eight personality types. He states that for a decision support to be useful, it should include some of the decision-makers preferred decision-making techniques. This is adopted in this research with the use of RIBA Outline Plan of Work, recognised by both architects and the construction industry in the UK (RIBA, 2011). Nevertheless, Dean (1991) referenced in Mallach (1994) categorises methods by which decision-makers decide into three dimensions:

- **Rationality:** the ability to collect and analyse information objectively and make a final choice according to the objectives;
- **Politically:** the ability to make decisions in a group within the team’s goals and power, when different goals exist among the members of the group: It is characterised by compromise and should aim at a win-win outcome;
- **Flexibility:** the ability to make decisions that break the mold of tradition and structure.

Another important factor that determines the type of preferred support is whether decisions are to be made by an individual or a group. This is because psychological types also affect how well people work together in teams. Sauter (1999) differentiates between four decision-making styles, which are: left-brain; right brain; accommodating and integrated while Table 4.4 from Mallach (1994) shows the preferred technique for each of the decision-making styles.

Table 4.4: Preferred decision-making techniques for personality types

Decision-making style	Preferred technique
Left-brain	Analytical and quantitative techniques
Right-brain	Unstructured and spontaneous procedures concerning the whole rather than its parts such as Brain-storming, emergent trend projection
Accommodating	Has dominant styles but adopt to require the alternate decision-making style
Integrated	Combines left- and right brain, taking advantage of their symbiosis filtering the information analytically (left-brain) while intuition helps decision-makers contend with uncertainty and complexity, constantly verifying the appropriateness of the decision

Source: Mallach (1994)

Systematic decision-making ensures that all aspects of the decision-making receive consideration. Hence, Mallach (1994) as part of the decision-making process proposed the following stages:

- State the decision purpose;
- Establish objectives;
- Classify the objectives by their importance;
- Generate alternatives;
- Evaluate the alternatives against their objectives;
- Make a tentative choice;
- Assess its potential adverse consequences;
- Make a final choice.

4.5.4 Decision-Making Models and Support Framework

Decision-making often involves the exploration of situations that do not yet exist. Analysing such situations requires a model or abstraction of reality, rather than reality itself. A model is a simplified representation or abstraction of reality (Turban *et al.*, 2001). Models are used to portray the important aspects of reality while eliminating other aspects, which cause difficulties in a particular situation. Mallach (1994) recognises building as a simple model while Turban *et al.*, (2001) provide extensive lists of benefits gained when presenting a problem by using a model. Turban *et al.*, (2001) further classify models as being *iconic, analogue, mathematical, and mental*, while Mallach (1994) classifies models into *graphical, narrative, physical, or symbolic* models.

The concepts are converse and collectively by which both authors ignore the central issue in decision making, which is the support and improvement of decision-making(such as the DSF, which will be proposed in Chapter Nine). Turban (1995) argues that it is far more beneficial to deal with the characteristics and capabilities of a Decision Support System (DSS). He formulated his working definition by defining a range of basic DSS to an ideal DSS. He stated that at minimum, a DSS is an interactive, flexible and adaptable Computer Based Information System (CBIS). It is specially developed for supporting the solution of a particular management problem for improved decision-making.

Design in the domain of structural engineering as well as in architecture, requires information of many kinds (textual, graphic, geometric, topological, and geographic) to describe different aspects of the designed building, such as its shape, extent, location, orientation, or topological relationships of spaces and components. Although much information is already available in the form of digital documents, the need for human interpretation of these documents still remains (Lawson, 2010). The process of decision making in De-Kock (2003) is in the Figure 4.1. Gorry and Scott-Morton (1971) first proposed the use of framework in decision making while Turban *et al.*, (2001) explore the use of a framework to determine the needs of decision support.

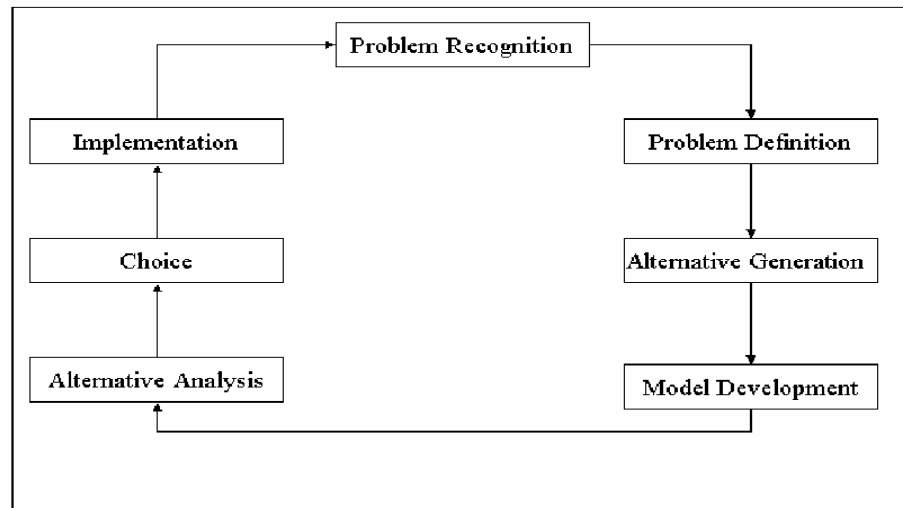


Figure 4.1: The DSS decision-making process

Source: De-Kock (2003)

4.6 Past Models and Frameworks

Buildings were described in Dibley *et al.*, (2012) as complex entities involving a wide range of stakeholders from a large number of disciplines. They are complex systems that involve several forms of interactions within and across systems, sub-systems, and components, which translate into patterns of structure and behaviour. Thus, the understanding and modelling of patterns of structure and behaviour can be approached by adopting a holistic view of the building systems as opposed to focussing on analysing the systems and constituent components individually (Dibley *et al.*, 2012). Strategic decision-making in the design and construction of buildings is a knowledge and information intensive process. Information services, such as the DSF, for this purpose, should ensure that the right information reaches users, in the right format and at the right time to make the right decisions. Neither too much information nor insufficient information, would be right for supporting the users (Sun and Liu, 2001).

To the author's best knowledge, there is no publication that addresses the limitations of existing tools for architects' decision making, through provision of architects requirements of BPES tools to achieve low carbon housing design in the UK. The approach adopted in this study involves the application of the DIR, with integration of BPES tools in decision-making to help architects at all

stages of the design process. This will fill the gap towards the need to dramatically reduce carbon usage in buildings from the onset of the design process, as well as achieving the significant changes precipitated by climate change.

Nevertheless, some related reviews in US, which influence this study, include Canada Mortgage and Housing Corporation (CMHC, 2004) from the International Energy Agency (IEA,2001), who organised tools by stage in the building life cycle. They further developed the Green Matrix website, which combines the LEED categories with the phase in the design/build process. Keysar and Pearce (2007) also, developed Decision Support Tools (DSTs) for green building. The DSTs facilitate selection among new adopters on public sector project for architects and engineers working for United States Army Corps of Engineers (USACE).

Other influencing reviews within the scope of this study include Dunsdon *et al.*, (2006), who proposed a computerised framework to map the design process. However, Dunsdon *et al.*, (2006) integrates energy analysis at the appropriate decision points, but, without the architects design information requirements as proposed in this study. Nevertheless, Verghese and Hes (2007), developed a qualitative and quantitative tool to support environmentally responsible decisions, but without the tools integration and computerisation as done by Dunsdon *et al.*, (2006).

Yang *et al.*, (2008) developed a matrix-based decision-making method (Quality Function Deployment -QFD) that enables a design team to specify clearly, the integrated requirements of designers' upstream customers (the clients) and their downstream customers (the construction professionals). A process framework for building design was further proposed in Loh *et al.*, (2010). They developed an ICT system to support multi stakeholder decision-making, and to facilitate inclusion of energy issues in the early design phase of buildings. They posit that this was supposed to be in addition to the existing green building guidelines and frameworks, which provide information about design standards to achieve (Loh *et al.*, 2010).

4.7 Summary

This chapter reviews the stages of the design process in the RIBA Outline plan of work towards defining the structure for the proposed decision support framework in this research. It reviews published and unpublished academic work on various types of design processes and establishes the critique of the conventional design process. The chapter finally reviews decision-making in the design process especially that of the early design stage towards development of the required decision support framework in this research.

Chapter Five: Design Information Requirements

5 Introduction

Chapter Two discussed the theoretical principles for understanding low impact housing design, including the generic processes for its formulation and the need for it. The existing statutory and non-statutory regulations, as well as environmental guidance for sustainability at both local and international levels relating to the design, were also discussed. Chapter Three focuses on the architects' role and BPS tools for the design and delivery of low carbon housing. Chapter Four reviews various academic publications and books relating to design processes, and particularly the RIBA Outline Plan of work, familiar to architects and the general construction industry in the UK. It further reviews decision-making towards the development of the Decision Support Framework (DSF) required of the study.

Based on the critique in the use of BPES tools by architects to achieve the design and the observed gap in the existing design processes, five case-based documents on integrated design process are identified in this chapter. This is towards the development of the integrated building design process (IBPD) that consist the theoretical model of design information requirements (DIR) that helps the classification of the design tasks in the decision support framework. The approach adopted in this research towards the design and development of the theoretical DIR (objective three of this study), is shown in Figure 5.1. The outline of the contents within the chapter is:

- Case-Based Documentary study and Analysis;
- Case-Based Documents;
- Analysis of Case based Documents on IBPD;
- Level 5, Case-based Documents;
- Integrated Building Design Process;
- Summary.

5.1 Case Based Documentary Study and Analysis

Documentary analysis looks at texts produced in relation to the culture or setting being researched, often generated by the culture itself, and which may be self-documenting (Atkinson and Coffey, 2004). Documents are usually used to confirm areas of interest to the researcher, as they have a tendency to be shrouded in subjectivity (Knight, 2002). Documentary analysis was used in several of the reviewed literature in this study, mainly to supplement data collected from other sources. Lowe *et al.*, (2003c) state that documents often formed part of the design process within the construction industry. This may include design documents and design briefs (Mackinder and Marvin, 1982), minutes from design team meetings (Wallace,1987; Beadle, 2008) and regulations (Hamel, 1994). Documentary analysis is also a good method of supplementing data collected from different sources, such as interviews, observation and questionnaires (Atkinson and Coffey, 2004). Thus, the five case-based documents analysed in this chapter are:

- The Integrated Design Process (IDP): a more holistic approach to sustainable architecture (Hansen and Knudstrup, 2005);
- Integrated Design Process of Sainte-Catherine Street West, Montreal, North America (Pearl, 2004);
- Integrated Building Design Process from Canada, Finland and United States (Reed and Gordon, 2000);
- Integrated design process of Energy star building design guidance in the United States (US) developed by Environmental Protection Agency (EPA) (National Institute of Building Science,2008; United State Environmental Protection Agency,2012);
- Federal Energy Management Programme (FEMP) IDP for Federal facilities and Housing in United State (Federal Energy Management Programme, 2001).

Relying on these documents alone, however, can be unwise, as it will rarely give the whole picture and may be biased by the author of the particular document. Hence, credibility for selecting the documents is discussed in Section 5.1.2.

5.1.1 Rationale for Case- Based Documents Identification

Low carbon housing and its delivery, as a term is a new field in UK, compared to definition of sustainable and low energy housing. Hence, identification of academic papers along with the design process were hard to come by as most of the construction professionals use the already in existence RIBA Outline plan of works stages. Consequently, internet search was used to accomplish the purpose by using the key word '*Design processes*'. This brought about different types of design processes analysed in chapter four. It also included design process as related to the engineering profession such as in chemical and mechanical field.

'Integrated building,' as a term was then added to the 'Design processes,' and used as key word search. This brought about publications and reports on integrated building design processes. However, most were not directly related to this study, as they were not in stages of design, identified from RIBA plan of work stages. However, five case-based documents were eventually identified based on the following criteria:

- **Significance to UK (RIBA) recognised design stages**

All the identified documents were selected based on their significance and relevance to stages of design from RIBA Outline plan of work stages which are: preparation stage '*A*' to technical design stage '*E*', discussed in section 4.1.5.

- **Appropriateness**

All the identified documents were checked for suitability in relation to the project they covered. '*Sustainability design*' or '*low energy design*' were used as a source of identification for the related documents by which, all the documents analysed in this chapter met this criterion. Reed and Gordon (2000) and Hansen and Knudsrup (2005) documents on integrated design processes are for the general building industry and not specifically for housing design. However, it is of the opinion that, these two are still relevant, since housing design is under the general building industry.

- **Source of Identification**

When checked for source of information, academic publications and theses on integrated design process are of great importance. This led to identification of six reviews on low energy design process, among which, was the structural wiki. However, structural wiki was not used, since it is neither an academic publication nor a thesis. Nevertheless, guidelines and reports, such as; Energy star building design guidance for low energy housing in the United States (US) developed by Environmental Protection Agency (National Institute of Building Science, 2008) and Federal Energy Management Programme (FEMP) for Federal facilities and Housing in United State (Federal Energy Management Programme, 2001) were used. These were used because; their credibility would have been checked (Section 5.1.2). Nevertheless, attempts were made to stay on top of the latest publications. This was done through weekly scans of the major institutions and organisations and through monitoring of various discussion groups at the academic and industry level.

- **Up to Date**

All the identified design processes especially those from UK were checked for suitability in relation to how current the academic journals and conference proceeding(s) were. The up-to-date rationale and suitability was based from the year 1987 in favour of Brundtland Commission Report (1987) on sustainability.

5.1.2 Credibility of Documents

The credibility of the documentary research depends on the originality and reliability of its source and the efforts employed to reduce the inherent biases (McCulloch, 2004). To demonstrate credibility, all documents that are in form of reports used for analysis in this chapter, were accessed from the original source, such as the homepage of the websites provided by the organisations of the department. The concerned documents include:

- Energy star building design guidance for low energy housing in the United States (US) developed by Environmental Protection Agency (EPA) (National Institute of Building Science, 2008);
- Federal Energy Management Programme (FEMP) for Federal facilities and Housing in United State (Federal Energy Management Programme, 2001);
- Code for Sustainable Homes: Case Studies (CLG, 2009);
- Five Sustainable Homes: The Old Apple Store (Ecos Homes, 2009).

To attest to the credibility of these reports, signatures of the board chairpersons, project sponsors and publication dates are contained on the identified documents. However, the main concern is the intrinsic biases, as these reports were prepared for the individual and approving authorities. The response to this was that the approving authority must have reviewed the documents prior to approval. Thus, providing the credibility that the biases, would have been thoroughly identified and addressed.

The other documents analysed are two published journal papers (Reed and Gordon, 2000; Pearl, 2004) and a conference proceeding (Hansen and Knudstrup, 2005) on integrated design processes. The credibility of the two journals and the conference proceeding is in the fact that they would have been reviewed by experts in the field before being published. This infers that their credibility has been well tested and checked to qualify them for analysis in this study.

5.1.3 Concept Adopted for the Case-Based Documentary Study

Hence, the case-based documentary study is adopted after Henjeweale (2010). It focuses on an integrated design processes (IDP) towards development of the IBDP. The set of design information requirements (DIR) within the process is towards determination of decision making applicable to different stages of the RIBA Outline Plan of Work with BPES tools, which fits into the working practice of architects at the different stages.

Past research, which influenced this study, include Macmillan *et al.*, (2002), who presented a model that concentrated on the concept stage of the design process. It was developed by comparing process maps, through interviews and case study analyses, over a two year period. Watson (2004) developed a theoretical model of the design process for low-energy housing, which would have been good for analysis. However, the model was a complex one and would be difficult to translate into practical guidance. The focus of the model was only on the design brief within the design process.

However, Hansen and Knudsrup (2005) analysed the stages of design in the integrated process for sustainable design. Their work was used as one of the case-based documents in section 5.3.1. The other case-based documents include: Reed and Gordon (2000); Pearl (2004); Energy Star Building Design Guidance (2008) in America and Federal Energy Management Programs for federal facilities and housing by the United States Department of Energy (FEMP, 2001).

5.1.4 Analysis of the Case -Based Documents

Template analysis, similar to researchers such as Beadle (2008), was adopted to summarise and synthesise the arguments and ideas from the case-based documents. This further serves as a handy guide to the topic.

Template analysis is a form of thematic analysis. To analyse data using template analysis, the researcher identifies or develops a number of themes or codes which summarise and join together some of the key ideas, actions, experiences and concepts from the data that is being analysed (Clarke and Gibbs, 2008). This was done in this research parallel to King (2004), which used template analysis of interviews carried out in his research and Au (2007), who analyses forty-nine qualitative studies. Beadle (2008) also used the same method to analyse the design team meetings that she attended during the course of her research. She finally developed a nine-step approach adopted after King (2006).

However, King (2004) states that the method can be used with any kind of textual data. Hence, the process for developing the template used in this particular study is outlined below, adopted after King (2004); Au (2007) and Beadle (2008). Eight steps were developed and used as a template to analyse the identified case-based documents on the integrated design processes. They are:

- **Set predefined terms for coding before grouping them into broader themes for analysis**

Themes are arranged into a hierarchy by which it can be generated before and during data analysis.

- **Note Taking and Initial coding**

Data were typed up as soon as possible after review of each case-based document. Initial coding was conducted by hand, using predefined codes and then applied to all notes and transcripts. However, the same passages can be coded to more than one code. Relevant texts relating to the research objectives were assigned an existing code. If a particular piece of text did not fit into an existing code, a new code was created to classify the text and that code was then added to the existing codes, when coding the rest of the data.

- **Initial template**

An initial template was created from the codes used in step two. Predefined codes outlined in stage one were removed if they were not applicable to the reviewed literature or document. Lower order codes were also added to provide greater specificity where required.

- **Developing the Template by re-reviewing all the Processes**

Identifying text relevant to the research objectives, and adding the appropriate code from the initial template. The template was modified as this process progressed to remove any inaccuracies in the template.

- **Validating the Template**

The developed template was validated, to make sure that it was appropriate for use. The main strategy to validate the template was inter-coder reliability, which involved asking an external advisor who had experience of analysing qualitative data to check if the template was sufficiently clear and comprehensive. The external advisor was asked to code a selection of a text in the literature being reviewed using the developed template. He then made some comments and correction about the process of coding the text using the developed template, which was then discussed and revised where required. However, disagreement occurred on some coding between the researcher and the advisor. These were discussed rather than quantified, since there are always a variety of ways of reading a text , which differ from one person to another (Robson, 2002).

- **The Final Template**

The final template was created after correction and validation based on the comments from the external advisor

- **Interpreting Coded Data**

The coded texts were interpreted by first listing all codes present in the case-based documents to draw attention to issues of importance. The codes, texts and themes that were seen to be most relevant to the research objectives were focused on; those that were not relevant discarded.

- **Writing up and Presenting the Findings**

The write up and presentation of the interpretation of the texts is the final step in the analysis. This involves summarising the notes made about the codes, selecting illustrative quotes and producing accounts of the findings. These accounts were based on the main themes identified.

5.2 Case Based Documents

Figure 5.1 shows the approach adopted towards development of the theoretical model of design information requirements within the IBDP in this chapter.

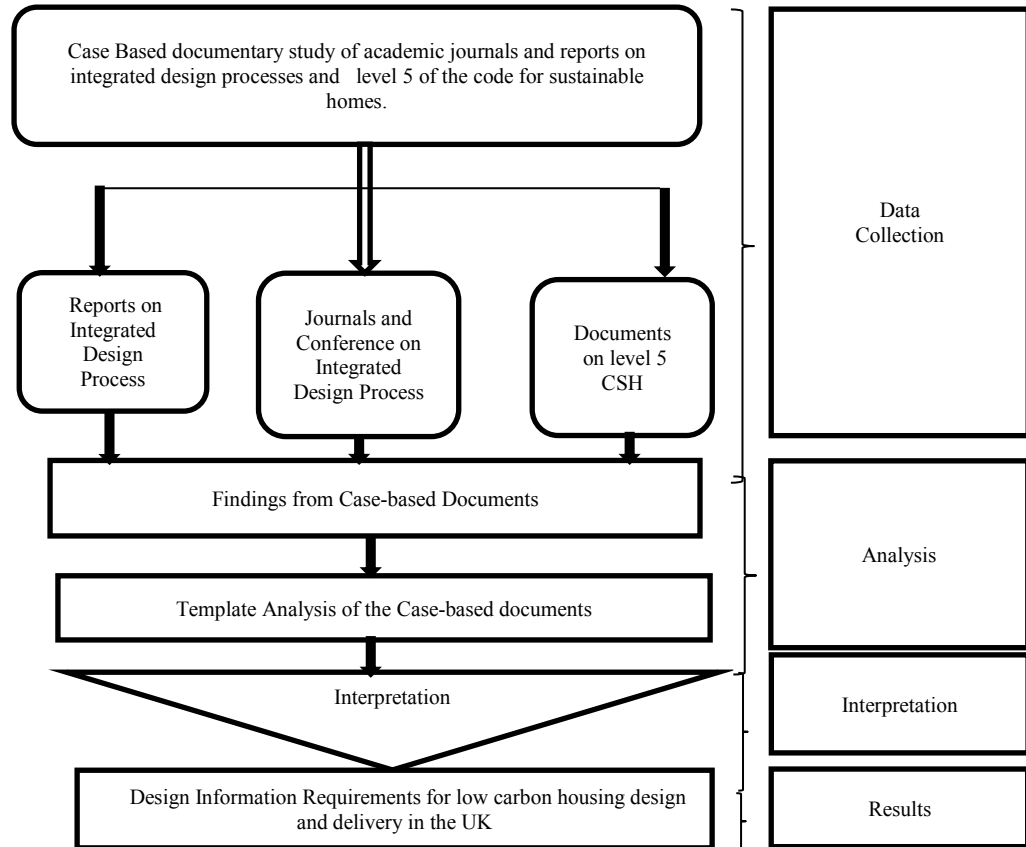


Figure 5.1: Method of DIR Development

The background addressing issues relating to the RIBA Outline Plan of Work was provided in Section 4.1. The observed gap results into the investigation of five case-based documents on the IDP. Analysis of documents on Level 5 of the Code for Sustainable (CSH) case studies were also carried out towards the development of the sustainability requirements within the IBDP. The aim of this particular chapter is thus:

- To identify, analyse and compare the case-based documents on integrated building design processes;
- To analyse documents on existing CSH, Level 5 case studies;

- To design and develop the IBDP, which consist the theoretical design information requirements to achieve low impact housing design in the UK.

The case-based documents (Reed and Gordon, 2000; FEMP,2001; Pearl,2004; Hansen and Knudstrup,2005; National Institute of Building Science,2008; CLG,2009; United States Environmental Agency, 2012) on Integrated Design Process (IDP) are used to develop the set of design information requirements (DIR) for each stage of the Integrated Building Design Process (IBDP).

5.2.1 Hansen and Knudstrup (2005)

Hansen and Knudstrup (2005) presented the IDP in an international conference proceeding (SB05) in Tokyo, on sustainable architecture and available design methods. Their paper focuses upon the ability to integrate knowledge from engineering and architecture to interact with each other in order to solve the often complicated problems associated with the design of sustainable buildings. Some of the aspects of the integrated design process were tested on a virtual design project to evaluate if the IDP can help achieve sustainable architecture. The environmental design information requirements in the form of an integrated team approach as derived from phases of design in their process (Appendix 1) is shown in Figure 5.2, reflected in Section 5.5 in the IBDP, to achieve low impact housing design in the UK.

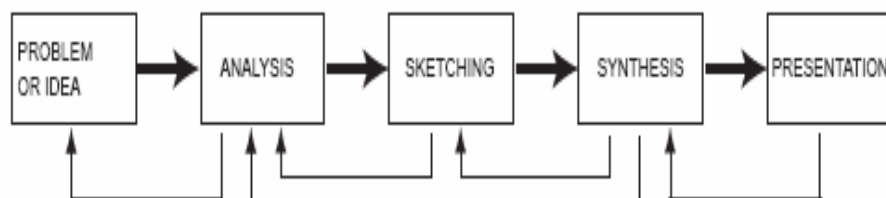


Figure 5.2: Phases of an integrated design process

Source: Hansen and Knudstrup (2005)

The illustration in Figure 5.3 indicates the number of iterations that has to be made in the IDP of Hansen and Knudstrup (2005). Illustrations like this, were

made for each parameter found in the IDP when applied to sustainable architecture. This illustrates the complexity of the design process and simultaneously provides a comprehensive view of the parameters involved in the IDP of Hansen and Knudstrup (2005). The parameters listed on the left side are those which influence the design of the climate, while the parameters listed on the right side are those which are influenced by the design of the climate screen (Hansen and Knudstrup, 2005).

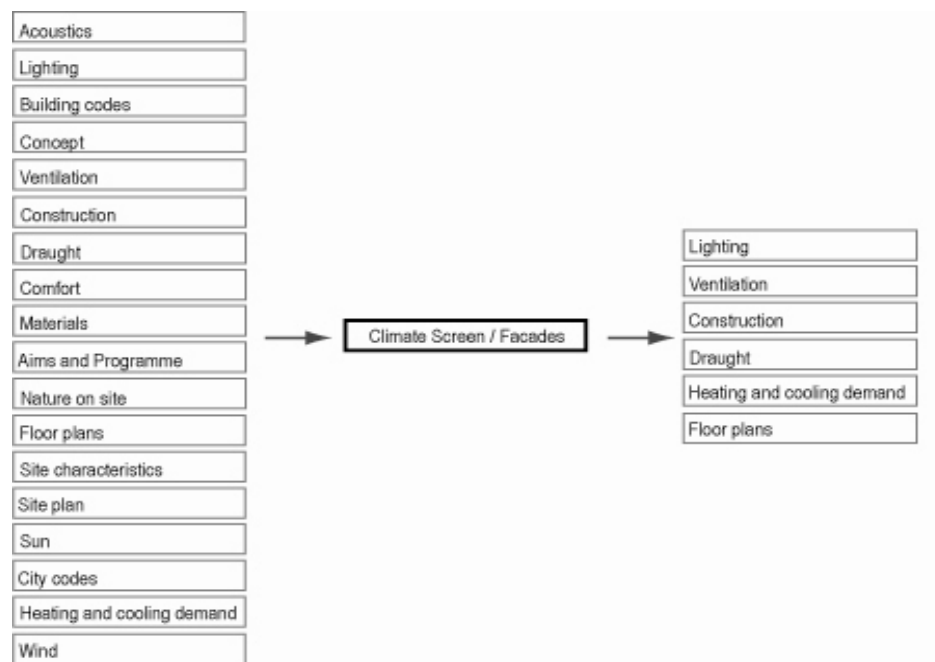


Figure 5.3: Iterations in decision making

Source: Hansen and Knudstrup (2005)

5.2.2 Pearl (2004)

Pearl (2004) is an academic paper published in North America. Pearl (2004) analysed the integrated models of the design to create a circular model, tested on a life project called the Sainte-Catherine Street West (SCSW). The IDP centred on an intensive design charrette where the client, architects, engineers, and other specialised consultants, were brought together to collectively examine and eventually establish a primary design direction. The client's

primary objective is to validate the economic potential in creating and building an innovative development that is predominantly environmentally sound.

The post-charrette work allowed a more precise evaluation of the different ideas and some technologies, such as a geothermal exchange loop, passive underground earth pipes for fresh air intake, natural day lighting, and passive solar design. However, technologies, such as green roof and breathing walls, although vital from an environmental perspective, were not shown to provide direct economic benefits that are indisputably quantifiable.

By having the pre-designed various scenarios, and having both financial and energy performance feedback on these scenarios before the commencement of the design charrette, the design team was able to spend more time on exploring the potential synthesis of divergent concepts than may typically be the case. Identification and research of numerous green technologies (specialised items) in advance (leading to the selection of quite an eclectic group of participants) enabled the design team to spend more time on concepts of the design.

By providing an opportunity for socio-cultural, historical and contextual design considerations within the charrette exercise (alongside the pragmatic and ecological goals), the architectural team also had an easier task to create the final design after the charrette was developed, since they do not have to start 'from the scratch'. Thus, Pearl (2004) IDP actively involves the client in the design process, so that sustainable concepts that are financially sound concepts are not flippantly eliminated at a later stage. The model was tested on architecture students in Canada, as well as on real projects such as the L'Oeuf charrette, to produce very good energy reduction results.

5.2.3 Reed and Gordon (2000)

Reed and Gordon (2000) is an academic paper in UK which focuses on Canada, Finland, and the United States. They presented two models of design processes; the conventional linear design process, and an IDP. Their IDP encompasses cross-disciplinary teamwork and enabled the improved

integration of the building, the community, and natural and economic systems as key to sustainable design delivery.

When the building industry is presented with workable and cost justified models for initiating and implementing integrated design, it will be able to test the benefits of sustainable design, which can have an enormous positive impact on the environment that can be a platform to define a new role for the building industry (Reed and Gordon, 2000). The summary of activity for the stages of design in the IDP of Reed and Gordon (2000), for a speculative green development practice in Canada, Finland and USA is in Appendix 1.

5.2.4 Energy Star Building Design Guidance

Energy Design Guidance is a management approach document for commercial and new home construction projects in the US (National Institute of Building Science, 2008; United States Environmental Agency, 2012). It is a set of suggested actions for building owners and design professionals to establish energy efficiency goals, as well as to ensure that energy is addressed at all levels of the project. The guide was designed to supplement technical design references for incorporating energy efficiency strategies and technologies.

To earn the ENERGY Star a home must meet strict guidelines for energy efficiency set by the USEPA. The homes are independently verified to be at least 15% more energy efficient than homes built to the 2009 International Energy Conservation Code (IECC). They also feature additional measures that deliver a total energy efficiency improvement of up to 30% compared with typical new homes and even more compared to most resale homes (United State Environmental Protection Agency, 2012). The stages of design as recognised by the guidance are in Appendix 1.

5.2.5 Federal Facilities and Housing Design Guidance

The document from FEMP (2001) identifies with all the criteria in section 5.2.1, except that it is not UK based and is not an academic paper. However, it is, accepted as a report for this study based on the credibility of documents discussed in section 5.1.1.

The Federal Government in the United States is the nation's single largest landlord and energy consumer, operating more than 500,000 facilities and comprising more than 3 billion square feet and 8,000 locations worldwide. Historically, approximately \$30 billion is spent annually on acquiring or substantially renovating Federal facilities (Federal Energy Management Programme, 2001). This represents 2.5% of all primary energy consumption in the United States.

The Federal Energy Management Program (FEMP) was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure (Federal Energy Management Programme, 2001, National Institute of Building Science, 2008).

Hence, FEMP (2001) is a guidebook for the design process of new building for federal facilities and housing by the United States Department of Energy, Office of Federal Energy Management Programs (FEMP). It defines low-energy building design as not just the result of applying one or more isolated technologies, rather, as an integrated whole-building process that requires advocacy and action on the part of the design team throughout the entire project and the development process. The whole-building approach justified, it can save 30% or more in energy costs over a conventional building designed in accordance with the Federal Standard.

The guidance emphasises that low-energy design does not necessarily have to result in increased construction costs. It further states that one of the key approaches to low-energy design is to invest in the building's form and enclosure (e.g., windows, walls) so that the heating, cooling and lighting loads are reduced, and in turn, smaller, less costly heating, ventilating, and air conditioning systems are needed (Federal Energy Management Programme, 2001). The identified stages of design in FEMP (2001) for integrating low energy concepts into the design process of housing development are shown in the Appendix 1.

5.2.6 Discussion on the Integrated Design Process

In all the reviewed case-based documents, it is only Hansen and Knudstrup (2005), who presented the IDP in sustainable architecture, as applied to design decision on climate in Figure 5.3. Pearl's (2004) methodology for developing the model was not explicitly explained; but is relevant to this present study as it is a model of a design process for low-energy projects applicable to 'real-life' design processes. The model was not presented clearly in the original document and it was difficult to distinguish what all the stages were. The performance targets being at the centre of the model were the key, as this enabled it to influence all stages of the design process, especially in the early design stage with incorporation of the clients within the design team. The inference in relation to this research from Pearl (2004) is that the design process should incorporate all the knowledgeable design team from the onset of the design, and the client should be part of the team. Pearl (2004) also identified an intensive design charrette as being important in allowing the design team spend more time on exploring the potential synthesis of divergent concepts.

Reed and Gordon (2000) demonstrate and document the cost benefits of an integrated building process on real projects. They attempted to produce concrete and useable data, time, costs, and descriptions for the integrated design approach. Their work is meant to demonstrate the advantages of integrating the design-through-building process, and the resulting building product. The change from typical practice conventions, to an integrated process, was to enable buildings to be environmentally responsive and responsible.

Exceptionally important, among the sustainability channel in FEMP (2001), is the setting of goals at the beginning of the design process and the importance of having experienced, knowledgeable and inter/multi E disciplinary team members. FEMP (2001) also made reference to including the client in the design team and the role of architects explicitly defined. The expertise of team members and communication are also considered important in their design process, with educating or organising a workshop of intensive design charrette.

In summary, the concept of integrated thinking prophesied in all the reviewed case-based documents was to change the building industry. However, more tools are now effective in permitting the building industry to go beyond the simple and limited processes defined by the era of specialisation. Design and construction of low-energy buildings (buildings that consume 50 to 70% less energy than code-compliant buildings) require the design team to follow an energy-design process that considers how the building envelope and systems work together (Torcellini *et al.*, 2011). A design team must set energy efficiency goals at the beginning of the pre-design phase. This can then be used throughout the design and construction phases to ensure the building is optimised for energy efficiency and that changes to the design do not adversely affect the energy performance (Beadle, 2008; Tortellini *et al.*, 2011). Proper commission of the building and educating the building operators are the final steps to the successful delivery of the design.

5.3 Level 5, Case-Based Documents

Selection of the Level 5 case studies analysis was based on the need to further justify the sustainability design information requirements. It is also to justify the IBDP as that, to achieve low-impact housing design up to level 5 of the energy criteria in the CSH. The selected case studies and their main features are summarized in sections 5.4.1 to 5.4.3.

5.3.1 Case study 1: The Old Apple Store, Stawell, Somerset

The Old Apple Store site (Figure 5.4) is a project built by Pippin Properties Ltd, a joint venture between the landowners and award winning developers Ecos Homes Ltd. It is a private housing with five units, detached and terraced residencies. Out of the five units, two are four bedroom houses, and the other three is a terrace of three bedroom units (CLG, 2009).

The project was originally designed to meet the criteria for Eco-Homes Excellent, although the final target was to achieve Code Level 5. The overall

vision was to produce an added value and sustainable development constructed from low impact materials and components. The materials used in the Old Apple Store homes minimise environmental impact, including timber from FSC and PEFC certified managed forests. All other materials have been rated according to the Building Research Establishment Green Specification guide.

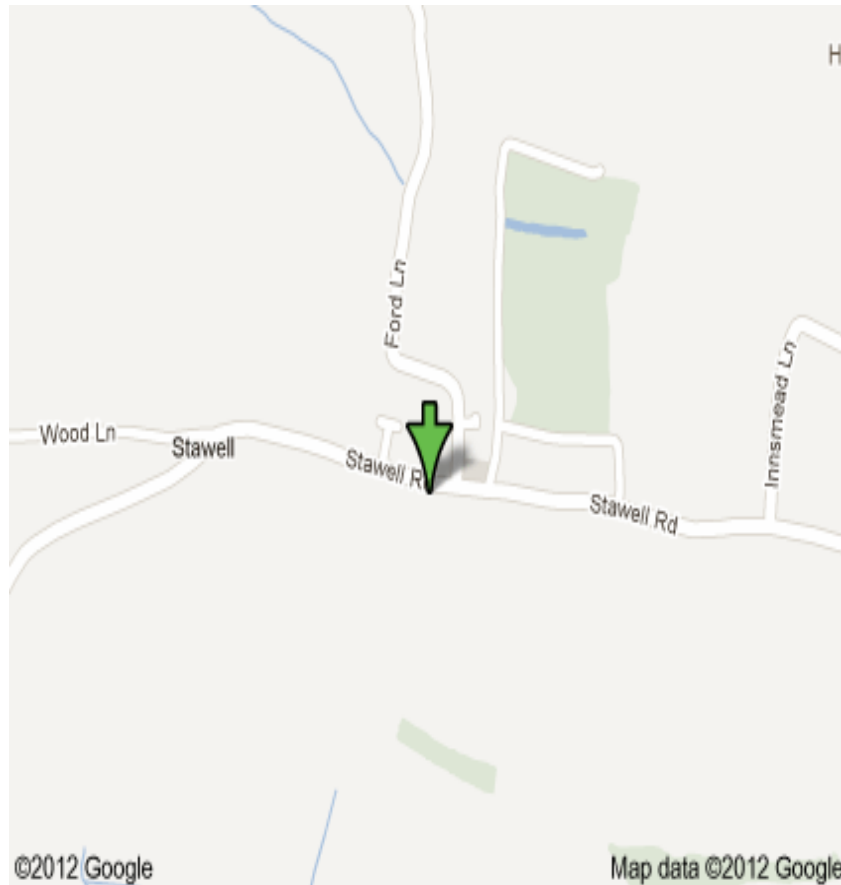


Figure 5.4: The Old Apple Store, Stawell Rd, Stawell, Bridgwater TA7 9AZ

Source: Google (2012)

The project is a case study which confirms how sustainable homes should be designed to make the best of nature's free resources. For example, they use: the sun's energy to heat the house and its hot water; sun light to light the house and to power appliances; and filtered rainwater for washing clothes and flushing toilets. The materials used for Old Apple store are itemises as follows:

- The timber frames are sourced from certified, sustainably managed forests;

- Insulation is made from recycled newspaper and waste wood fibre;
- The houses have minimal PVC and formaldehyde chemicals that can cause air quality deterioration;
- Natural paints and finishes are used for decoration;
- Reclaimed bricks from the original Apple Store buildings have been incorporated.

Each house was independently assessed to a new national standard for sustainable homes, which is the Code for Sustainable Homes. All the homes at the Old Apple Store have achieved Code 5. This means, they are in the top 1 per cent of the most sustainable homes built in the country in 2008 (Ecos Homes, 2009). The energy assessment calculates the cost of heating the three bed homes as being less than £400 per year. Each home will also generate more than 1700 kWh or units of electricity per year, which, Energy watch figures say, this is well over half the annual consumption of the average home (Ecos Homes, 2009).

5.3.1.1 The main lessons learnt from Old Apple Store

- Designing for compliance with Code Level 5 or 6 requires a holistic approach to design and a very detailed knowledge and careful consideration of CSH criteria at the earliest design stage;
- The administration of the Code process should be considered from the outset of a project and suitable systems implemented with contractual obligations for suppliers/ contractors to provide information relevant to the agreed design and construction programmes; and
- Assembling and educating a dedicated construction team is essential to meeting the challenges of higher level Code developments, particularly when new materials and construction methods are being used (CLG, 2009; Eco Homes, 2009).

5.3.2 Case Study 2: CO₂ Zero, Bristol

CO₂ Zero is a development of nine, three storey, live-work units located on Wilder Street in the heart of Bristol. The development has been constructed on a brownfield site on the location of an old car park in a built-up area of the city by developer/contractor Logic CDS Ltd (CLG, 2009).

It is made up of individual units, each containing a two-bedroom duplex flat over a ground floor office/work space. The developer sought to achieve high environmental standards and to generate the maximum amount of renewable energy from within the site boundaries as practicable as possible by creating a near zero-carbon development for heating, lighting, and ventilation. Achievement of a high Code level meant that the developer had to consider all aspects of the Code from the start of the project.

The sustainability features include: green roof on the plant room; passive solar design strategy, low flow rate sanitary ware, rainwater harvesting (recycling), low energy LED lighting, PV array, biomass pellet boiler, low energy rated white goods, FSC timber, Use of environmentally benign materials, Triple-glazed windows, a biomass pellet boiler and MVHR (Mechanical Ventilation with Heat Recovery) incorporating a heater coil for space heating and MVHR (CLG, 2009).

5.3.2.1 The main lessons learnt from the CO₂ Zero development

- The need for the greater understanding of the implications of detailing to achieve low U-values and low levels of air-permeability;
- The use of specialist sub-contractors for design and installation can be beneficial in terms of ensuring successful delivery;
- Preparing well-co-ordinated construction and delivery management programmes at an early stage to understand and avoid likely difficulties;
- The need for a greater awareness of zero carbon and the implications of building to high levels of the CSH throughout the construction industry.

5.3.3 Case Study 3: Mid Street, South Nutfield, Surrey

Mid-Street is a development of 2 x two-bedroom flats located in the village of South Nutfield in Surrey. It was constructed in a rural area by building contractors Osborne on behalf of Raven Housing Trust. The development was initially planned to meet the requirements of the Code Level 3, hence, planning consent was gained on that basis. However, because Osborne had previous experience in building high-level sustainable housing, Raven Housing Trust saw this as a great opportunity to explore the cost and practicalities of new technologies, the development was therefore redesigned to meet Code Level 5.

The development is in a rural area; hence, the final design had to reflect the planning requirements for it to blend with its surroundings. Further planning consent was also required to construct an external boiler house and pellet store for the biomass boiler, which had not been included in the original consent. From the Code requirements, achieving the heating, hot water and water consumption requirements were found to be most difficult for the development because the project had initially been designed to meet the requirements of Code Level 3.

The roof areas were insufficient to accommodate both photovoltaic (PV) and solar thermal renewable energy technologies with the result that only the PV panels were finally installed. An accredited assessor was appointed to carry out a full Code assessment on the major changes required to bring the development from Code Level 3 to 5 (CLG, 2009). The major changes include:

- The use of a biomass boiler to replace mains gas for heating and hot water;
- PVs were added to provide renewable energy;
- Whole house MVHR was utilised;
- Higher thermal efficiency of floors, walls, windows and roofs were required;
- A reduction in thermal-bridging was required;

- Lower air-permeability was required;
- Rainwater harvesting and water saving appliances were introduced;
- Very low energy appliances were required.

Sustainability features finally included passive solar design, low flow rate sanitary ware, rainwater recycling, low energy lighting, PV array, biomass pellet boiler, low energy rated white goods, FSC timber, and MHVR (CLG, 2009).

5.3.3.1 The main lessons from Mid-Street development

- It is important to involve a code assessor with experience in energy efficiency before drafting of the initial designs;
- Construction details need to be produced early in the design process, because remedial work is not as effective as achieving low levels of air permeability on the first attempt;
- MVHR (Mechanical Ventilation with Heat Recovery) can offer significant advantages in reducing energy requirements if correctly specified and installed;
- Local planning constraints may limit the available design options;
- For small dwellings in rural locations, wood pellet boilers can be an attractive option;
- Shared heating systems can be a practical and cost effective solution;
- Good relationship and understanding with the site manager is necessary for a design to be realised; and
- Heating, ventilation, and renewable energy systems specified in a project need to be demonstrated to the occupants with clear written guidance on their use (CLG, 2009).

5.3.4 Synthesis of Case studies: Design Information Requirements (DIR)

In technical terms, there are a number of common issues on how best to achieve code compliance especially the Level 5, of the CSH. They are:

- A high quality and highly insulated building shell with low air-permeability and best use of passive solutions;
- Code design criteria to be incorporated from the earliest design phases of a project in order to understand the overall design implications;
- Code assessor should be included in the project plans from the outset;
- The build systems and the design approach should be integrated from the earliest design phases;
- Renewable energy technologies should be integrated into the overall design concept from the earliest design phases;
- Success depends on a dedicated and skilled design, project and construction teams with a strong commitment to sustainability to bring goodwill and innovation to the use of new systems.

In summary, the key issues that should be considered for sustainability design information requirements within the IBDP include:

- Maximising the site-based credits when buying land for development, looking at ecological value and flood risk;
- The early appointment, before any design work has been carried out of a Code assessor or an energy assessor;
- Energy feasibility study to establish the best sources of energy for the dwellings, including any need for renewable technologies;
- Early appointment, before any site work has been carried out, of a 'suitably qualified ecologist and protecting the ecological features of the site;
- Early commissioning of a flood risk and drainage assessment report as part of the design process;

- Consideration of the orientation and positioning of dwellings to maximise potential for passive solar design;
- Consideration and installation of renewable technologies, such as solar panels day light;
- Registering for the Considerate Constructors Scheme before site work start; and
- Establishing a SWMP before work commences (CLG, 2009).

5.4 IBDP and Design Information Requirements (DIR)

One of the most significant barriers to energy-efficient building design is that buildings are complex systems. While the typical design process is linear and sequential, minimising energy use requires optimising the system as a whole by systematically addressing building form; orientation; envelope; glazing area and a host of interaction and control issues involving the building's mechanical and electrical systems (International Panel on Climate Change, 2007). Assuring the long-term energy performance and sustainability of buildings is all the more difficult when decisions at each stage of design, construction and operation involve multiple stakeholders. This division of responsibilities can contribute to suboptimal results, such as under-investment in energy-efficient approaches to envelope design because of a failure to capitalise on opportunities to down-size HVAC equipment (International Panel on Climate Change, 2007).

In Switzerland, this barrier was addressed through integration of architects into the selection and installation of energy-using devices in buildings (Jefferson, 2000). On the other hand, the European Directive on the Energy Performance of Buildings in the EU also has the aim to bring engineers in at early stages of the design process through its whole-building, performance-based approach. The integrated building design process will allow the adaptive use of tools for different purposes, by different users and at different design stages of the design process (Tianzhen and Jinqian 1997).

However, for effective performance of architects within the IDP; it is proposed in this study that, they should be equipped with BPES tools, which fit into their working practice, to enable them make relevant and important design decision as the design progress. This is because; decisions vary according to the stage in the design process, which in turn affects the level of information required. In the early design stages, decisions are broad since there is minimal concern for detail. As projects progress, decisions become more refined as the focus is on very detailed aspects of the design (Mirani and Mahdjoubi, 2012). Such BPES tools should not distract architects from the design at hand, but rather help them in decision making. Decisions made by them during the design process vary greatly in accuracy. In the early design phases, design decisions are very rough and concern only the parts of the building without the need for much detail. However, decisions in the later phase of the design process are very precise, and concern very detailed information of the design.

Thus, RIBA Outline Plan of Work, discussed in Section 4.1 is used as the baseline design process. The documents on the IDP were reviewed. Analysis were done using the template described in section 5.1.3 to develop the list of themes as related to environmental (5.3.1 to 5.3.5) and sustainability (5.4.1 to 5.4.3) design information requirements for each stage of the design process (early to later stage), as mapped to the different stages (preparation stage A to Technical design stage E) of the RIBA Outline plan of work.

Preparation Stage A: Project Pre-Planning and Setting Goals

- Identify Client Needs, Objectives and Budget (Reed and Gordon,2000; National Institute of Building Science, 2008);
- Develop scope of work, project budget, and schedule and energy target (FEMP,2001; United States Environmental Agency, 2012);
- Set Energy Performance goal to level 5 of the CSH (Pearl, 2004; CLG, 2009; United States Environmental Agency, 2012);
- Conduct all required feasibility analysis and maximise site based credits by checking site factors like ecological value and flood risk

especially if just purchasing the site (FEMP, 2001; Hansen and Knudstrup, 2005; CLG, 2009);

- Appraise the site and building orientation with energy performance in mind (Pearl, 2004);
- Review all existing directives and policies (FEMP, 2001);
- Identify and prioritise potential envelope-based energy efficiency strategies;
- Establish performance targets and strategies to achieve the set goal (CLG, 2009);
- Select and review existing case studies that are from Level 3 to 6 of the CSH with particular focus on illustration and demonstration of enhanced energy performance (CLG, 2009; United States Environmental Agency, 2012);
- Allocate sufficient funds for an integrated design process and early appointment of a code/energy assessor (CLG, 2009).

Preparation Stage B

- Select 'Top Level' multi-disciplinary design team (Reed and Gordon, 2000; United States Environmental Agency, 2012);
- Adopt an integrated approach to include clients (Pearl, 2004);
- Communicate the '*Set and agreed*' environmental and energy design principles to the top level design team (Reed and Gordon, 2000); and
- Revisit and agree on energy related goals and principles (United States Environmental Agency, 2012).

Concept Stage C

- Implementation of Design Brief and preparation of additional data (RIBA, 2012); Watson (2004) stated that the design brief is key to the aim of the project, and if the problem is not set out in the design brief, then it is unlikely to form part of the design solution. Thus, recording the issues considered, goals set and decisions made benefits not only the project for which the brief is being developed, but future project,

due to the complex nature of environmental issue to deliver the low carbon homes.

- Select and assemble second level of the design team (Project Team) (Reed and Gordon, 2000);
- Identify synergies between design concepts and energy use (United States Environmental Agency, 2012) ;
- Conduct a comprehensive lists that addresses architecture, energy and other environmental issues like Local Sourcing, and Specification of building materials and elements, Water Consumption, Insulation, Lighting, Heating and Hot Water Systems, Renewable Energy Technology and Ventilation;
- Identify technologies and strategies that enhance energy performance (United States Environmental Agency, 2012);
- Decision on the agreed goals should be communicated to all members of the team (Reed and Gordon, 2000; Pearl, 2004); and
- Include energy experts and begin detail energy analysis of design concept (United States Environmental Agency, 2012).

Design Development Stage D

- Educate the design team on goals, costs and benefits by holding charrette or workshop on the design (FEMP, 2001; Pearl, 2004);
- Identify synergies between design concepts and energy use,
- Revisiting goals and standard in relation to the desired CSH Level 5 (CLG, 2009);
- Focus on local sourcing, and specification of building materials and elements, Water Consumption, Insulation, Lighting, Heating and Hot Water Systems, Renewable Energy /Technology and Ventilation; and
- Develop scope of work, project budget, and schedule.

All decision taken from this stage onward must have a continuous reference to the required level of the CSH, which is the level 5 of the CSH.

Technical Design Stage E

- Critical team members meet, life cycle value engineering session is conducted and critical subcontractors are brought in to give input (Reed and Gordon, 2000);
- Detailed energy analysis of design concepts, which incorporate computational techniques such as finite difference, finite elements, state space, and function for building load and energy calculation;
- Detail natural shading features to reduce cooling load;
- Detailed day lighting in order to reduce electrical lighting requirement and air conditioning load;
- Review energy strategies with energy expert (FEMP, 2001; United States Environmental Agency, 2012);
- Compare estimated energy use to design target;
- Make adjustments and integrate energy performance strategies; and
- Revisit energy related goals and principles in relation to the required level of the CSH (CLG, 2009).

5.4.1 Discussion of some other factors in the IBDP

William and Lindsay (2007) emphasise that no precise data exists on the extent of sustainable buildings. However, Loh *et al.*, (2010) developed a process framework along with an ICT system to support multi stakeholder decision-making, which facilitates the inclusion of energy issues in the early design phase of buildings. The approach in this research is to incorporate BPES tools for the various stages of the IBDP in order to help architects in decision-making as well as to enable them to achieve low impact housing design in the UK. Other considerations within the IBDP, for discussion in this chapter include: setting energy efficiency principles; integrated design team; experience; knowledge and expertise.

5.4.1.1 Setting Energy Efficiency Principle at the Early Design Stage

Set/agree energy efficiency principles such as the level 5, energy level of the CSH at the early stage of the design process was deemed fit in the IBDP because: all parties must agree to and be committed to standards and principles set; performance targets must be set for a range of parameters; and environmental standards must be appropriate and realistic for the development.

The construction industry is becoming increasingly concerned with understanding the whole life impact of buildings. Consequently, customers are shifting their focus towards declaration of the greenhouse gas (GHG), carbon footprint or CO₂ emissions, to maximise potential for reduction (Fieldson, 2009). The energy efficiency will best be considered at the outset of the design process with constant revision and reflection on the impact of the design changes at the later stages of the process.

In support of the analysed case-based documents in this chapter, a number of studies, such as Weytjens and Verbeeck (2009); Lawson, (2010), and many more referred to in section 4.5.2, had also demonstrated the importance of early environmental and sustainable decisions in the design process, as having the largest impact on the sustainability of the final design.

5.4.1.2 Integrated Design Approach

An integrated design approach is required to ensure that the architectural elements and the engineering systems work effectively together (Intergovernmental Panel on Climate Change, 2007). Analysis that informed the inclusion of formation of team in the IBDP was deemed important because: all parties must be committed from the beginning of the design process. Also, good working relationships and communication must be established between team members and partnering, coupled with transparency and trust to be embraced by all parties in the integrated team from the beginning of the design process.

FEMP (2001) involves the design team establishing minimised energy use as a high priority goal at the inception of the design process. Hence, a balanced and

appropriately funded team must be assembled. They should be able to work closely together, maintain open lines of communication, and remain responsive to key actions and items throughout the delivery of the project. Continuing advocacy of low carbon design strategies is essential to realising the goal. Therefore, it is important that at least one technically astute member of the design team be designated as the energy advocate. This team member performs many useful functions which include:

- Introducing other team members to design strategies that are appropriate to building type, size, and location;
- Maintaining enthusiasm for the integration of low carbon design strategies as central components of the overall design solution;
- Ensuring that these strategies are not abandoned or eliminated during the later phases;
- Overseeing construction to ensure that the strategies are not thwarted or compromised by field changes (FEMP, 2001, CLG, 2009).

In the Pearl (2004) approach to IDP, the client as part of the design team takes a more active role than usual and the architect becomes a team leader, rather than the sole form-giver, while the structural, mechanical and electrical engineers take on active roles at early design stages.

In professional practice, IDP has a significant impact on the makeup and role-playing of the initial design team. The primary objective is to validate the economic potential in creating and building an innovative concept that is predominantly environmentally sound. When carried out in a spirit of cooperation among the key players, it results in a design that is highly efficient with minimal or even, no incremental capital costs, along with reduced long-term operating and maintenance costs.

The benefits of the IDP process are not limited to the improvement of environmental performance. There is also the advantage of the open interdisciplinary discussion and synergistic approach. This contributes to improvements in the functional program, in the selection of structural systems and in architectural expression. The IDP process is based on the well-proven

observation that changes and improvements in the design process are relatively easy to make at the beginning of the process, but become increasingly difficult, expensive and even disruptive as the process unfolds (Larsson,2004).

Design strategies for energy-efficient buildings include reducing loads, selecting systems that make the most effective use of ambient energy sources and heat sinks, and using efficient equipment and effective control strategies. Urge-Vorsatz *et al.* (2007) emphasise the need for an integrated design approach that ensures the architectural elements and the engineering systems work effectively together. In designing sustainable buildings, a careful selection process that ensures that each member of the professional design team has enough experience on design of such buildings must be in place. The performance of designers within the design team is especially important because any decision made at inception of the project will affect the project performance (Oyedele and Tham, 2007).

The Green overlay (2011) also emphasised the importance of the design team and especially that of a senior management position and/ or appointment of a sustainability champion in the team at the appraisal stage. Elforгани and Rahmat (2010) argument is that the first steps in a building construction project should be the selection of optimal members like the architect-engineers team.

However, complexity and multi- disciplinary are the challenges that the design and construction of sustainable buildings usually face. The architect alone cannot have all the skills required, and should be able to rely on other expert professionals, because it takes a lot of specialist knowledge to incorporate environmental concerns or its concept into a design (Gangemi *et al.*, 2000). This often goes beyond the technical confines of an architect, hence the need of an integrated design team, which consists of top and low-level multidisciplinary design team selection for the successful delivery of the design.

This was further supported in Laudon and Laudon, (1998) and Sor (2004), which emphasised two clear issues facing the actors working within the design process. These are the management of the diverse and ever changing body of

sustainability related knowledge contained within the organisations and individuals which make up the project team.

5.4.1.3 Experience, Knowledge and Expertise of the Design Team

- ***Experience***

A good design team must have proper design capability and ability to interpret the clients' needs. These needs are essential attributes because unless the design is right, a satisfactory building can never be produced. According to Graham (2000) and Ling (2002), a good design team must be equipped with professionals that have enough experience to translate the increasingly stringent environmental performance goals required by the client into design and create buildings that meet the new objectives.

Based on this argument, it is reasonable to assume that experience is the basis for an initial approach to a problem. For most projects, it is also highly advisable to retain an experienced low-energy design consultant, because low-energy design is not entirely intuitive, experience gained from a range of projects is vital. This is because the energy use and cost of a building depend on the complex interaction of many parameters and variables that require detailed analysis on a project-by-project basis.

- ***Knowledge***

Some reviews, in addition to the case-based documents in this chapter, have shown that working on low-energy projects increases the knowledge of the design and project team. Selecting the 'right' team (Beadle, 2008), at the right time is critical to the success of design and construction, not only within UK, but internationally too. Lee and Egbu (2006) cite the importance of having knowledgeable project team members, or the lack of it as a value source or a risk source to the project. Elforгани and Rahmat (2010) echoed this view, suggesting selection of an appropriate and knowledgeable design team increases the chance of delivering a project on time and within budget.

Knowledge of information sources, such as those from the Building Research Establishments, Chartered Institute of Building (CIOB); Royal Institute of

British Architects (RIBA); Construction Industry Institute; Energy Saving Trust (EST); Department of Communities and Local Government (DCLG); Department for Business Innovation and Skills and Department of Trade and Industry (DTI), are key to the success of the design and project team members.

This was further addressed and reviewed by Sandahl *et al.*, (1994), who surveyed architects and designers to investigate their knowledge of energy standards and the influence that these have on the design process. They concluded that all parties can influence the energy use of a building and that this is most effective at the pre-design stage of the design process. Lowe *et al.* (2003) used interviews with the core project team to explore their knowledge and understanding of environmental issues. The project team members were grouped into four categories, according to their existing knowledge.

The integration of construction experience and knowledge in the early design phase provide the best opportunity to improve overall project performance in the construction industry (Construction Task Force, 1998). To realise this integration, De-Groot and Mallory-Hill (1999) argue that it is not only essential to provide a structural and systematic way to aid the transfer and utilisation of construction knowledge and experience during the early design decision making process, experience and knowledge should be organised in a manageable format so that they can be input effectively and efficiently into the design process. In relation to design, Lawson (2010) verifies that design has been known to require the use of experience, judgement and intuition.

- ***Expertise***

Embedding expertise, knowledge and collaboration as criteria measures in the IBDP is an area of great potential. In addition to them being identified from the case-based documents, expertise (Oyedele and Tham, 2007); knowledge (Sandahl *et al.*, 1994) and collaboration (Weingardt, 1996; Lowe *et al.*, 2003) are recognised, as important to the success of the team, as well as to the project. These have been actively explored for this purpose and are expected to be increasingly developed for practical applications.

Developing expertise involves acquiring much knowledge about specific situations, so that new situation can be dealt with depending on how it resembles situations faced before. According to Greeno (1980), most of what is called ‘*real problem solving*’, is due to an inability to identify the knowledge underlying the problem solver’s performance. This is similar to De-Groot (1966), who studied the skill of chess masters. He states that expertise, which is one of the prerequisites for master chess players, comes from years of study and detailed visual memory of chess positions.

5.5 Summary

This chapter has presented the methodological development of the environmental and sustainable design information requirements to fulfill objective three of the study. Five case-based documents on integrated building design process (IBDP) had been identified and analysed, based on varying goal and rationale of criteria selection. Even though the development patterns of each of the documents were historically different, their current objectives are identical; to improve design and construction effectiveness by better utilisation of design information criteria at the right time of the design process and through an integrated design approach. Level 5, case-based documents on CSH were also analysed in this chapter, towards development of the sustainability design information requirements within the IBDP. The IBDP will enable UK architects achieve low carbon housing design and delivery, up to energy Level 5 of the CSH.

The theoretical model of the IBDP developed in this chapter has been adopted after the RIBA Outline Plan of work, being the familiar framework for architects and the general construction industry in the UK. Variables within the model were further discussed within five dimensions which are: setting goals; integrated design team; experience, knowledge and expertise. The model can provide a solid basis for evaluating promising areas and identifying driving factors for practical and sustainability effectiveness.

Chapter Six: Research Methodology

6 Introduction

The critique from the literature review chapters led to the development of the theoretical model of the IBDP from the case-based documents analysis in Chapter Five. This chapter introduces the general research methodology and methods of the research along with data collection, towards evaluating the effectiveness of decision support tools as well as the other information to deliver the design in the UK.

The way in which research is conducted may be conceived of in terms of the research philosophy subscribed to, the research strategy employed (the research instruments utilised and perhaps developed) in the pursuit of a goal - the research objective(s) -and the quest for the solution of a problem - the research questions. The research questions and research objectives had been outlined in Chapter One. In the pragmatic spirit and positivist approach spirit of this research, rather than selecting a single method, such as the qualitative method, thus neglecting the quantitative aspects, which have been considered important, both methods (mixed) are used.

To understand the basis upon which the research method was adopted, three principal research approaches in social sciences (qualitative, quantitative and mixed methods) will be discussed. Arguments will be presented to justify the choice of the research approach as applied to the specific method of data collection in the study. Thus, this chapter detail the practical processes and data captured, are reported. The research methods employed are considered the most appropriate strategy in the context of this study for collecting data on low carbon housing design and delivery. The procedure in Figure 6.1 is consequent to the relevant information on potential respondents, the sampling frame and sample size, towards investigation of decision support tools characteristics in Chapter seven and evaluating the effectiveness of existing Building Performance Energy Simulation (BPES) tools in Chapter Eight.

The outline of the Chapter is thus:

- Research Design and Methodology;
- Research Methods;
- Data Collection;
- Development and Evaluation of DSF;
- Research Ethics and Confidentiality;
- Summary.

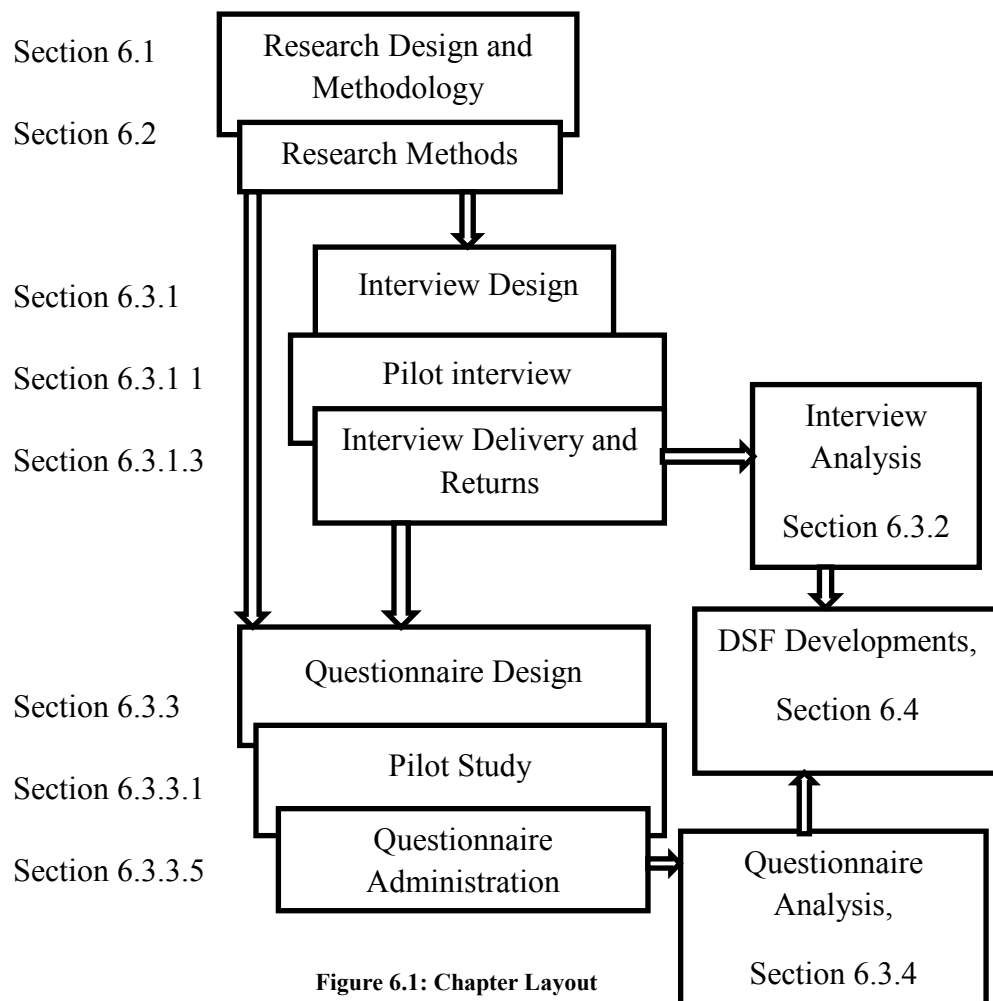


Figure 6.1: Chapter Layout

6.1 Research Design and Methodology

6.1.1 Research Design

The aim of this particular research, in line with the definition of research design from Henn *et al.*,(2008) and Blaikie (2010), is to develop a decision support framework to enable architects achieve the design of low carbon housing in the UK. Research is one of the ways to find answers to questions (Kumar, 2005). Naoum (1998) considers it as inquiry, study, or investigation conducted in a careful, scientific, and/or critical manner. Henn *et al.*, (2008) and Blaikie (2010), however, emphasise design, as the basic plan for any research. It includes five main components, which are: research aim; research questions; research strategy; research procedure, research methodology and methods.

6.1.2 Research Strategy

The research strategy provides the logic or a set of procedures to generate new knowledge (Blaikie 2010). It is also a way of presenting the logic to achieve the objectives of the research. Bryman (2008) and Blaikie (2010) classify research strategies into four main types, which are: inductive; deductive; retroductive and abductive. The inductive strategy collects data and proceeds to derive generalisation through inductive logic. It is useful for researches investigating phenomena with limited underpinning theoretical basis, particularly when the intention is to answer a ‘*What*’ question (Bryman, 2008; Blaikie, 2010). Nevertheless, this particular research has a little bit of retroductive, manifested in the use of ‘*How*’ to discover a structure or mechanism in the set of research questions outlined in Section 1.5 to achieve the set of objectives in section 1.4. towards the design and development of the theoretical model of design information requirements, as well as the decision support framework (DSF), which defines architects required characteristics of design decision-support tools. As further contribution to knowledge, the study will finally outline the implication of research findings on practice, policy and research communities.

6.1.3 Research Methodology

A Positivist approach to research is based on knowledge gained from 'positive' verification of observable experience rather than, for example, introspection or intuition (Bryman, 2004). Scientific methods or experimental testing are the best way of achieving this knowledge (Cohen and Crabtree, 2006). The positivist position is grounded in the theoretical belief that there is an objective reality that can be known to the researcher, if she or he uses the correct methods and applies those methods in a correct manner. In the positivist approach from Cohen and Crabtree (2006), research is evaluated using the following three criteria:

- Validity - the extent to which a measurement approach or procedure gives the correct answer (allowing the researcher to measure or evaluate an objective reality);
- Reliability - the extent to which a measurement approach or procedure gives the same answer whenever it is carried out; and
- Generalizability - extent to which the findings of a study can be applied externally or more broadly outside of the study context.

Research methods refer to the specific techniques of doing the particular research, while methodology has to do with the strategy of the research as a whole. The research methodology includes the theoretical and philosophical implications of the particular choices of methods chosen for the research (Seale, 2004). The research methodologies adopted in this study are categorised into qualitative, quantitative and the combination of both, which is referred to as the mixed methodology of research highlighted in Figure 6.2.

6.1.3.1 Qualitative Research and Strategy

Smith (1983) and Lincoln and Guba (1985) described the qualitative research approach as an enquiry process of comprehending a social or human problem /phenomenon based on building a complex holistic picture. It is formed with words, to report detailed views of informants conducted in a natural setting. Qualitative methodology is further described as explanatory in nature, with the

principal aim of trying to unearth answers to (how and why) questions (Walker, 1997; Creswell, 2003). In qualitative research, theory or hypothesis are not established as a priority. The research questions may also change, and, be refined as the enquirer learns what question to ask. The strategies associated with qualitative approach are; enography; grounded; case-study, phenomenological and narrative (Ikpe, 2009). A number of authors (Seymour and Rooke, 1995; Rooke *et al.*, 1997; Creswell, 2003) had further advocated for the use of these strategies in construction management research.

Qualitative methods of research are more concerned with producing discursive descriptions and exploring social actors, meanings, and interpretation (Blaikie 2010). The various methods of collecting data includes interviews; focus group; direct observation and case studies (Manase, 2008). Henn *et al.*, (2008) states, the two most common qualitative methodologies in social research are the focus group and in-depth interviews. The group discussions or the focus groups defined in Henn *et al.*, (2008) are usually designed for those who want to assess how several people work out a common view or the range of views about same topic.

Nevertheless, the in-depth interviews may take the form of one-to-one or group interviews. In a one-to-one interview, individual respondents are interviewed at length on their experience about a particular issue or event. This was done in this research through semi structured in-depth interviews with selected experienced architects in the UK. It was primarily to investigate the effectiveness of design and decision support tools identified from the desk study of literature review and documentary study of reports. It was also to investigate the insights of architects on the Code for Sustainable Homes (CSH), being the latest tool for the design in the UK.

What is central to the interviews, regardless of the perception of emerging data is in their provision of the qualitative depth, which allow interviewees (architects) to talk about the subject in terms of their own frames of references. This enabled the author, as the interviewer, to maximise understanding of the architects' point of view. For Blaikie (2010), the qualitative method of research is more often than not associated with an interpretive perspective. Bryman

(2008) identifies research strategies, by which, social reality is the product of its inhabitants. It is a world interpreted by the meanings that participants produce and reproduce as the necessary part of their everyday activities (Blaikie 2010).

Nevertheless, the logic of qualitative research defined by Henn *et al.* (2008) is not so much to test out given theories about what guides human behaviour, but to develop an appreciation of the underlying motivation that people have for doing what they do. In relation to this particular research, this involves interviewing experts in the field such as the sustainable UK architects to investigate the following issues:

- Design and decision support tools for low carbon housing design and delivery in the UK;
- Other information needs of UK architects for the design; and
- Insights of UK architects on the CSH, being the latest tool in the UK for the design.

The semi-structured in depth interview, as used in this study, was also to identify:

- Characteristics/requirements of BPES tools to include in the questionnaire survey;
- Presentation/format of the DSF in a manner that will enable UK architects to achieve the design.

Detail of the interview template is in the Appendix 2a.

6.1.3.2 Quantitative Research Approach and Strategy of Inquiry

Creswell (2003) defined quantitative research as one in which the investigator primarily uses positivist and post-positivist claims to develop knowledge on the truth about quantitative measures. It employs strategies of inquiry, such as experiments and surveys, to collect data on predetermined instruments to yield statistical data. Quantitative methods are generally concerned with counting and measuring aspects of social life (Blaikie 2010). Their approaches are

usually associated with the positivist perspectives from experience, in which anything that cannot be verified by experience is meaningless.

Henn *et al.*, (2008) provide a useful definition for the quantitative method of research. They define the term, 'quantitative method', as the adoption of natural science experiment to model scientific research. The key features are the quantitative measurement of the phenomena studied and systematic control of the theoretical variables influencing those phenomena (Henn *et al.*, 2008). Thus, the logic of quantitative research is to:

- Collect data using standardised approaches on a range of variables;
- Search for patterns of causal relationships between the variables;
- Test given theory by confirming or denying precise hypothesis.

A number of researchers (Naoum, 1998; Creswell, 2003; Anderson, 2004; Punch, 2005) identified quantitative research as an enquiry into social or human problem. It is based on testing a theory, which comprises of variables, measured with numbers and analysed using statistical procedures to determine whether the predictive generalisation of the theory is true. In conducting quantitative research, three main approaches are usually employed. They are identified by Fellows and Liu (1997) and Creswell (2003) as desk research, experiments and surveys. Fellows and Liu (1997) described desk research as suitable for studies such as macro-economic, where data cannot be obtained by any other viable alternatives. Hence, it involves using data by others and analysing it in alternative ways to yield fresh insight. Nevertheless, Hammond *et al.*, (2000) described experiment as a test of cause-effect relationships, which collect evidence to demonstrate the effect of one variable on another. The experiments include the random assignment of subjects to treatment conditions as well as quasi-experiments that use non-randomised designs (Keppel, 1991).

Surveys, however, involve cross-sectional and longitudinal studies using questionnaires or structured interviews for data collection, with the intent of generalizing from a sample to a population (Babbie, 1990). Thus, the two most common types of quantitative approach are experimental and survey methods

of research. A questionnaire survey is a research tool, through which people are asked to respond to the same set of questions (Gray, 2004). It is adopted in this study and administered on-line through the Survey Monkey software (www.surveymonkey.com). The targets were architectural practices from the RIBA directory of chartered architects in the UK. The survey approach was adopted for this study because of its various advantages over the others and its strength in enabling attributes of a larger population to be identified from a small group of individuals (Babbie, 1990).

The survey approach was used in this study, to quantitatively evaluate the state-of-the-art /effectiveness of the identified decision support, in form of BPES tools, on a larger scale, along with the statutory and non-statutory regulations in the UK. It asks architects to recognise the stage(s) of the design process for application of the following:

- Design and decision support tools such as IES-VE and environmental assessment tool such as BREEAM;
- Statutory regulations such as planning and building regulations like the Merton rule standards; Building regulations, Part L1A and Non Statutory energy and environmental standards such as the EST best practice; CSH; Passive House Standards.

The questionnaire also asked architects for the stages of the design process:

- Which needs more focus in terms of design and decision support for low carbon housing design in the UK;
- Where most design decisions are made.

The detail of the questionnaire is in the Appendix 3.

In order to analyse relationships in a research survey and to draw widespread conclusions, it requires the researcher to generate large amounts of data. This will enable conclusions to be generalised from the sample survey to the wider population from which the survey respondents were drawn. The questionnaire administration in this research covers the entire geographical region in the UK, so that the samples from each region act as a representative of architects'

knowledge and views from that region. This was in accordance with Blaikie (2010) who states that sample surveys are a means of gathering information by means of personal interviews or questionnaires. They are sometimes referred to as ‘mass interviews’, because they collect similar information from a large number of people at the same time. He further declares that they usually make use of standardised approaches with the aid of standardised instruments.

6.2 Research Methods

Research methods refer to the specific techniques of doing a particular research. It is presented in Figure 6.2 as related to this research from the beginning (literature review) to the end (recommendation from the research). The series of sub objectives, relates to Bryman (2009) and Blaikie (2010) on their definition of *inductive* to answer the ‘*what*’ and *retroductive* strategies to answer the ‘*how*’ questions towards achieving the main aim and objectives of the study.

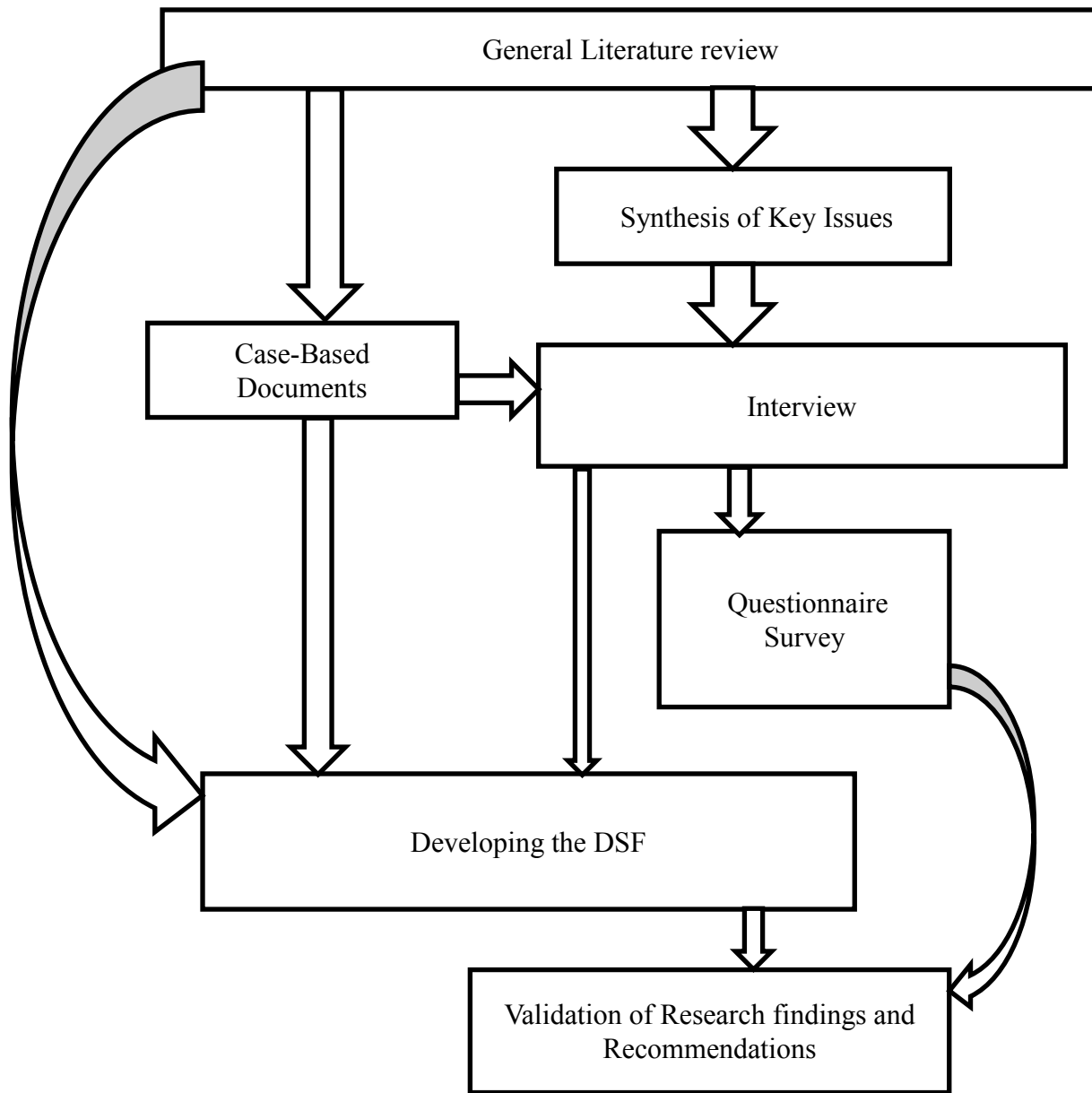


Figure 6.2: Research Methods

<p>Problem Identification Review LCHs and design and decision support tools; Review CSH and other information needs of architects for the design; and Review Case-based documents on IDP</p>
<p>Problem Analysis Find out relevance between LCHs, sustainability requirements and other information needs; Find out insights of architects in the use of CSH, being the latest tool for UK design; Analyse the case- based documents on RIBA and IDP; Identify design and decision support tools; and Evaluate the state-of- the -art /effectiveness of BPES tools.</p>
<p>Developing a solution Develop Design Information Requirements Develop the DSF.</p>
<p>Validation and Recommendations Validate findings based on past reviews; Test the appropriateness of the DSF through expert and professional review at conferences and workshops; and Recommend research findings</p>

6.2.1 Mixed Method Approach

A mixed method approach is one whereby the researcher tends to base knowledge claims on pragmatic grounds such as consequence, oriented, problem-centered and pluralistic (Creswell, 2003). This method employs strategies of inquiry that involve collecting two main sets of data, either simultaneously or sequentially, depending on the nature of the research problem. In the mixed method approach, the researcher bases the inquiry on the assumption that collecting diverse types of data best provides an understanding of the research problem.

The mixed method approach is also the concept of using multiple methods to generate and analyse different kinds of data in the same study. Blaikie (2010) refers to it as studies that combine qualitative and quantitative methods; either in parallel or in sequence, as in the combination of the qualitative in-depth semi structured interviews and the quantitative online questionnaire survey in this study. Blaikie (2010) further classifies the mixed method of research into four types: *triangulation* (concurrent use of both qualitative and quantitative methods); *embedded* (one type of method is supplementary to the other); *explanatory* (sequential use with quantitative preceding); and *exploratory* (sequential use in the reverse order). The mixed method as an approach in research has also been called different names, such as integrated approach, hybrid approach and combined methods (Blaikie 2010). The exploratory mixed method is applicable in this particular study, such that the quantitative semi structured in-depth interviews precede the qualitative on- line questionnaire.

6.2.2 The Paradigm of the Mixed Method Approach

A paradigm is a cluster of beliefs and dictates. It influences what should be studied, how research should be done and how results should be interpreted (Henjewe, 2010). It is essentially a set of assumptions on how to study the issue of concern to the researcher, with the appropriateness in deciding the different methodologies to achieve the aim of the research (Bryman 2008).

The paradigm war in this research is the difference between qualitative and quantitative research methods, which in fact, has no clear boundaries. This is because validity of their separation has often been questioned, especially in relation to data collection and analysis, but definitely not in relation to the outcome of the research. Amongst those who think of this difference as a useful distinction, is a debate about the grounds that the choice of method used for a particular research should be, that is, whether it should be qualitative or quantitative. Some argue, choice of the methods is essentially a matter of epistemology, which should inform the methodology used, then inform the methods (Henn *et al.*, 2008).

Although, it is convenient to classify methods of research as either qualitative or quantitative, Blaikie (2010) states there is growing body of literature which questions the legitimacy of the dichotomy. Their argument is that research methods should be a matter of selecting appropriate techniques for the particular research task, or question at hand (Pawson and Tiley, 1994; Blaikie, 2010). The paradigm war described above, adopted by Adeyeye *et al.*, (2007); Osmani and O'Reiley (2009); Henjeweale (2010) and Isiadinso *et al.*, (2011) is defined as the principles, logic, and evidence that are best suited to advancing the knowledge within the area of study (Case, 2002).

Hence, the study combines both qualitative and quantitative methods of research to explore and investigate the set of objectives in Section 1.4, to achieve the aim of the research. The combination of both methods is described as the new paradigm, which differs from the two common paradigms (qualitative and quantitative). Blaikie (2010) verifies the mixed methods approach as involving the collection, analysis and mixing of both the quantitative and qualitative data in a single and series of studies. In this study, it combines qualitative and quantitative methods of the data collection (Section 6.3), and can be either parallel or in sequence.

The mixed method approach can further be defined as the operation-lisation of a concept in several and different ways to seek evidence on a hypothesis. This is often the case when a researcher feels that the best way of achieving the best result is to combine methodologies (Jones, 1985). It is used in this study as the

exploratory mixed method of research, where the qualitative interviews precede the quantitative online survey.

It is appropriate in this study to establish the validity of the research, hence, a combination of the qualitative approach in Section 6.1.2.1 with the quantitative online questionnaire survey discussed in Section 6.1.2.2. This was done because using only the qualitative, semi structured, in-depth interviews with architects across the UK would have been too expensive and time consuming in relation to travelling and telephoning, coupled with the fact that the evidence provided would have been less comprehensive.

Conversely, restricting the interview to only one region in the UK would have provided an isolated view of that particular region and offer less validity. Hence, justification of the mixed method approaches in form of the online survey to cover the whole of the UK region. Furthermore, the strengths of one method will offset any weakness in the other method. The advantageous summary of the online survey, when combined with the qualitative semi structure in depth interviews, in this study is to:

- Verify the validity of the result on a larger sample;
- Provide evidence that is more comprehensive;
- Help to answer questions, such as objective two in Section 1.4, where one research method cannot achieve all the answers (Adeyeye *et al.*, 2007; Yudelson, 2008; Osmani and O'Reilly, 2009; Isiadinso *et al.*, 2011; Thomas-Alvarez and Mahdjoubi,2012).

Surveys have been recognised to be usually weak in explanatory research, coupled with low response rate, hence the use of the in-depth semi- structured interviews in this study, to supplement. This is in support of Busha and Harter (1980), who state that investigators are generally cautious of placing too much faith in just one instrument or technique. They tend to rely upon multiple data-gathering methods. Nevertheless, use of multiple techniques, otherwise called the exploratory mixed method, will among many advantages, give strength to the research, in the different areas to support conclusions and establish the validity of the research.

In practice, using only qualitative or quantitative methods of research is rare. This was established by Osmani and O'Reilly (2009), who presented a comprehensive opinion on the feasibility of building zero carbon homes in England by 2016, from the house builders' perspectives. Their investigation was carried out using quantitative and qualitative methods of research. Their questionnaire survey was augmented via eight in-depth, semi structured interviews to provide the qualitative research for their study, as done in this study. Isiadinso *et al.*, (2011) also explored the complexity of the contexts, philosophies and demonstrations involved in best practice for low carbon buildings. They used the mixed method approach through an online survey and interviews with thirteen experts.

6.2.3 Approach Adopted in the Review Chapters

A literature review is a body of text that aims to review the critical points of current knowledge. It includes substantive findings, as well as theoretical and methodological contributions, to a particular topic and links the proposed research to the current state of relevant knowledge (Blaikie 2010). A well-structured literature review is characterised by a logical flow of ideas; current and relevant references with consistent, appropriate referencing style; proper use of terminology; and an unbiased and comprehensive view of the previous research on the topic, as done in Chapters two to four of this thesis.

Blaikie (2010) further laid emphasis on the fact that the literature review is most often associated with academic-oriented literature, such as the review of books, related past journals and theses, and usually precedes the results section. Its ultimate goal is to bring the reader up-to-date with current literature on the topic.

The desk study of literature reviewed in this research covered published and unpublished materials and conference proceedings, using a variety of web-based search engines and exhaustive databases including: Emerald Database; Science Direct; Informa-World; SAGE Journals Service; Avery index to Architectural Periodicals; Geobase; Planex and Goggle Scholar. This is similar to Williams and Lindsay (2007) who also used web-based search engines and

databases that were both general purpose and industry specific, and Keysar and Pearce (2007) who used extensive internet-based searches to identify 275 green buildings decision support tools (DSTs). Literature review in general, and as done in this research, further serves as a good starting point for acquiring good academic standards, as well as to summarise the views and arguments of the earlier research on the topic in a fair way. This is regarded as a good practice to extract the useful information and create a new synthesis (Hart, 1998).

6.3 Data Collection

The systematic procedures for data collection and analysis in this research include the following steps:

- Data collection through interview;
- Data collection through online questionnaire survey;
- Qualitative analysis of the data collected from the interview with the architects towards design of the questionnaire;
- Quantitative analysis for the data collected through questionnaire survey towards evaluating the effectiveness of decision support tools.

6.3.1 Interview Design

Sociologists have always been interested in the attitudes and beliefs of social groups. The methodological refinement has come about by engaging with the problems posed in trying to get at other's people feeling (Gilbert, 2001). The key method of researching into this attitude is by interviewing. This is because it has a strong claim as the most widely used research method to generate data in qualitative social research. Nunkoosin (2005) further established how the popularity of using interviews has spawned many other types of collecting data.

Berg (2004) defined interviews as a conversation with a purpose in which the purpose is to specifically gather information. Patton (1990), however, sets the

list of types of interviews. These are structured, semi-structured or unstructured, by which the approach used is dependent on the stage of the research and the nature of the data or information being sought.

Semi-structured, in-depth interview, as used in this study, investigate information needs of architects as well as the required characteristics of decision support tools to achieve low impact housing design in the UK. They also investigate insights of architects on the use and knowledge of the CSH in UK. The approach was informed by five major publications (Mackinder and Marvin, 1982; Imrie, 2007; Ko and Fenner, 2008; Osmani and O'Reilly, 2009; Isiadinso *et al.* 2011)

Mackinder and Marvin (1982) used interviews with architects to determine the role of information, experience and other influences on the design process. Open-ended questions were used at intervals in the interview process and architects were encouraged to lead the discussion. Imrie (2007) also, combined analysis from the interview with a sample of architectural practices primarily based in London with other web-based information. Nevertheless, Ko and Fenner (2008) used interviews with commercial developers, local and central government bodies, architectural consultancies and housing associations to identify barriers relating to their willingness, motivation and capacity for change in introducing energy efficient measures into new build housing in the UK.

Osmani and O'Reilly (2009) presented a comprehensive view on the feasibility of building zero carbon homes in England by 2016, from the house builders' perspectives. They conducted eight in-depth, semi-structured interviews, to provide the qualitative research for their study. Finally, Isiadinso *et al.*, (2011) explored the complexity of the contexts, philosophies and demonstrations involved in best practice for low carbon buildings. They conducted an online survey and interviewed thirteen experts who were construction professionals in sustainable design both in the industry and academia.

Wallace (1987) investigated the interactions between design team members. He used open-ended questions focussing on the role of architects as informed by observations of design team interactions. Fortune and Welham (1995)

assessed the environmental awareness of thirty construction professionals. They used structured interviews of fifteen minutes in duration, looking at background and subject information along with general environmental awareness of terms, organisations, and other issues. Lowe *et al.*, (2003c) used open-ended interview questions with project team members of a housing development to enhance understanding of the impact that a new environmental standard being implemented had on them and on the design and construction processes.

Consequently, questions for the interviews in this study were formed. They were mainly informed by the aim and objectives of the research, coupled with analysis from some of the reviewed publications and reports. Thus some of the questions had already been tested and the answers could be used for comparison, if needed. The questions in the interview focused on five main issues, which are:

- Section A: Background/Personal Information;
- Section B and C: Design and Decision Support Tools;
- Section D: Format and Presentation of the DSF;
- Section E: Other Information: Code for Sustainable Homes (being UK latest tool for low carbon housing design);
- Section F: Sustainability Design Information Requirements.

Questions used in the interviews (Appendix 2a) total twenty, including the personal data section to simplify the theme towards achieving the issues listed above, as well as addressing some objectives of the study.

Questions in section 'A' were on the background information. They were similar to publications reviewed, such as Lowe *et al.*, (2003c) and Fortune and Welham (1995).

Questions in Sections 'B' and 'C' were influenced by the aim and objectives of the research. Section 'B' focuses on design and decision support tools, while Section 'C' asked questions as a follow up to the questions in section B.

Section 'D' focused on the format and presentation of the DSF. Questions in this section were informed by the aspiration to influence the future of LCH design in the UK. It asks architects for preference of presentation for the DSF.

Section 'E' focuses on statutory and non-statutory information needs, which include the CSH. It investigates architects' knowledge in the use of the CSH to deliver low carbon housing design in the UK. It further asked questions on their level of awareness, barriers to its implementation and use in the design of LCH.

The final section, F, allowed architects to view their opinion on sustainability and environmental design information requirements for the design and delivery of low carbon housing in the UK. It asked probing questions to allow room for elaboration.

6.3.1.1 Pilot Interview

A pilot experiment, also called a pilot study, is a small-scale preliminary study conducted before the main research. It is to check the feasibility or improve the design of the research (Haralambos and Holborn, 2000). A pilot study is usually carried out on members of the relevant population, but not on those who will form part of the final sample. This is because it may influence the later behaviour of research subjects if they have already been involved in the research. In sociology, a pilot study refers to small-scale studies that help in identifying the design issues before the main research is done.

The pilot interview for this research was with a renowned Professor of Architecture, who has an understanding of sustainability in housing design. This was very helpful to the research, because, it highlighted shortcomings of some of the ideas initially put forward. The pilot study was also used to assess whether questions were clear and understandable, as well as to check if the structure and flow was acceptable. Questions were then revised accordingly.

6.3.1.2 *Representative Sample*

Ten experts in the field of sustainable housing design in the UK were interviewed to investigate the following:

- Design and decision support tools for low carbon housing design;
- Characteristics of BPES tools to include in the DSF;
- Presentation of the DSF in a format that will enable UK architects to achieve the design;
- Statutory and non-statutory regulations (such as CSH) for UK architect to achieve the design.

Their selection was based on their experience and types of projects they had worked on. This was in line with Pedrini and Szokolay (2005), who targeted four main groups of architects to investigate their approach to energy- efficient buildings in warm climates and the importance of design methods at different stages of design. The stages from Pedrini and Szokolay (2005) were the pre-design, schematic and detail design stage of the RIBA Outline Plan of Work.

The use of interviews in this research have the following benefits: immediacy; mutual exploration; investigation of causation; personal contact and speed (Gorman and Clayton, 1997). These advantages were realised, because the ten interviews were conducted personally, hence, room for follow-up of the questions. The interviewees were encouraged to expand their given explanations; thereby, providing investigation and causation of any particular comment or exploration by either party regarding the topic of discussion.

6.3.1.3 *Interview Delivery and Returns*

To ensure the richness of the method, interviewees were first informed about the aim of the study, the objectives, what their participation would involve and how the results would be disseminated. As the interviews in this study were carried out in person, there was the additional effect of putting the interviewee at ease.

During the interviews, notes were made; interviews recorded and transcribed immediately after each interview (as will be detailed in Chapter seven). The length of the interviews ranged from forty-five to sixty minutes, with most lasting fifty minutes. Prior to the interviews being organised, members were given an introduction to the purpose of the interview and were asked their permission for the interview to be digitally recorded. The interviewees were allowed to choose locations for the interview, in order to make them feel comfortable and relaxed. All the interviews were conducted between March and June 2011, recorded using a digital voice recorder and files stored in a safe and secure location. The transcripts of the interviews as well as details of the questions are in Appendix 2b.

All questions were open-ended to enable the participants to answer freely and provide as much information as they felt necessary. Additional questions were asked if the researcher felt that more information on a particular question was necessary or if an interesting line of discussion was developing, which was not covered by the original questions. Prior to the interviews being transcribed, a page summary of each interview was produced to outline the key themes and points of the interview. This was undertaken straight after the interviews, to note down any thoughts and feelings about the interview, whilst fresh in the researcher's memory, as recommended in Robson (2002). The researcher transcribed the digital voice recordings as soon as possible after the interview to enable in-depth analysis. The interviews were transcribed as thoroughly as was needed for the analysis, with all words transcribed apart from unintended repetitions and filling sounds, such as 'ermm...' and 'ah...'

6.3.1.4 Bias to Interview

Gorman and Clayton (1997) made an inventory of some potential drawbacks of interviews (*cost; uncritical; too personal and open to bias*). In response to this, the researcher notes that an interview is indeed noted as being costly, due to travel, time commitments coupled with the potential bias from the interviewer. However, it is important to note that bias of some nature can appear in any research work. Hence, interviewees in this research are architects

in academia and practitioners who were randomly selected at the March 2011 Eco-build in London and a project site in Bristol city.

Although, the use of telephone interviews would have enabled the interviews to be carried out more quickly, telephone interviews have been noted to be too impersonal for some people; hence, they may not be comfortable answering questions in this manner. It also does not afford the interviewer the chance to monitor the subject's reactions to questions. In addition, it was felt that the rapport developed with subjects during the course of the interview was necessary and sufficient to put them at ease towards eliciting free and frank responses.

Finally, Brenner *et al.*, (1985) noted the difficulty in collecting data by interviews. They felt that the researcher's perception of what they see and hear is all-important and can affect the response. However, this was addressed in this research, by checking with the subjects to make sure that the understanding and purpose of the research was clear, correct and agreed upon by them.

6.3.2 Interview Analysis

Content analysis has been defined as a systematic, replicable technique for compressing many words of texts into fewer content categories based on rules of coding (Stemlar, 2001). It is a research tool used to determine the presence of certain words or concepts within texts or sets of texts. Researchers quantify and analyse the presence, meanings and relationships of such words and concepts, then subsequently make inferences about the messages within the texts, the writer(s), the audience, and even the culture and time of which, these are a part.

Texts can be defined broadly as books; book chapters; essays; interviews; discussions; newspaper headlines and articles; historical documents; speeches; conversations; advertising; informal conversation, or; any occurrence of communicative language. Texts in a single study may also represent a variety of different types of occurrences (King, 2006). To conduct a content analysis

on any text, the text is coded or broken down, into manageable categories on a variety of levels, word, word sense, phrase, sentence, or theme and then examined using one of content analysis' basic methods, such as conceptual analysis or relational analysis.

Content analysis provides a relatively systematic and comprehensive summary or overview of the data set as a whole, sometimes incorporating a quantitative element (Wilkinson, 2004). It is usually undertaken by coding textual data so that the number of occurrences of a particular code could be compared and further analysed as part of qualitative research (David and Sutton, 2004).

Content analysis was used in this research, similar to publications such as Wallace (1987) and Beadle (2008). The former used a combination of six techniques, including content analysis, to explore the interactions in design team meetings, while the latter used four techniques, which are template analysis; content analysis; documentary analysis and decision analysis.

Content analysis is a systematic coding and categorising approach. It is used in this study to explore textual information, which, in this case, are interviews with architects, to ascertain trends and patterns of words used, their frequency, relationships, structures and discourses of communication (Grbich, 2007). According to Robson (2002), computer aid to content analysis of text can be in the following aspects:

- Key word context;
- Word frequency list;
- Category count; and
- Combined criteria list.

Consequently, Nvivo 9 of QSR qualitative analysis was used. It provides a set of tools that can assist researchers to undertake an analysis of qualitative data (Bazeley, 2007). QSR Nvivo 9 can perform content analysis, such as key words search, hence, its adoption in this study to analyse the interview with experts towards design of the questionnaire survey. This is parallel to Meng (2008), who used it to analyse expert interviews towards development of

assessment framework for construction supply chain relationships. The identification of key words using content analysis is in Chapter Seven. It gives a simple quantitative measure of how often a given theme from the interview was used to be followed by the query analysis from the Nvivo 9.

6.3.3 Questionnaire Design

A questionnaire survey is a research tool through which people are asked to respond to the same set of questions (Gray, 2004). Surveys, defined from Henn *et al.*, (2008), are usually used to collect data in quantitative ways for them to be added or analysed together, or to gain a view of the sector and the people concerned. Naoum (1998) emphasised the wide use of questionnaires for descriptive and analytical purposes, as well as to find out facts, opinions, and views. Surveys can be used for both descriptive and explanatory needs within the research to a degree (Naoum, 1998). The questionnaire survey in this study was designed with the aim and objectives of the research in mind, coupled with the critiques from the desk study of literature review (Chapters two to four), and the analysis from the in-depth, semi- structured interviews with practitioners and architects in academia.

Balnaves and Cupti (2001) described surveys as a method of collecting data from people about who they are (occupations), how they think (motivations, beliefs) and what they do (behavior). Babbie (1990) further described survey research as a way to generalize, from a sample to a population, so that inferences can be made about some characteristic, attitude, or behavior of the population. It usually takes the form of a questionnaire that a person fills out alone or by interview schedule, in person or by phone, which is carried out through sampling.

The use of a questionnaire survey in this research corresponds with researchers (Adeyeye *et al.*, 2007; Osmani and O'Reilly, 2009; Thomas-Alvarez and Mahdjoubi, 2012) who used it to enable large amounts of information to be gathered and then compared (Yudelson, 2008) cheaply, effectively and in a structured and manageable form (Adeyeye *et al.*, 2007).

Other researchers who influenced the use of survey, especially the online method of administration used in this study, include Lovell (2005). She conducted an internet-based survey of low energy housing to reveal over 150 low energy housing developments that have been built or planned in the UK, from 1990 to 2004, comprising over 24 000 dwellings. Isiadinso *et al.*, (2011) also explored the complexity of the contexts, philosophies, and demonstrations involved in best practice for low carbon buildings. They used a mixed research approach that also included survey and interviews. The detail of the questionnaire is in Appendix 3. The themes of the questions include:

Section A: Personal Information: This focuses on year of experience and geographical location of respondents.

Section B: Design and decision support tools: This focuses on the use and implementation of design and decision support tools by architects at various stages of the design process.

Section C: Statutory and Non Statutory regulations and standards.

Section D: Other Support: This focuses on the stage(s) of the design process, that architects take decision.

6.3.3.1 Pilot Study

In order to evaluate the clarity and comprehensiveness of the questionnaire, as well as the feasibility of the survey as a whole, a pilot survey was conducted prior to the major survey administration. The aim of the pilot study was to test the wording of the questionnaire, identify ambiguous questions, test the intended technique for data collection and measure the effectiveness of the potential response (Creswell, 2003). A pilot study is a trial run that helps researchers to smoothen-out the survey instrument. It ensures that the participants in the main survey do not have trouble in completing it (Ahadzie, 2007). As argued by Munn and Drever (1990), test run surveys are necessary to demonstrate the methodological rigor of the survey.

Two practicing architects filled the initial pilot questionnaire manually. One had experience of twenty years in practice, while the other had just three years of experience. Ten graduating architectural students, who have been to practice, were also used for the pilot phase of the questionnaires. All these were done because a questionnaire, which appears to be clear and clear-cut to its designer, may not appear that way to the target population (Henjewe, 2010).

It was found, however, that the contents of the initial questionnaire were too many. The questionnaire was then reviewed with further help from supervisors and other members of the staff in the department, who have a background in psychology and social research. This helped to sharpen the final version of the questionnaire for the main survey. Following this study, the main questionnaire was modified based on the feedback received; some questions were amended or removed, some new ones were added, depending on which were deemed appropriate and applicable as recommended by the pilot respondents.

The final questionnaire, outlined in Section 6.3.3, consists of ten main questions and thirty-nine sub-questions. The pilot study was, therefore, a useful exercise, particularly with regard to gathering information on issues such as questions asked, and their relevance to low carbon housing design and delivery in the UK.

6.3.3.2 *Representative Sample*

Past research works that influenced the selection of architects as the focus of the target sample include: Pedrini and Szokolay (2005) and Adeyeye *et al.*, (2007). The former used a survey to investigate the architects' approach to the project of energy efficient buildings in warm climate and the importance of design methods at the stages of design; the pre-design, schematic and detail design stages. Their survey targeted four main groups of architects. However, Adeyeye *et al.*, (2007) did a survey of architectural design practices to assess the impact of current energy conservation policies and legislation on current

building design. Their sampling frame was confined to 100 UK architectural design practices selected from the RIBA database of registered architects.

Consequently, RIBA directory of architects, detailing around 3000 firms in the UK, was used in this study. All architects within the scope of the 3000 practices are RIBA chartered, that is, they had met the RIBA's world-leading standards of professional practice, covering matters such as quality, customer service, and insurance (Royal Institute of British Architects, 2012b).

Location; RIBA region; Domestic projects, Project sector; and Architectural services were used as search criteria for selection of the sustainable architectural practices from the RIBA directory. By using these search criterions, a total of 716 practices were obtained. From this, the researcher was able to acquire the email contacts, phone numbers, firms' contact addresses and past projects of the 716 practices that fell within the criterion.

6.3.3.3 Sampling Technique

Whichever research methodology is adopted for a specific research project, it is often not possible to study the whole population (Creswell, 2003). Thus, samples have to be selected within the 716 practices. There are two types of sampling: non-probability (non-random) and probability (random) samples (Guba, 2000).

Non-random samples are mostly used in qualitative studies and market research, consulting with experts or for developing hypothesis for future research and in circumstances where adequate sampling frames are not available (Creswell, 2003). This type of sampling focuses on volunteer subjects. It is easily available to potential subjects or those who just happen to be present when the research is carried out, since there are no systematic selection procedures. However, random sampling generally incorporates some type of systematic selection procedure to ensure that each unit or element has an equal chance of being selected.

Random sampling was the method adopted in this research. As indicated in Babbie (1990) and Creswell (2003), sampling is necessary because of the constraints of time. The main advantage of this method is its ability to achieve reliability of measurements and also its ability to generalise about an entire population by drawing inferences based on data drawn from a small portion of that population (Rea and Parker, 1997). The greatest advantage is in the relatively low cost associated with gathering of the data. Nevertheless, it has its disadvantage in that data are unduly susceptible to time of measurement effects (Ikpe, 2009).

From the 716 identified architectural practices in Section 6.3.3.2, a total of 425 sustainable practices were randomly selected. Thus, questionnaires were mailed to 425 architectural practices for participation in the survey. With randomisation, a representative sample from a population provides the ability to generalise to a population (Babbie, 1990). The selection of the 425 samples is explained below to follow the examples of Soetano *et al.*, (2001); Xiao (2002); Ankrah (2007); Ikpe (2009) and Baba *et al.*, (2012a). To determine a suitable size for the sample, the following formula from Creative Research Systems (2003), also cited from past research works (Ankrah, 2007; Ikpe, 2009; Baba *et al.*, 2012b) was applied.

$$SS = Z^2 * P(1-P) / C^2 \text{-----Equation 6.1}$$

Where SS = sample size

Z = standardized variable

P = percentage picking a choice expressed as decimal (0.5 used for needed sample)

C = confidence interval expressed as decimal

As with most other research, a confidence level of 95 per cent was assumed (Creative Research Systems, 2003). For 95 per cent confidence level (i.e. significance level of P = 0.05) Z = 1.96. Based on the need to find a balance between the level of precision, resources available and usefulness of the findings (Maisel and Persell, 1996), a confidence interval (C) of +_10 per cent was assumed in this research.

According to Creative Research Systems (2003) and, as cited in Ankrah (2007), when determining the sample size for a given level of accuracy, the worst case percentage picking (P) should be assumed, given as 50 per cent or 0.5. Based on this assumption, the sample size was computed as follows:

$$SS = 1.96^2 \times 0.5 (1-0.5) / 0.1^2 \text{-----Equation 6.2}$$

$$SS = 96.04$$

Therefore, the required sample size for the questionnaire is approximately 96 in contrast to the 85 calculated from the creative research systems sample size calculator. However, this figure required a further correction for finite population. The formula for this was further given in Creative Research Systems (2003) as:

$$\text{New SS} = \frac{ss}{1 + \frac{ss-1}{pop}} \text{-----Equation 6.3}$$

Where pop = population

$$\text{New SS} = \frac{96.04}{1 + \frac{96.04 - 1}{716}} = 84.99$$

The new sample size is approximately equal to eighty-five sustainable architectural practices. This implies that if a sample size of approximately eighty-five respondents is obtained from the practices, the data would be large enough for the sampling distribution to have a normal distribution. Nevertheless, the UK construction industry is notorious for poor responses to questionnaire surveys (Ankrah, 2007). Therefore, 20-30 per cent is believed to be normal (Takim *et al.*, 2004; Ankrah, 2007). Based on this reasoning, it was necessary to adjust the sample size to account for a high non-response rate. Assuming a conservative response rate of 20 per cent, the appropriate sample is calculated as:

$$\text{New SS Response rate} = \frac{85}{0.20} = 425 \text{ Sustainable architectural practices.}$$

Based on this, 425 sustainable architectural practices were randomly selected to cover the whole geographical location in the UK. Thus, each architectural practice within the 716 targeted populations had an equal probability of being selected.

6.3.3.4 Validation of Questionnaire

The draft questionnaire was rigorously tested for validation significance, easiness, flexibility, and conformity with the ethnicity and confidentiality required. Table 6.1 summarises the validation process.

Table 6.1: Questionnaire Validation

Status	Sub Status	Contents	Reviewers	Comments
Draft 1	Drafts a - g	20 Questions 110 sub - questions Covering 6 pages	Research Team	Too many questions Irrelevant questions Some questions are too complicated Unstructured Questionnaire
Draft 2	Drafts h - k	22 Questions 64 sub -questions Covering 5 pages	Research Team Post Graduate Colleagues	
Draft 3	Drafts 1- 4	16 Questions 56 sub - questions Covering 4 pages	Research Team Practising Architects	Questionnaire too long Reduce sub questions Format not well presented and attractive
Final Draft	Drafts 5- 8	10 Questions 39 sub questions Covering 4 pages	Research Team, Senior Experienced Researcher with Psychology Background Post Graduate Researchers Practicing Architectural Students	Add space for respondents' opinion Make use of click system for answering the questions Be consistent in the scaling

The draft questionnaires were discussed with colleagues in the postgraduate school and were also reviewed several times by senior colleagues and supervisors from January 2012 to March 2012. The wording of the questionnaire was reviewed as suggested in the pilot study to ensure that the

questions were easily readable and appealing to the respondents. The layout and format of the questionnaire was also given much consideration to maximize response and to ensure that respondents did not miss questions. This step was taken to encourage respondents to tick the appropriate questions as applies to their organisation.

6.3.3.5 Questionnaire Administration

There are five strategies that the quantitative researcher can adopt to administer questionnaires (Nesbary, 2000). These are mail, fax, phone, web-based or internal surveys and personal face-face interviews. The mail option was adopted in this research and questionnaires were sent to proposed participants through their email. This has the advantage of being cheap and easy to organise in order to cover a wider area, coupled with faster availability of data through simplification of data entry and editing, better data quality and more user friendly than the paper questionnaire (Creswell, 2003).

The questionnaire was formatted to suit online administration, first with the help of 'Qualtrics' software, followed by Survey Monkey' software. After careful consideration, Survey monkey was decided upon for administration of the questionnaire. Although Qualtrics had better advantages over the survey monkey, however Survey Monkey, which is equally effective, was used because of the option to upgrade from a trial version without affecting the data collected previously. In addition, the targeted numbers of the practices necessitate the use of the upgraded version of the Survey Monkey (Table 6.2).

The principal focus of using an online questionnaire survey in this research was to evaluate the effectiveness of design and decision support tools on a larger scale. In order to encourage a good response, the questionnaires were mailed out with an accompanying personalised and signed cover letter. As recognised by Creswell (2003), this has the advantage of cost saving; convenient; ample times, impression and anonymity.

Table 6.2: Survey Software for Questionnaire Administration

	Survey Monkey Trial	Qualtrics Trial
Advantages	Has a trial period	Has a trial period
	Can be linked	The trial period is unlimited
	Provision for upgrading	The trial software can take many questions
		Can be linked
Disadvantages	The trial software can be used for only one month	The number of respondents is limited to 100
	The trial software can only take 10 questions	The link to the upgrading section was not going through

To maximise response, reminders were sent with a subsequent set of questionnaires to all the non-respondents at intervals of two weeks after the first mail, as opposed to Creswell (2003) who recommended three weeks, but not at regular intervals. This was undertaken in the form of a gentle reminder, by which fourteen emails were sent between June and August 2012. To increase the response rate, postal self-addressed envelopes were also used in this research. These were for some respondents identified at the architectural event exhibition, organised by the Faculty of Environmental Technology, University of West England on the 7th of June, 2012.

The questionnaire asks architects to recognise the stage of the design process for application of the identified design and decision support tools. This includes: simulation tools; dynamic and energy simulation tools; and non-statutory energy and environmental standards, such as the EST best practice; CSH; Passive House Standards and many more.

The survey contains simple and short structured questions that were easy to complete electronically. To attract a better response, respondents were asked to provide simple answers by *ticking* the box that best represents their opinion or information relevant to the research. The inclusion of ‘*Tick*’ within the Likert Scale and the use of ‘*other*’ sections that need to be completed by the respondents, serve as the qualitative element of the survey. This was to provide

the macro and micro linkages for the research and helps to “flesh out” unnecessary data previously collected on the topic from the other methodologies.

6.3.3.6 Questionnaire: Benefits and Disadvantages

The decision to use a questionnaire survey was made primarily to get a large representative sample and to cover a wide geographical area in the UK within a reasonable time scale. Use of questionnaire have the benefits for this study in that, large amount of data was collected in short amount of time. For a single researcher, such as in this case, this is paramount, for it would have been impossible to interview the large number of UK practices to cover a wide geographical area. It also offers anonymity to information being provided to the researcher that may not otherwise have been given in the case of interview. This is because, it is difficult to argue true anonymous value in an interview, even if the researcher makes a pledge to this effect when conducting face-to-face interviews, the interviewee may still feel that it is not truly anonymous (Brine,2008).

However, there exists some drawbacks to the use of questionnaires; response rates can be very poor (Frankfort-Nachmias and Nachmias, 1996). This, from many researchers is not strange in construction survey. Osmani and O’Reilly (2009) recorded poor (41 per cent) response rate in their postal questionnaires to major UK housing providers. Adeyeye *et al.*, (2007) also acknowledged the poor response rate in their online survey of architects using the RIBA database. Examples of surveys with similar response rate include: Soetanto *et al.*, (2001), who reported 14.7 per cent for their comprehensive questionnaire survey; Takim *et al.*, (2004) reported that a response rate of 20-30% is a norm in the survey within the construction industry. In support of this, Ankrah (2007) achieved a response rate of combined pilot and main survey of 15.42%.

6.3.4 Questionnaire Survey Analysis

The main analysis of survey data in this research was undertaken using the Statistical Package for the Social Sciences (SPSS). Data collected from the Survey monkey were downloaded and modified to fit the SPSS 19 method of analysis. Consequently, frequency distribution and cross tabulation of the descriptive statistics in SPSS were used to evaluate the fitness of purpose between decision-support tools and design decision-making of architects to achieve low carbon housing design at the various stages of the design process. The stages of data captured have been discussed in Section 6.2.2, while the framework development will be the target of Chapter Nine. Chapters Seven and Eight will clearly show the way in which the data analysis stages establishes the state- of-the- art on design and decision support tools.

6.3.4.1 Frequency Distribution and Descriptive Analysis

Once data are collected, the very useful thing to do is to plot graph of how many times each score occurs. This is known as frequency distribution, or histogram. It is simply a graph plotting values of observations on the horizontal axis; with a bar showing how many times each value occurred in the data set. Hence, it is useful for checking distribution (Field, 2009).

Frequency distributions can be very useful for assessing properties of the distribution of scores. For one thing, by looking at which tool has the tallest bar, one can immediately see the mode, which is simply the tool that occurs most frequently in the data set. Based on this analysis, the most typical values (mean, median and mode) are adopted (Meng, 2008; Field, 2009).

Descriptive analysis is a way of describing a particular situation or event (Reaves, 1992). It is an aspect of statistics, which allows researchers to summarise large quantities of data using measures that are easily understood by observers (Burns, 2000). Descriptive statistics summarises raw scores, such as average, percentage and variance (Hammond *et al.*, 2000). This will be done in this research to evaluate the state -of- the-art of BPES tools similar to Meng (2008), who used arithmetic mean to score criteria and generate distribution of

Construction Supply Chain (CSC) relationship. Analysis of frequency data in this research deals with data that has been tabulated; that is, the number of sampled items that fall into different categories, which is the design stages within the RIBA Outline plan of work.

6.3.4.2 Cross Tabulation and Chi Test Statistics

Cross tabulation (or crosstabs for short) is the process made with two or more data sources (variables) that are tabulating the results of one against the other. It is the process of creating a contingency table from the multivariate frequency distribution of statistical variables. It is heavily used in survey research and can be produced by a range of statistical packages, including some that are specialised for the task. They give a basic picture about the interrelation of two variables and help to find out interactions between them. They further make it easy to zoom into "hot spots" to see the most significant relationships between the two selected data sources.

To do the Chi- test statistics of the crosstab function in the descriptive function of the SPSS, the first step is to calculate the Chi-squared test statistics χ^2 , which resembles a normalised sum of squared deviations between observed and theoretical frequencies. The second step is to determine the degrees of freedom of that statistic, which is essentially the number of frequencies reduced by the number of parameters of the fitted distribution. In the third step, χ^2 is compared to the critical value of no significance from the χ^2 d. The formula is represented below:

$$\chi^2 = \sum_i \sum_j \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \text{-----Equation 6.4}$$

6.4 Development and Evaluation of the DSF

The development of the decision support framework (DSF) that defines the characteristics of BPES tools to fulfil objectives 4 in this study include:

- Findings analysed from the interview findings;

- The state- of -the -art evaluated from the Questionnaire survey;
- Reflection from past research works;
- Design information requirements from IBDP derived from the analysis of the case-based documents in Chapter five;
- Sourced documents from tools marketed for the various stages of the design process.

6.4.1 Rationale and Development for the Framework

It was established in Chapters Two and Three that current plans, policies, programmes, trends, guides, design and decision support tools, although so many and from variety of sources, seem not to be sufficient towards realisation of the specified target for new low carbon housing design in the UK. William and Lindsay (2007) argue that the information base available to undertake a sustainable review is inadequate.

Hence, this research makes the first attempt to develop a decision support framework that will help architects in the UK to achieve low-impact housing design up to Level 5 of the energy criteria in the Code for Sustainable Homes and 100% more energy efficiency homes over building regulations Part L.

6.4.2 Validation of Research Findings and Evaluating the DSF

The findings from this research will be validated, based on past research works in chapter Ten. It will be statically tested for reliability with the aid of the SPSS 19 in Chapter Eight. The developed DSF is recommended for testing on a live project as future research. Its validation and evaluation is not within the scope of this present study. However, it will be evaluated in future through expert and professional reviews at conferences and workshops already registered for, but the date of the conference is beyond the submission of this particular thesis. This type of evaluation was chosen due to cost and time by which to test it on a live project will take another three years of PhD study.

Nevertheless, discussion and validation of research findings along with their implications towards determination of the adequacy between design decisions, taken at the various stages of the design process and BPES tools is in Chapter Ten. Conclusions will be made, and an outline of the implication of the research findings on practice, policy and research communities will be recommended in Chapter Eleven and through journals and further presentations at workshops and conferences.

6.5 Research Ethics and Confidentiality

The research targets are a particular group of professionals (architects). This infers no special ethical considerations other than the confidentiality and anonymous value of the interview and questionnaire survey to be guaranteed. Ethical considerations for each of the methods involved in this particular research are as follows:

- **Literature Review and Case-Based Documentary Study**

All documents and sources of information were referenced. Project names and sources of data collection will further be acknowledged by the end of the research for reliability and dependability.

- **Interviews**

Throughout this research, the researcher's university, and ESRC (Economic and Social Research Council) ethnicity of research were complied with. During the interview, architects' consent was sought before interview. As part of the consent seeking, it was made known to them that the interview transcripts will be available to them if they so wish in order for them to remove any part of the interview that they do not want to be included in the analysis, interpretation, and report of the research.

Moreover, in the analysis of the interview, the respondents were coded to protect their privacy, to ensure that their anonymity is preserved and confidentiality of the data is guaranteed.

- **Questionnaire Survey**

For the questionnaire survey, respondents were informed of the purpose for data collection and how the information provided will be stored and used. This was done through the covering letter, which clearly states the rights of the respondents to withdraw at any time of the process. Questionnaire administration software like the survey monkey will also be acknowledged by the end of the research.

6.6 Summary

The chapter has analysed the methods underpinning the research. Research design and general research methodologies were introduced at the beginning of the chapter. Research methods adopted at different stages of the research were further discussed in detail. Reasons were given for selection of the methods to fulfil the objectives of the study and towards realization of the research aim.

The adopted methods of research discussed in this chapter include interview and questionnaire survey. The in-depth, semi-structured interview is the qualitative method analysed through content analysis, while the online questionnaire survey is the quantitative method statistically analysed.

Based on the literature review (Chapters Two, Three and Four) findings; design information requirements from the IBDP in Chapter Five; findings from the interview and questionnaire survey on the BPES tools analysed in Chapters Seven and Eight, the DSF will be developed in Chapter Nine. Discussions and implications of the research findings will be in Chapter Ten, while conclusions and recommendations from the research will finalise the thesis in Chapter Eleven.

Chapter Seven: Analysis of Interview Findings

7 Introduction

Having formulated the theoretical model of design information requirements (DIR) in Chapter Five, and described the research method for data collection in Chapter Six, this chapter presents the findings obtained from part of the field survey. It addresses part of objective two, in Section 1.4 and reports data collected from the interview sessions with sustainable architects. The outline summary of the chapter is:

- Overview and Scope of the Interview;
- Interview Findings;
- Design and Decision Support Tools;
- Statutory and Non-Statutory Regulations: Code for Sustainable Homes;
- Design Information Requirements;
- Summary

7.1 Overview and Scope of the Interview

Subsequent to the review of literature presented in Chapters Two to Four and theoretical model of design information requirements from the IBDP in Chapter Five, interviews were carried out. The purpose of carrying out the interviews has two main aims. The first is to investigate needs of architects, towards definition of BPES tools characteristics that will fit into the intrinsic way of architects' decision- making. The second is to inference the results towards the design of the questionnaire survey that will be used to explore the subject matter on a wider perspective and coverage. By the end of the interview analysis in this section, the deduction should lead to the following contributions:

- Knowledge of the current trend in the use of design and decision support tools along with required characteristics of BPES tools fit for architects decision making;

- Knowledge of the current trend in the use and implementation of other information such as the Code for Sustainable (CSH), being the latest statutory regulation recognised by the government to deliver the design;
- Knowledge on some sustainability design information requirements (DIR) from architects' point of view.

The underlying principle for the interview, its design, and pilot study had been discussed in Section 6.3.1. The face-to-face, semi-structured and in-depth interviews were of the format recommended by Mason (2002), where questions were simplified into informal sub-questions. There were a total of eighteen informal questions towards achieving the contributions to knowledge listed above as well as to quantitatively address objective two in Section 1.4.

7.2 Interview Findings

The first task carried out on the interview transcripts was the identification of key words within the context. Content analysis as used in this study has been defined in Section 6.3.2. The texts being analysed are from the transcripts of the interview sessions with UK architects towards the design of the questionnaire survey. Two ways are used for the identification; these are, through prior knowledge gained from literature review, and the initial analysis of transcript to find core concepts or key issues in the context. These were completed in this study before giving codes to the identified key words systematically discussed in sections 7.3 to 7.5 of this chapter.

7.2.1 Interviewees' Profile

Ten architects were interviewed in all, not including the pilot study. The respondents were architects in academia and practitioners with diverse qualifications and years of experiences. The criterion for their selection is based on whether they have designed sustainable housing projects in the UK.

Details of their profiles and years of experience as derived from section A of the interview questions are detailed below.

- Interviewee ‘A’ is a practicing architect in practice with twenty years of experience and a wide knowledge of different areas of sustainability issues and housing in the UK.
- Interviewee ‘B’ is an architect in academia with eighteen years of experience.
- Interviewee ‘C’ is an architect, also in academia with ten years of experience and vast knowledge of sustainability.
- Interviewee ‘D’ was a practicing architect now in academia. He has sixteen years of experience and participated in design of Green Millennium Village (GMV).
- Interviewee ‘E’ is an international architect in practice. He has thirty years of experience using sustainable materials. He also has a vast knowledge of current legislation in UK, especially the knowledge of CSH and passivhaus.
- Interviewee ‘F’ is a practising architect with twenty- five years of experience in design of houses and especially the sustainable housing developments.
- Interviewee ‘G’ is a young, dynamic, and enthusiastic architect with strong ideas and innovation on sustainability. He has three years of experience.
- Interviewee ‘H’ is an international architect with a dynamic record of past sustainable projects. He has thirty years of experience.
- Interviewee ‘I’ is a practicing architects of ten years’ experience. He is currently working on a project to achieve Level 4 of the CSH for a housing corporation.

- Interviewee ‘J’ is a practicing architect of fifteen years’ experience. He is also working on the same project with interviewee ‘I’.

7.3 Design and Decision Support Tools

The questions in relation to the topic above are in section B and C of the interview template and were directed to all the interviewees. All subjects acknowledged the importance of design and decision support tools. Interviewee E specified, ‘*SAP, Passive House Planning Package (PHPP) and Integrated Environmental Solutions (IES) tools*’ (Figure 7.1). Although, he does not think that these tools will necessarily deliver the design. In his opinion, ‘*These are the best at the moment*’.

Interviewee H stated, ‘*It seems PHPP is more like the tool (Figure 7.1) to achieve low carbon housing because it has recipe of how to attack the problems*’. To qualitatively evaluate decision support tools in the UK, calculation, simulation, energy calculator, carbon embodiment, code compliance, and checking tools software were all confirmed by more than half of the interviewees as being necessary to the design and delivery of low carbon housing in the UK.

However, in relation to BPES tools criteria ranking for architects friendly tools characteristics to deliver low impact buildings in the UK, the following were acknowledged for the early and detail stages of the design process.

- **Degree of approximation /accuracy as related to design stages;**

Early Design Stages:

- Minimal details are available;
- Approximation and flexibility are paramount;
- Accuracy is less important;
- Low input to avoid hampering creativity and design thinking;
- Quick output in a language understood by architects.

Detail Design Stages:

- Much details are available;
- Precision and specification are paramount;
- Higher level of Accuracy is required;
- Higher level of detail input required;
- To produce 'Realistic' or 'as built' output.

Interviewee A stated that such tools should enable the designers using it to understand it much better, that is to take responsibility for and understand what they (designers) are using at the different stages of the design process. The tools, at various stages of the design process, should link with ventilation strategy, air tightness, energy calculator, carbon embodiment, code compliance and checking of results. Interviewee B stated, '*Tools for decision support should be easily accessible and less complex*'. Interviewee E specifically stated, '*It will be good to have a tool that starts from when the client writes a brief to the management level, and it should include health and safety issues, that is, it should be a tool (Figure 7.1), which include the CDM regulations*' (Table 7. 1 and 7.2).

Interviewee I on 'U-Value Calculator stated, '*Architects understand this, since it is the basic thing, it is therefore definite. However, carbon embodiment is useful but there is not enough data to produce reliable prediction (but useful in design of the Olympic for example)*'. He further said, '*Code compliance and checking tools are okay, but it will be good if confidence can be tested against reality, just like PHPP*'. Hence, a degree of prediction against reality of the design and confidence in the use of tools for decision support were added to the list of requirements for recommending tools that fit into the way architects work.

Nevertheless, interviewee H categorically made this statement in response to his own general view on low carbon housing design and delivery in the UK, '*We are the clients' servants: we can only do what we are asked. Very few clients want to have low carbon homes. Those that do, (owner-occupiers, by*

and large, and how many 'self-builders' are there in the UK?) frequently stop wanting them as soon as the additional costs become apparent. Developers and I include many social housing providers here, unfortunately, only want to do an elegant sufficiency to comply with statutory requirements. How many 'tools' can you be using when the total fee for designing a dwelling is frequently only a couple or three hundred pounds?'

Table 7.1: Identification of the key word 'TOOL' and Reference Coded-1

	Quotes on Current Tools in Use	Quotes on other Support Required	Keywords	Reference Coded	% Coverage
A		You don't need tools, what is need is Government spending money on it (LCHs).	Government Involvement	8	2.23
B			Support/Tool	5	0.68
C		Tools on products selection and skills of services and technology. An informed support to check for current and emerging information It is more about good understanding of what LCHs are, The support should therefore be educative and informative with good strategy and principles from academy level and continue to professional level	Informed /educative support for design. Good strategy /Principles/criteria of design	12	1.03
	Bre Green guide and BREEAM related information.	Lack of informed support to check for current and emerging information on tools. There are lots of competing system set up with slightly different initial goal which makes designers end up with sets of different sustainability measure.	Informed support with good and tested sets of sustainability measures.	12	1.34

Table 7.2: Identification of the key word ‘TOOL’ and Reference Coded-2

Quotes on Current Tools in Use	on Tools	Quotes on other Support Required	Keywords	Reference Coded	% Coverage
SAP. PHPP.	IES,	Design tools to include predicted and measured evaluation.	Support Tool,	18	1.82
Tools will not necessarily deliver LCHs, although they are the best at the moment.		Look into green guide to specifications .(He talks about how to calculate NBS)	/Framework that travels (to guide design from the preparation to the management level		
		Tool that travel. It will be good to have a tool that start from when the client write brief to the management level, and it should include health and safety issues			
He uses literature to check for current information and prefer it to using any sort of design software.				11	1.01
		A recipe on how to achieve sustainability measure in decision making		9	
-	-		-	6	
He is a bit conversant with CSH			Support tool that will work with the stages of the RIBA design process	8	
A bit familiar with CSH				10	

Other quotes from the interview transcript were analysed to identify related key words to ‘Tools’ in Tables 7.1 and 7.2. This was further confirmed with the query analysis of the qualitative analysis in QSR Nvivo 9 in Figure 7.1. However, other words that relate to tools in the key words identification include words such as ‘support’ in Figure 7.1 and ‘framework’ in Table 7.1 and 7.2.

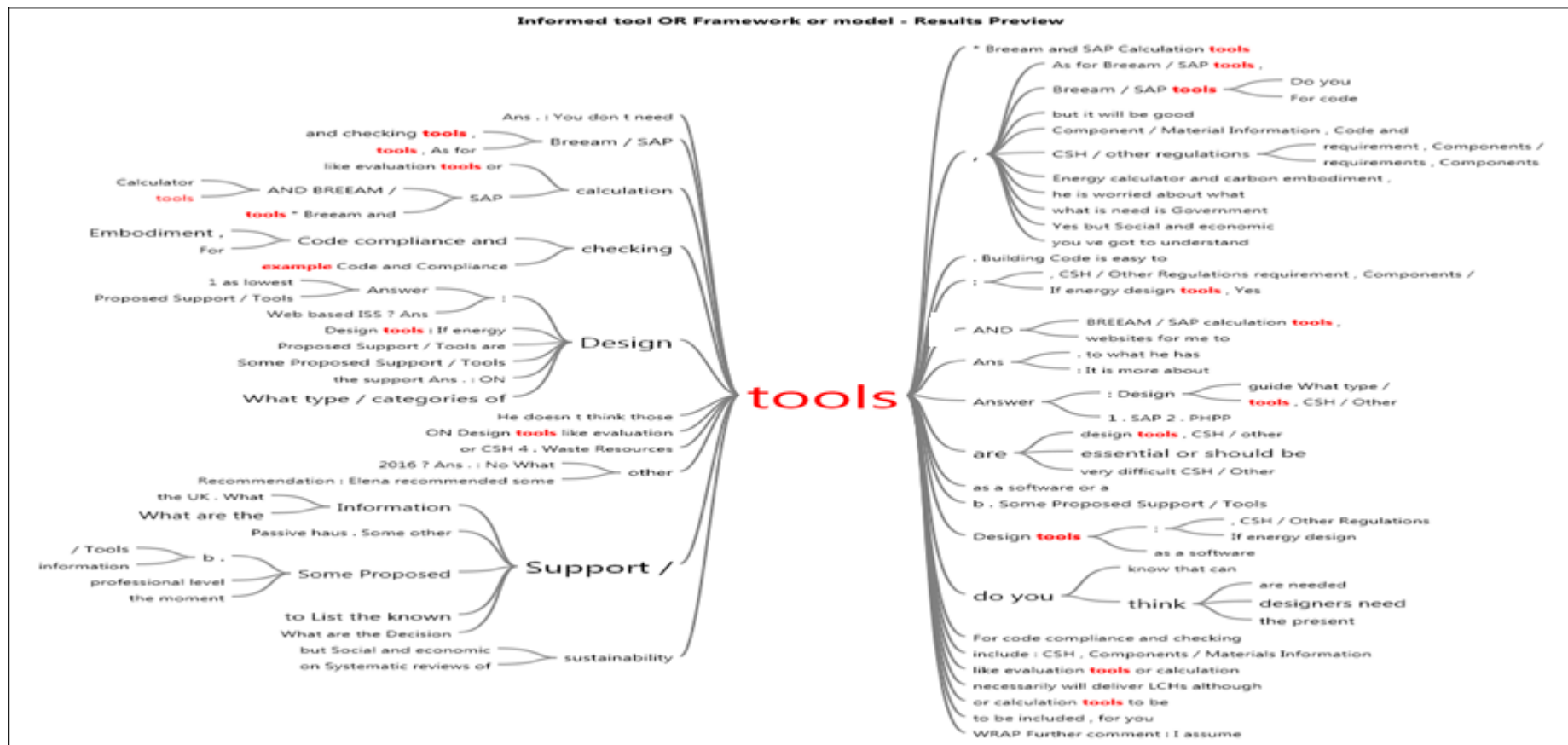


Figure7.1: Nvivo-Result-Preview-on-Key-Words-related to Tools

7.3.1 Decision Support Presentation

This relates to section D of the interview questions. Analyses were sought on preference for delivery of the proposed framework. Interviewee B stated, *'You don't have to read the biggest manual in the world to understand it. It should enable the designers using it to understand it much better, that is, to take responsibility for and understand what they (designers) are using'*. Interviewee E opinion on the question above was that, *'It will be good for it to start from the brief and finally to the management level'* (Table 7.3). Interviewee A stated, *'You have to build everybody expectation and value into it.'*

However, Building Research Environment (BRE), best practice guidance from EST, the Carbon Trust and articles in architectural press were each stated as being used for guidance by one respondent. This suggested that the RIBA Plan of work was not enabling those who participate in the design to easily incorporate sustainability into the process. The guidance used is varied, but the BRE was consistently mentioned as source of information. Consequently, stages of design in the RIBA Outline plan of works, with tools integration for decision making on sustainability were recognised as a good format to present the framework.

Seven of the interviewees agreed that a framework with use of tools within the stages of the design process most useful. Three respondents, however, thought that a guideline or checklist would be useful, with two of them wanting both a checklist and a flowchart.

All the responses strongly suggested the need for a framework, which incorporate sustainability, hence, the DSF development in Chapter Nine. The DSF will include BPES tools to simulate sustainability decisions made by architects at the different stages of the design process, and especially the early design stage, where major decision that has environmental impacts are made. The *'family'* of tools should have a certain characteristics to fit in with the different stages (Table 7.3).

However, interviewee A specifically stated, *'I will prefer it to be layered, so that it will be useful at the different stages, just like an Encyclopaedia'* (Table 7.3). Hence, in Chapter Nine, the framework proposes characteristics for BPES

tools that will fit into various stages of the design process. Nevertheless, the list of design information requirements from the IBDP in Chapter Five is in form of checklists. Some quotes from the interview, key word citing, reference coded and percentage coverage of the reference coded from the query analysis are in Table 7.3.

Table 7.3: Key word identification ‘Design Process/Stages’ on DSF Presentation

	Quote from the Interviewee	Identified Word/Inference	Key	Ref. Coded	% Coverage.
A	I will prefer it to be layered, so that it will be useful at the different stages, just like an Encyclopaedia	Design Stages/Process		13	4.31
B	Categorisation based on design stages	Design Stages		25	4.56
C	Based on what you can achieve for each type of the design stage(s) and health and safety should be included.	Design Stages		34	4.11
D	Something architects are used to	Pictorial, Graphical Stages of Design	or	34	5.33
E	It should be based on design stages and be able to predict and the outcomes, so as to compare the actual completed project with the design.	Design Stages		31	4.07
F	It should be based on what people will recognise.	RIBA Design Stages		32	4.15
G	Something architects will recognise	Pictorial, Graphical Stages of Design	or	28	4.54
H	Be based on Carbon Energy for there is confusion between Carbon and Energy	Energy Criteria		26	5.8
I	Be based on Stages of design	Design Stages		18	1.02
J	Be based on RIBA plan of work stages	Design Stages		6	0.97

7.3.2 Barrier(s) to Low Carbon Housing Design and Delivery in UK

Skills; confidence and competence; financial structure; unwillingness to change (earlier) with more people ready to change for now (Table 7.4) were all recognised by one of the interviewees as barriers to low carbon housing design and delivery in the UK. He further states that the way housing is being delivered (Tables 7.4 and 7.5) in the UK through the volume house modeling also makes it more difficult for the delivery.

Interviewee I (an architect on site) posits, *‘One of the key barrier to low carbon housing design and delivery is to perhaps understand how much it costs at an early stage’*. Interviewee J, an architect working on the same project with Interviewee I emphasised, *‘One of the main key issues is probably affordability’*. He added, *‘This needed to be balanced with delivering the right product’*. He further stated that most of the time, the main client was much worried about the commercial viability of the project and realised that some changes to the original concept needed to be made because of this. He accentuated how most clients wanted to show the business case for the development, so that other house builders would see that the design could be delivered commercially. He further noted, *‘Most clients believe costs are more important than environmental issues’*.

Interviewee I made reference to a selection of materials in relation to cost, such as not using timber for the rainwater goods and how he was dedicated to using non-PVC wiring in the houses but was not put off by the contractor's overestimation of the cost for this. He also stated that his recommendation for most decision that has to do with renewable energy is that no renewable energy technologies should be provided in the houses due to cost implications. Nevertheless, he emphasised, *‘More money should be spend on making the houses 'solar ready', so that if people are willing to pay for solar thermal panels, then it would be very easy to install’*.

Interviewee G, who has once been a project manager emphasised that he has always been more motivated by cost. He admitted, *‘The cost to build low carbon houses is slightly more than that of a conventional house’*. However, he

further emphasised, '*Running costs would be considerably less, saving money in the long term.*'

Interviewee A further indicates affordability as the driver for most of the decision he makes to reduce the cost of the houses. This is because developers are the main factor and they want building to be cheaper so they can realise more profit. Cost was therefore discussed a great deal by all the architects, especially those in practice. This relates more to insulation levels for the design, as it was necessary that any extra money spent on insulation should be balanced by the increase in performance.

Consequently, '*Cost*' (Tables 7.4; 7.5 and Figure 7.2), was identified as a key barrier to low carbon housing design in the UK. When it was first met in the context of the interview analysis, it was marked as a key word. By going through the other transcripts of the interviews, other words such as *financial structure, economical/economy, affordability, cheaper and profit* (Table 7.4) that have the same and /or related meaning to cost were identified and marked the same.

Referring to a workshop attended at the University of West England, on Nvivo, each key word identified is coded as a free node/code. If the same key word is met again in the same source, it is then coded at the existing node rather than a new node. Using the 'Queries tab' of the QSR Nvivo 9 to analyse cost and its related word produces the relationship in Figure 7.2.

Tables 7.4 and 7.5 show the reference coded and percentage coverage of cost and its related words as analysed in the query analysis of the Nvivo 9. The way housing is being delivered in the UK by which house builders are more interested in the profit. Interviewee C, '*They want cheaper buildings, for them to realise more profit*' (Table 7.4 and 7.5; Figure 7.2).

Table 7.4: Identification of the Key word ‘Cost’-1

	Quotes in relation to Barriers to Low Carbon Housing design and delivery	Key Words	Ref. Coded	% Coverage
A	<p>Lack of information and knowledge on available tools from designers’ point of view (it will help if I am aware)</p> <p>An informed support to check for current and emerging information will be an advantage.</p> <p>Other barriers are Cost and the building industry in the UK.</p>	<p>Knowledge of Design and Decision support tools</p> <p>Informed Tool/Framework</p> <p>Cost</p> <p>UK Building Industry</p>	5	-
B	<p>Economical</p> <p>Social people not asking for it</p> <p>Misunderstanding about what sustainability is and what is involved</p> <p>Existing Housing Stock needs to be retrofitted first (There is no strategy to retrofit existing housing stock)</p>	<p>Cost</p> <p>Sustainability Definition</p> <p>Retrofitting</p>	4	0.44
C	<p>Real or Perceived affordability cost (Client economy) ,this depends so much on the house builders and client economy and because of the way housing is delivered in the UK by which House builders are more interested in the profit</p>	<p>Cost</p> <p>UK Building Industry</p> <p>Developers Profit</p>	1	0.07

Table 7.5: Identification of the Key word ‘Cost’-2

	Quotes in relation to Barriers to Low Carbon Housing design and delivery	Key Words	Ref. Coded	% Coverage
D	Skills; Confidence and competence; Financial Structure, Unwillingness to change (earlier) but people are more willing for now but is just 5 years away The way housing is being delivered in the UK through the volume house modeling make it more difficult for delivery	Skill, Cost, UK Building Industry	2	0.17
E	The developers are the main factor, because they want the building to be cheaper so they can realise more profit Sometimes one put elements in the design decision support tools just to make sure you tick the box	Cost Cheaper More profit Developers Profit	1	0.08
F		Budget	2	0.15
G		Affordability	2	0.19
H		Cost	2	0.27
I	Decision that no renewable energy technologies would be provided in the houses, due to cost implications	Cost Pay Money Marketing Developers Profit	12	1.03
J	Affordability was the driver for most of the decision, he made to reduce the cost of the houses	Affordability, Cost	8	1.02

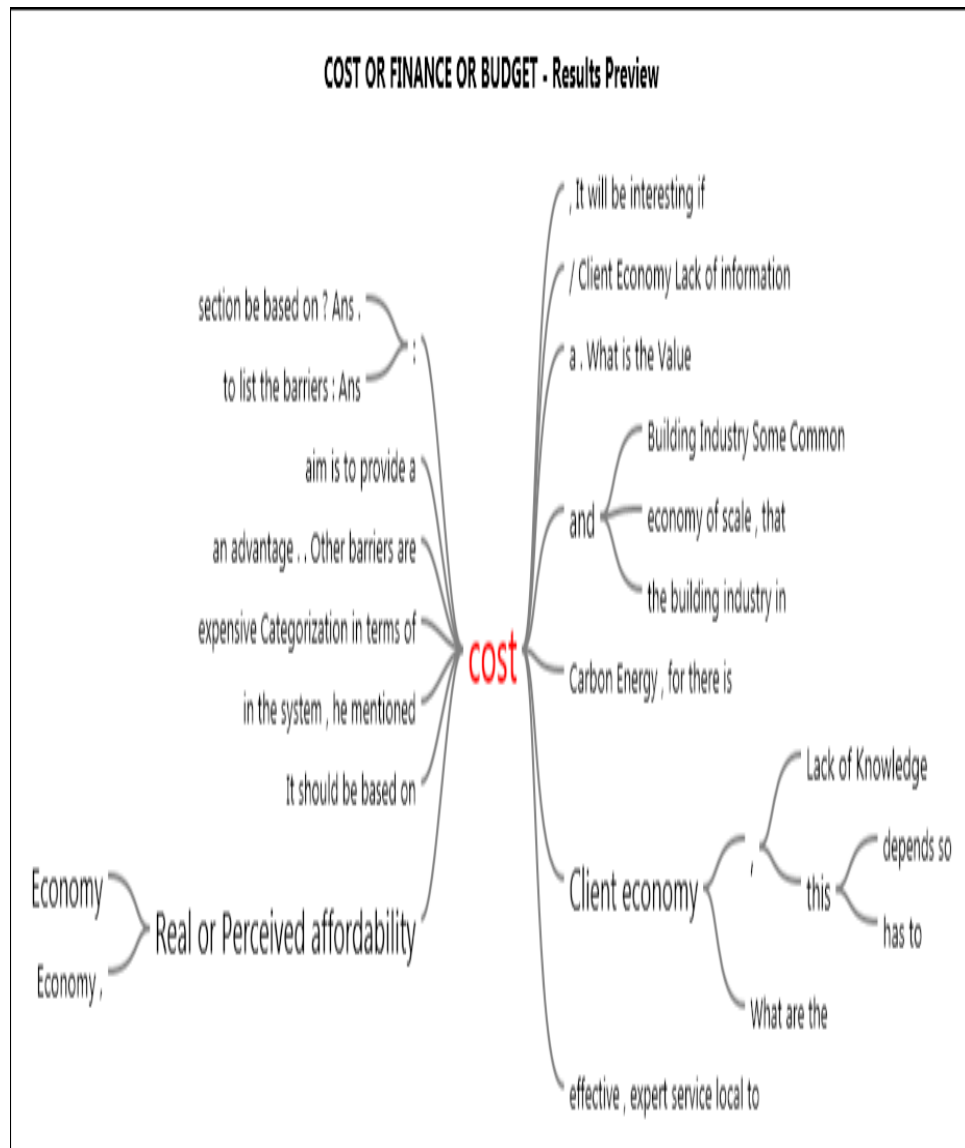


Figure 7.2: Nvivo keywords preview on key words related to Cost

7.4 Statutory and Non Statutory Regulations: CSH

This relates to section ‘E’ of the interview questions. Analysis sought to discover how the CSH has been received and implemented in practice in the form of architects’ insights on the knowledge and use of CSH. The ten interviewees were asked to describe their familiarity with the CSH. Responses varied; six out of the ten respondents said they know the code, three said, ‘*Not so well*’, and only one interviewee said, ‘*No*’, he does not know CSH at all.

On the CSH producing a credible route map to zero carbon homes by 2016, Interviewee A, B and C, answered, 'No', by which they were further asked what they thought were the barriers to the zero carbon targets by 2016, in addition to the barriers listed in the interview templates, which were: country economy; real or perceived affordability; lack of information knowledge from architects' point of view; limited availability of products and skills of services and Technology; lack of an informed system to check for current and emerging information.

Interviewee E answer to the question was, '*Yes (Optimistically) and No (Worried that it won't, because the industry has to learn too much between now and then)*'. Interviewee E answer to the question, in addition to the provided lists was, '*The whole concept of the route map was a brilliant idea (refers to what zero carbon hubs has done) but with problems in the code 6 achievement, which is sort of dead, definition of Zero carbon is not very clear yet*'. He further said, '*Theory of route map is good but how you achieve it is the problem, it is a credible route map, but it still has problems*'. Interviewee A stated, '*CSH is a beurocratic nightmare invented by an institution, once a fully funded government research institute, to be sure, but now simply a rather piratical commercial organisation. We do TRY really we do but we have to be realistic*'.

On the uptake and format of the CSH, Interviewee C suggested, '*It should be much more easily accessible, less complex (you don't have to read the biggest manual in the world to understand it) and enable the designers using it to understand it much better*'. Interviewee E said, '*CSH is fine, but it has some flaws like it not be able to deliver level 6 coupled with people spending much money on wrong technology*'. He further stated: '*It will be good for any tool like CSH to start from when the client write brief to the management level*'. From the ten interviewees, insights of architects by more than half of the interviewee in relation to CSH, being the latest tool for the design are:

- Code Level 5 may be practical by 2016 for new homes while Code Level 6 is not practical at all for achievement by 2016;

- Half of the interviewees have heard, know and use CSH. Less than half do not like the present format of the CSH and only two (2) of the interviewees like the CSH present format;
- More than half of the interviewees, (With exception of an interviewee out of the eight who has no response and another who said, ‘I don’t know,’ agreed that CSH could not produce credible route to zero carbon target for new homes by 2016;
- Level 4 of the CSH is found to be the most current level and practical enough to achieve that architects in UK have designed to in the year 2011 followed by Level three.

7.4.1 Uptake on other Statutory and Non-statutory Regulations in UK

Analyses were further sought on some other statutory and non-statutory regulations and standards in the UK. These include building regulations, Part L1a, Structural Assessment Procedure (SAP), The Green Guide to specification, components/materials information, and case studies. These were first identified from the literature review but further investigated in the interview to find out how important they are to architects for design and decision making to deliver low carbon housing design in the UK. Below is the summary from the interview section:

- Building Regulations, Part L1A: All the interviewees agreed on the importance of building regulations Part L1A in design of new homes in the UK;
- Eco-Homes: Half of the respondents feel that Eco Homes is old, and has since been replaced by CSH. This has an impact on the questionnaire design by which Eco-Homes is not included in the questionnaire design;
- Components and Materials Information: More than half of the interviewees agreed on the importance of components and material information when designing low carbon housing in the UK. The impact of this on the design of the questionnaire is to ask architects, the stage

of design that ‘Green Guide to Specification is used in their design of low carbon housing in the UK.

- Design Guides: Only four of the interviewees agreed on the need for design guides in the design delivery. The reason for this as some of them emphasised is that, design guides are different from one borough to the other within UK. An interviewee particularly stated, ‘*I think the design guides will be especially useful to those designers new to the field and to the country*’.
- Case Studies: Analyses were sought on the appropriateness to have knowledge on existing and related case studies towards delivering low carbon housing design in the UK. Seven of the interviewees agreed on the need to have knowledge of existing case studies on LCHs. The impact in the design of the questionnaire survey was to ask architects: ‘*What stage(s) of design will they need information on existing case studies?*’

The template showing the summary of the conducted interviews is in Appendix 2b. The template is coded based on the questions from the interview, which can also be view in Appendix 2a. The audio recording of all the interviews made the analysis to be fairly easy and unbiased.

7.5 Design Information Requirements (DIR)

This has to do with the final Section ‘F’, of the questionnaire. Analysis sought to identify architects’ needs, in form of sustainability and environmental design information requirements to achieve low carbon housing design and delivery in the UK. These, as explained to the interviewees, are apart from the identified design-decision support tools, CSH, and the identified statutory and non-statutory regulations from sections A to E of the questionnaire. The quotes from the interviewee and keywords identification of design information requirements (DIR) are further used to validate the sustainability DIR within the IBDP proposed in Chapter Five.

Interviewee I emphasised how conventional developers viewed the design process differently because, *'Sustainability offers long term savings whereas many developers usually base their decisions on the short term'*. Interview B's view on design information requirements (DIR) is, *'Focus should be on reduction of CO₂ emissions, conservation of energy, waste recycling etc. rather than on costs, programme and density.'*

Towards the design information requirements (DIR) validation, there exists a plethora of low carbon housing related information. The following, are cited from the interview quotes towards the validation of the sustainability DIR within the IBDP in Chapter Five:

- Approaches to envelope design/ orientation;
- Ventilation Strategy;
- Air Tightness;
- Design principles
- Multi-disciplinary team;
- Environmental impacts;
- Insulation/Passive technology.

7.6 Summary

This chapter had collected data from the interviewees to comply with part of objective two in Section 1.4. It investigated effectiveness of design and decision support tools, along with the other information needs of architects in the form of statutory and non-statutory regulations to deliver low carbon housing design in the UK. Objective one has been met in the literature review, Chapter Two and Three. Chapter Four has reviewed the design and decision making process towards achieving objective three in Chapter Five identified the design information requirements that will deliver the low impact housing design in the UK.

The qualitative analysis in this chapter was based on the semi- structured, in-depth interviews with UK architects. It was context and key word based analysed, combined with the query analysis in QSR Nvivo 9. Ten architects

were interviewed; seven are in practice, while three are in academia. Tools in the form of BPES tools are the major decision support tools recognised by the architects. The most common, which include, Integrated Environmental Solutions (IES-VE) are used to verify and check design on calculation, energy, and carbon embodiment. Hence, lists of tools requirements by architects for different stages of the design process were compiled from the interview towards design of the questions for the questionnaire survey.

On existing statutory and non-statutory regulations in the UK to design and deliver low carbon housing, all interviewees recognised the Code for Sustainable Homes as the latest legislation for the delivery. However, Code Level 5 may be practical by 2016 for new homes, while Code Level 6 is not practical at all for achievement by 2016. More than half of the interviewees agreed that the CSH could not produce a credible route to zero carbon targets for new homes by 2016. Level 4 of the CSH is found to be the most current level and practical enough to achieve that architects in UK have designed to in the year 2011 followed by Level 3. The notable barriers to low carbon housing design and delivery in the UK for most of the interviewees are the real or perceived capital and affordability cost of the technology involved and the way that housing is being delivered in the UK, with most developers targeting their profit in favour of sustainability.

Chapter Eight: Results and Analysis of Questionnaire Survey

8 Introduction

Subsequent to the interview, a Questionnaire survey was carried out. The analyses from the interview on the complexity of the existing design and decision support tools, with the extant study of the literature review were combined to form the basis for the Questionnaire design. The Questionnaire was administered to sustainable architectural practices identified from RIBA directory. The Questionnaire survey was to explore a wider perspective and coverage than the subjects who were interviewed. The purpose of this was to achieve the quantitative part of objective two in the study, to evaluate decision support tools and other information for architects in the UK.

The use of a Questionnaire survey was similar to studies conducted by Adeyeye *et al.*, (2007); Osmani and O'Reilly (2009) and Thomas-Alvarez and Mahdjoubi (2012). The evaluation of the data collected from the Questionnaire regarding the targeted architectural practices in this chapter makes use of frequency distribution and cross tabulation function of the Statistical Package for the Social Sciences (SPSS). In summary, the chapter set out to explore the following issue:

- Overview of the Questionnaire design and response rate;
- BPES Tools and Analysis;
- BPES Tools and Degree of Frequency;
- BPES Tools and Stages of Design that needs focus;
- Other Information needs and Analysis ;
- Decision making and Stages of the Design Process;
- Reliability Tests; and
- Summary.

8.1 Overview of the Questionnaire Design and Response Rate

The design of the Questionnaire has been discussed in section 6.3.3. The Questionnaire is in the Appendix 3. In the Questionnaire survey, there were total of four major sections, ten main Questions and thirty nine sub Questions, defined in Section 6.3.3. However, it was not possible to collect data from all these architectural practices; hence, random sampling was used as explained in Section 6.3.3.2 to arrive at the total number of 425 sustainable practices discussed in Section 6.3.3.3.

To recap, fourteen e- mails were sent in all to elicit response from the targeted samples. Out of the 425 randomly selected practices, sixty-eight opted out, and 357 were delivered successfully to achieve a response rate of 17.4 per cent. The response rate is in line with similar surveys in the construction industry (Soetanto *et al.*, 2001; Takim *et al.*, 2004; Ankrah, 2007; Meng, 2008).

Soetanto *et al.*, (2001) reported 14.7 per cent for their comprehensive Questionnaire survey while Takim *et al.* (2004) regarded a response rate of 20-30 per cent, as norm of survey responses within the construction industry. In support of this, Ankrah (2007) achieved a response rate of combined pilot and main survey of 15.42 per cent. Meng (2008) carried out a survey on the membership database of Constructing Excellence South West by email, out of the 345 Questionnaire delivered, a total of seventy-six responses were received and seventy were duly completed to achieve a 20 per cent response rate. From these examples and due to the sensitive nature of this research, a response rate of 17.4 per cent can therefore be considered adequate.

8.1.1 Response Rate

To assess the reasons, why potential respondents did not fill the Questionnaires, some of the non-respondents were contacted on phone. Emails were further sent as reminder from 24th July to September 7th of 2012. Further target were sought at an architectural exhibition organised by the Department of Architecture, University of the West England on the 7th of June 2012. In all, a period of five months was allowed for the completed Questionnaires to be

retrieved. Sixty-two responses were finally received from the target sample to achieve 17.4 per cent response rate. After data collection, analysis was made using SPSS 19 to explore the characteristics.

8.1.2 Years of Experience

For the reason stated in Section 3.1.2, architects were targeted in the Questionnaire, as the main respondents. They are the key players in the construction industry, whose services are needed from the conception stage of a project, to its final handing over (Oyedele and Tham, 2007). They also have the major responsibility to get the message across in the participatory decision making processes and thereby educate other stakeholders into more genuinely collaborative roles (Chen *et al.*, 2008). They were, thus, most likely to offer more reliable and informed responses to the theme of the Questions posed in the research, as outlined in Section 6.3.3. This presumption converges with the contention of Borman (1978) who states that people who are suitably experienced in what they do should be in a better position to provide relatively accurate responses.

Table 8.1 summarises the respondents' years of experience in relation to Question one of the Questionnaire survey. From Table 8.1, it can be seen that almost 5 per cent have less than two years' experience (column 3, row 1). This is to say, 95 per cent of the respondents, representing the targeted architectural practices representatives have more than two years of experience as registered architects of RIBA. Nevertheless, from the total number of sixty-two respondents, 79.3 per cent (30.6+48.7) have over ten years of experience. This indicates that almost 80 per cent of the respondents to the Questionnaire have a reasonable number of years of experience to provide sufficient data that can be recognised as being credible.

Table 8.1: Respondent years of experience

	Frequency	Percent	Cumulative Percent
Less than 2 years	3	4.8	4.8
2-5 years	3	4.8	9.8
6-10 years	7	11.3	21.3
11-20years	19	30.6	50.8
Greater than 20years	30	48.7	100.0
Total	62	100.0	

From Table 8.1 and Figure 8.1, architects with experience greater than twenty years are the highest number of respondents with a response rate of 48.7 per cent (n = 30). This is followed by those with experience between: eleven to twenty years = 30.6 per cent (n = 19); six to ten years - response rate = 11.3 per cent (n = 7); two to five years - response rate = 4.8 per cent (n = 3); less than two years-response rate= 4.8 per cent (n = 3). This result was not unexpected especially in relation to those with less than ten years of experience, given that the subjects are architects who are mostly sole practitioners.



Figure 8.1: Years of Experience

8.2 BPES Tools and Analysis

The Building Performance Energy Simulation (BPES) tools discussed in Section 3.4 are tools that are used to simulate:

- Energy performance analysis for design and retrofitting;
- Compliance with building regulations, codes, and standards;
- Passive energy saving options;
- Building Energy Management and Control System (EMCS) design;
- Cost analysis;
- Computational Fluid Dynamics (CFD).

The choice of using BPS tools had also been discussed in Section 3.3.4. Nevertheless, a BPS tool that would fulfil all tasks in decision-making for architects and in relation to early and late design stages, does not exist in the market. This is because within the design process, architects are more concerned with building design issues such as geometry, orientation, aesthetic, natural ventilation and day lighting, while engineers are concerned with mechanical systems and controls; hence the difference in the type of tools required by each profession.

Tools provide different degrees of confidence, depending on the quality and amount of the input data, the complexity of the calculations and the skill of the user. However, beyond a certain level of design complexity, the accuracy of predictions usually decline. Thus, when using simulation tools to support the decision of a low carbon building, a staged approach should be adopted with complexity of simulation increasing in proportion to the complexity of the design.

8.2.1 Early Simulation Tools (ETs)

As established in the literature review chapters, the most important decisions concerning building energy usage are to be carried out at the very beginning of the building design process. Tools should allow the description and simulation of a building in fewer minutes and without extensive training on the part of

architects. The results from such output should be in a form that can be understood, even by non-experts, and be able to give architects a quick and fairly accurate output with minimum input. This is because at this stage of the preliminary studies, the focus is mainly on the differences between design alternatives, hence, calculations and all simulations should be performed quickly and effectively. Also, the input data for simulations at this stage are mainly assumptions.

8.2.2 Detail Simulation Tools (DSTs)

When the building design process continues, simulation tools are needed again, especially for thermal function, and when selecting and sizing the systems and equipment for the building. At this phase, the input values should be much more accurate than in the previous design phase, and the results of the calculations should be rather accurate as the equipment and systems selections are based on these values. The user should be able to tailor the layout of the results according to the special needs of the project, such as energy needs and ventilation needs.

By the end of the building design process, the designer calculates target values for the building energy consumption; and calculations should be based on the actual building data. Results should also be accurate, since real energy consumption values are compared to simulation results at this very later stage of the design process.

8.2.3 ETs and DSTs for Stages of the Design Process

From the RIBA Climate Change Toolkit 05, it was made known that all design tools, from simple calculation procedures to complex simulation models, are a means of estimating the approximate performance of a given design. Consequently, the early design phase tools are called early simulation tools (ETs), defined in Section 8.2.1 and the late design phase's tools are called detailed simulation tools (DSTs) (Section 8.2.2). Towards evaluating the

effectiveness of existing BPES (ETs and DSTs) tools, the study set out to find out the following:

- The degree of frequency in the use of BPES tools by architects;
- The stages of design that needs focus on BPES tools development for architects to deliver low carbon housing design in the UK;
- Decision-making by architects at different stages of the design process.

8.3 BPES Tools and Degree of Frequency

Based on the characteristics for identifying tools from the interview analysis, BPES tools that match the identified characteristics, in one way or the other (complexity of tools), include MIT Design Advisor and Autodesk Green Building Studio (AGBS) in Question 3.1, simulation tools (Ecotect and Energy 10) for predicting the performance of buildings in Question 3.2, for the early design phase. However, dynamic simulation tools for modelling the effect on performance of the thermal capacity (thermal mass) of the building fabric (Question 3.3) and energy simulation tools such as IES, eQUEST and Energy plus (Question 3.4) are mostly applicable for use at the later phase of the design process. Hence, these are categorised as detailed simulation tools (DSTs).

8.3.1 Early Simulation Tools (ETs) and Degree of Frequency

Frequency distribution and descriptive analysis discussed in section 6.3.4.1 are useful for assessing distribution of scores. For example, by looking at which tools for low carbon housing design from (Questions 3 to 7) have the tallest bar; one can see the mode, which is simply the tool that occurs most frequently in the data set. Analysis of frequency data in this section comprises of data on ETs that has been tabulated; that is, the number of sampled respondents that fall within the different stage(s) of the design process. By using the function of frequency statistics in SPSS 19, the frequencies in the use of such tools in Question 3.1 were configured in Table 8.2.

From the sixty-two architectural practices representatives in Table 8.2: 32.8 per cent (n=20) use tools such as AGBS tools at the technical design stage; 31.3 per

cent (n=19) use it at the design development stage of the RIBA Outline plan of work; 13.1 per cent (n=8) use it at the concept stage C and 8.2 per cent (n=5) use it at the preparation stages A and B. However, 11.7 per cent (n=7) specified that they use such tools at all stages of their design, while 3.3 per cent (n=2) responded that, they have not used them at all in their design. On the use of early simulation tools, such as Ecotect and Energy 10, for predicting the performance of building (Question 3.2): 37.1 per cent use such tools at the design development stage; 33.9 per cent use it at the technical design stage; 8.1 per cent use such tools at the concept stage of the design process while none of the respondents uses it at the preparation stages A and B.

Table 8.2: Degree of Frequency

BPES Tools	Preparation Stages A and B	Concept Stage C	Design Development Stage D	Technical Design Stage E	All Stages	N/A	Rating Average	Response Count
Early Tools, such as AGBS	5	8	19	20	7	2	3.27	61
Early Simulation Tools, such as Ecotect	0	5	23	21	5	8	3.48	62
Dynamic Simulation Tools	1	4	6	13	3	32	3.48	59
Energy simulation tools	1	3	3	9	4	37	3.60	57
<i>answered Question</i>								62

8.3.2 Detail Simulation Tools and Degree of Frequency

The dynamic simulation of building energy consumption focuses on the hourly variations of the outdoor climatic conditions and the indoor design criteria about temperature and humidity (Hui and Cheung, 1998). Thus, the dynamic simulation tools defined for the purpose of this study are tools based on the specific characteristics of climatic conditions and indoor design requirements. They are also more active and complex than those marketed for the very early stage.

From the sixty-two respondents shown in Table 8.2, on dynamic simulation tools for all other functions (except energy) such as modelling the effect on performance of the thermal capacity (thermal mass) of the building fabric and variations of the outdoor climatic conditions and the indoor design criteria at the later stage of the design process (Question 3.3), more than half (54.2 per cent) of the architectural practices acknowledged that dynamic simulation tools are not applicable to their design of low carbon housing. However, 22.0 per cent had used it at the technical design stage, while 10.2 per cent had used it at the design development stage.

Nevertheless, on energy simulation tools such as IES, eQUEST, Energy plus software (Question 3.4), more than half (64.9 per cent) of the architectural practices acknowledged that they have not used such tools in their design. However, 15.8 per cent of the architectural practices had used it at the technical design stage, while 7.0 per cent responded that they had used energy simulation tools at all stages of the design process.

This finding corresponds to Ellis and Mathews (2001) who attribute the failure of existing tools to influence energy performance outcomes to the fact that they do not accommodate architects nor fit into the current design process. Morbitzer (2003) further pointed out the reason for limited use of the simulation tools within the architectural design process, especially at the early design stages. He stated that architects are seen as visual people while simulation is seen as being too abstract. Moreover, energy performance has not traditionally been the concern of architects but has been seen as a responsibility of service engineers, who are tasked with implementing an already formulated design.

8.4 BPES Tools and Stages of Design that needs Focus

To know the stage(s) of design that need focus on BPES tools to design and deliver low carbon housing in the UK, percentage distribution of the cross tabulation in SPSS 19 was used. The design stages (as specified in Questions 3 and 8) are: preparation stages A and B; the concept stage C; the design

development stage D and technical design stage E, of the RIBA Outline plan of work.

8.4.1 ETs and Stages of Design Process that needs focus

Table 8.3 shows the percentage of the respondents analysed from the cross tabulation. This was achieved by cross tabulating tools in Question 3.1 with the stage(s) of the design process that needs focus in Question eight. This is to know the stage(s) of the design process, which UK architectural practices consider as the stage(s) that need focus, for further development of such tools.

The concept stage of the design process (37.3 per cent response rate), is the stage that needs the most focus for tools such as AGBS and MIT Design Advisor. This is followed by preparation stages A and B (35.6 per cent). For early simulation tools, such as Ecotect and Energy 10, for predicting the performance of buildings (Question 3.2), the concept stage C (38.9 per cent) also has higher percentage over the preparation stages A and B for the stage that needs focus. These two stages, as defined in this research, make up the early phase of the design process. Hence, the percentage of respondents indicating that these two stages need focus at the early design phase (stages A to C) is higher, in comparison to the later phase (stages D and E) of the design process (Table 8.3).

Table 8.3: Percentage distribution of ETs and Stages of Design Process that needs focus

Stages of Design	RIBA Stages of Design Process	% Distribution of respondents in the stages of design that needs focus in ETs such as AGBS	% Distribution of respondents in the stages of design that needs focus on Simulation tools such as Ecotect
Preparatory Stage	A and B	35.6	35.2
Concept Stage	C	37.3	38.9
Design Development	D	11.9	11.1
Technical Design	E	3.4	3.7
Total		88.2%	88.9%

Notes Differences in total value of percentage is due to removal of 'All Stages' and 'Not Applicable', hence figures do not round up to 100%.

8.4.2 DSTs and Stages of Design Process that needs focus

To know the stage(s) of design that need focus for the development of DSTs to design and deliver low carbon housing in the UK, percentage distribution of the cross tabulation of SPSS 19 was used. Table 8.4 shows the percentage of the respondents analysed from the cross tabulation of BPES tools (Question 3.3 and 3.4) with stage(s) of the design process that need focus (Question 8). This was made in order to know the stage(s) of the design process that architects in the UK consider as the stage(s), which need focus for the development of DSTs to deliver the low impact housing design.

From Table 8.4, the early phase (stages A to C) has higher percentages. For dynamic simulation tools (Question 3.3), all stages within the early phase need focus. However, for energy simulation tools (Question 3.4), preparation stages A and B (40 per cent) have higher percentage over (36 per cent) the concept stage of the design process.

Table 8.4: Percentage distribution of DSTs and Stages of Design Process that needs focus

Stages of Design	RIBA Stages of Design process	% Distribution of respondents in the stages of design that needs focus on Dynamic Simulation tools	% Distribution of respondents in the stages of design that needs focus on Energy Simulation tools
Preparatory Stages	A and B	37.0	40.0
Concept Stage	C	37.0	36.0
Design	D	18.5	12.0
Development	E	7.4	4.0
Technical Design			
Total		99.9	92.0

Notes: Differences in total value of percentage is due to removal of 'All Stages' and 'Not Applicable', hence figures do not round up to 100%.

The high percentages of the two stages which make up the early phase of the design process infer that the practicing architects recognised the phase as the one that needs focus for all the BPES tools categorised for both the early and late design phases. This finding is parallel to TSB (2009), Mora *et al.*, (2006) and Dunsdon *et al.*, (2006), who state that the design support at the early design phase, and especially at the conceptual stage of the design process, is poor. Hence, there is need for focus for support for the conceptual stage of the

design process where major decision that has to do with the design is usually taken.

8.5 Other Information and Degree of Frequency

The findings shown in Table 8.5 on the degree of frequency in the use of statutory and non-statutory regulations, along with other information necessary to design and delivery of low carbon housing in the UK, can be reported as follows:

- **Building Information Modelling (BIM) software such as Autodesk Revit and ArChiCad:** Almost half (49.2 per cent), of the architectural practices acknowledged that they had not used BIM in their past design of low carbon housing in the UK. However, 22.0 per cent had used it at all stages of the process, while 15.3 per cent responded that they had used only at the concept design stage.
- **Green Guide to Specification:** Among the 62 respondents: 36.2 per cent had used Green Guide to specification at the design development stage; 17.2 per cent had used it at the concept design stage C of the RIBA Outline plan of work stages of design process; 15.5 per cent had used it at the technical design stage E and 5.3 per cent at the preparation stages A and B.
- **Building regulations, Part L1A:** Of the 62 architectural practices: 29.0 per cent use building regulations part L1A at all stages of the design process; 24.2 per cent use it at the design development stage; 24.2 per cent of the respondents had sought for information on the building regulations, part L1A at the concept stage of the RIBA Outline plan of work stages and 16.1 per cent had used it only at the technical design stage. However, only 3.3 per cent had sought for information on the regulations at the preparation stages A and B.
- **Code for Sustainable Homes (CSH):** 36.7 per cent of the architectural practices representatives use CSH at the concept stage C of the design process; 21.7 per cent make use of the CSH at all stages of the process,

while 20.0 per cent use it at the design development stage. At the preparation stages A and B and the technical design stage E, only 3.3 per cent had made use of CSH.

- **Merton rule standards for renewable energy contributions as set by planning authorities’ and other agencies like English partnership:** 45.0 per cent stated that they do not apply Merton rule or such in their design of low carbon housing in the UK; 26.7 per cent had used it at the concept stage C of the process; 11.7 per cent had used at the design development stage and 8.3 per cent had used at all stages of the RIBA Outline plan of work stages.

Table 8.5: Other Types of Tools and other Information for Low carbon housing design

What stage of design do you use the following in your design of low carbon homes in the UK?								
Other Information	Stages A and B	Stage C	Stage D	Stage E	All Stages	NA	Rating Average	Response Count
Building Information Modelling (BIM)	1	9	4	3	13	29	3.60	59
Building Environmental Assessment tool (BEA) (Envest II)	0	1	4	6	1	46	3.58	58
Life Cycle Assessment tool	0	1	6	4	2	44	3.54	57
Life Cycle Cost Assessment (LCCA) tool	0	1	4	5	1	46	3.55	57
Green Guide to Specification	3	10	21	9	7	8	3.14	58
Other (please specify)								4
							<i>answered Question</i>	62
							<i>skipped Question</i>	0

- **Standard Assessment Procedure (SAP):** From the 62 architectural practices respondents: 43.5 per cent carried out the SAP calculation at the design development stage; 17.7 per cent at the technical design stage, and 12.9 per cent at the concept stage.
- **Energy Performance Certificates (EPCs):** From the 62 architectural practices respondents, more than half (53.3 per cent) prepare the EPCs

at the technical design stage, 15.0 per cent at the design development stage, while 21.7 per cent responded that it is not applicable in their design.

- **Domestic Energy Rating (DER):** 24.6 per cent use DER at the design development and technical design stages of the RIBA Outline plan of work stages; 8.2 per cent at all stages of the design process, while 41.0 per cent responded that it is not applicable in their design.
- **Building Research Establishments Environmental Assessment Method (BREEAM):** 21.7 per cent use BREEAM at the design development stage; 16.7 per cent use it at the concept design stage of the RIBA Outline plan of work stages; 8.3 per cent use it at the technical design stage, and all stages of the process and 3.3 per cent responded that they use it at the preparation stages A and B. However, 41.7 per cent responded that BREEAM is not applicable.
- **Energy Savings Trust (EST) Best Practices:** 22.8 per cent use guides from the EST best practices at the concept stage; 14.0 per cent at the design development stage D; 7.0 per cent at the technical design stage E and 5.3 per cent use EST best practice standard at all stages of their design. None of the respondents use EST at the preparation stages A and B, and 50.9 per cent responded that it is not applicable in their design.

Table 8.5 shows how more than half of the respondents had not used some of the other type of tools. These include: building environmental assessment tool (BEA) such as Envest II and life cycle assessment tool such as Environmental Impact Estimator in their design. Quotes from respondents in the Questionnaire include:

- *'I have not been in practice for long'* (19/7/2012);
- *'Use of PHPP should be encouraged'* (3/7/2012);
- *'Use of these tools had usually been undertaken by another consultant'*(12/6/2012);
- *'Availability, Cost and applicability of these tools should be of great consideration'* (02/05/2012).

8.5.1 Other Information and Stages of Design Process that need focus

To know the stage(s) of design that need focus on some of the other information for the design and delivery of low carbon housing in the UK, percentage distribution of the cross tabulation of the SPSS 19 was used. The cross tabulation of Question 3.5 on BIM (Autodesk Revit, ArChicad etc) and The Green Guide to specification in Question 3.10, with the stages of design that need focus in Question 8 were carried out. The percentage distribution is in Table 8.6.

Table 8.6: Percentage distribution on BIM and Green guide to specification and Stages of Design Process that needs focus

Stages of Design	RIBA Plan of work Stages	% Distribution of respondents in the stages of design that needs focus on BIM	% Distribution of respondents in the stages of design that needs focus on Green guide to Specification
Preparatory Stages	A and B	33.0	34.0
Concept Stage	C	36.7	36.0
Design Development	D	10.0	12.0
Technical Design	E	6.7	4.0
Total		86.7	86.0

Notes: Differences in total value of percentage is due to removal of “All Stages” and ‘Non applicable’, hence figures do not round up to 100%.

The early phase (stages A to C) has the higher percentages of respondents on the stage of design that needs focus for BIM and Green Guide to specification over the later phase (stages D and E) of the design process. BIM tools (Autodesk Revit and Archi-Cad) have 36.7 per cent while Green Guide to specification has 36 per cent for the concept stage C of the design process as the stage that needs focus

The foregoing discussions from section 8.3 to 8.5, establish that the use of tools for the delivery of low carbon housing in the UK, need focus from the preparation stage A to the concept stage C of the RIBA Outline plan of work stages. Architects use the existing tools and other information more at the design development and technical stage of the design process. Thus, the role of energy analysis has been simply to give endorsement to a completed design, rather than to assist during the design process.

8.6 Decision making and Stages of Design

The analyses in this section were carried out using the Chi square formula discussed in section 6.3.4.2. The Chi square is useful for exploring frequency data (Field, 2009). However, the method adopted in this section of the thesis is similar to Gruneberg and Hughes (2004), who adopted it after Black (1994). They used the Chi square goodness-of-fit test to compare frequencies in the two data sets. The formula of the test is:

- $\chi^2 = \sum[(f_o - f_e)^2 / f_e]$Equation 8.1
- $df = k - 1 - c = \text{row}-1 * \text{column}-1$Equation 8.2

Where,

- f_o = frequency of observed values;
- f_e = frequency of expected values;
- k = number of categories;
- c = number of parameters being estimated from the sample data; and
- df = degrees of freedom (Black, 1994, Gruneberg and Hughes, 2004).

Consequently, it is used in this research to establish the association between the act of making design decisions (Dm1 –Dm5) and stages of design process in the RIBA Outline plan of work (Question 9). The hypotheses being tested are:

- H_0 : There is no association between decision-making and stages of the design process;
- H_1 : There is association between decision-making and stages of design process.

The five types of decision making in Question 9 are denoted as:

- Dm1- Thermal Implication on Building Forms;
- Dm2- Thermal Characteristics on Building Performance;
- Dm3- Building Services System;
- Dm4- New and Renewable Energy Systems for use in the building;

- Dm5- Integrated Low Carbon design principles.

Types of decision making, Dm1 to Dm5, from Question 9 were cross tabulated with stages A to E of the design process. This was to establish if there is an association between the various decision-making and stage(s) of the design process. Table 8.7 shows the contingency of the observed and expected values for the various decisions, Dm1 to Dm5.

Table 8.7: Contingency table of Decision Making and Stages of design

Decision Making	Stages A and B	Stage C	Stage D	Stage E	Total
Dm1	11(6.77)	33(24.41)	9(18.46)	3(6.36)	56
Dm2	7(6.77)	31(24.41)	10(18.46)	8(6.34)	56
Dm3	3(6.53)	13(23.54)	30(17.80)	8(6.13)	54
DM4	5(6.53)	21(23.54)	21(17.80)	7(6.13)	53
DM5	7(6.41)	21(23.10)	20(17.47)	5(6.03)	53

Notes: Differences in total numbers of respondents is due to removal of those who answered “All Stages” and ‘Non applicable’, hence figures do not round up to the total number of 62.

The Chi square test, denoted by ‘ χ^2 ’ compares the frequency in one type of decision- making to the frequency of the other types within the same data. The χ^2 test used gives the 95 per cent confidence level of significance. This implies that the difference in frequencies between the sets of data within the table is only significant if it would normally occur once in every twenty (row*column = 5*4) similar trials. The Chi square calculated from Table 8.7 is 36.04 with p value of 0.0003, which is less than 0.05 at 95 per cent confidence level. Nevertheless, the Chi square value of 36.04 is greater than the critical Chi square of 21.03. Hence, the hypothesis H_0 , which states that there is no

association between decision making and stages of design, can be rejected. The alternative conclusion is that, there is an association between decision-making and the stages of the design process.

The foregoing conclusion is that: decision on thermal implication on building forms-Dm1; thermal characteristics on building performance-Dm2; building services system-Dm3; new and renewable energy systems for use in the building-Dm4 and integrated low carbon design principles-Dm5, are all related to the different stages of the design process in the RIBA Outline plan of work.

8.6.1 ETs and Decision making

Since the association between decision-making and stages of the design process has been tested, and it has been confirmed that there is an association between the two, the next thing is to test the association between each decision-making (Dm1-Dm5) in Question 9 and use of BPES tools in Questions 3.1. The hypotheses being tested are:

- H_0 : There is no association between decision-making and use of ETs;
- H_1 : There is association between decision-making and use of ETs.

The Chi-square tests show whether two variables are associated. If the significance p value is small enough (less than 0.05), then the conditions can be said to be met and the hypothesis that the variables are not related can then be rejected, with confidence gained that they are in some ways related (Field, 2009). That is, some degree of association exists between the particular decision-making and use of the identified tools. This is in accordance to Field (2009) who states that if the significance value is less than 0.05, there exists a significant relationship between the variables.

Table 8.8 contains the summary output of the Chi square tests from the cross-tabulation function of the SPSS 19 between Question 3.1 to 3.2, and 9 of the Questionnaire, to show the association between ETs and the different categories of decision-making (Dm1-Dm5).

Table 8.8: Chi square Statistical test between ETs and Decision making (Dm)

Tools	Decision Making	Chi square Value	Degree of Freedom (Df)	Critical value of Chi square at Df	P Value	Association
ETs	Dm1 Dm2 Dm3	60.91	9	16.92	0.000	Significant Association
ETs	Dm3 Dm4 Dm5	26.838	9	16.92	0.001	Significant Association

All the p values in the Table 8.8 are less than 0.05 on the matrix of decision making (Dm1-Dm3) and (Dm3-Dm5). This infers that decision-making (Dm1-Dm5) has a relationship with the use of ETs. Hence, the hypothesis H_0 that, there is no association between decision making (Dm1-Dm5) and use of ETs can be rejected and the null hypothesis that there is positive association between them is accepted.

8.6.2 ETs and Decision Making at stages of Design Process

The cross tabulation of Question 3.1 to 3.2 on ETs and decision-making in Question 9 at different stages of design process, produces the percentage distribution in Table 8.9. Early Simulation Tools such as AGBS and MIT Design Advisor have the highest percentage of association on decision-making (57.9 per cent) on thermal implication on building forms (Dm1) at the concept stage of the design process, followed by decision-making on thermal characteristics on building performance (Dm2) (53.4 per cent), also at the concept stage of the design process.

Table 8.9 : Percentage distribution in the use of ETs and Decision making (Dm1-Dm5)

Tools	Decision Making	Stage A and B (%)	Stage C (%)	Stage D (%)	Stage E (%)	Total (%)
ETs	Dm1	17.5	57.9	15.8	5.3	96.5
	Dm2	12.1	53.4	15.5	13.8	94.8
	Dm3	5.4	23.2	51.8	14.3	94.7
	Dm4	8.6	36.2	34.5	12.1	91.4
	Dm5	10.7	37.5	35.7	8.9	92.6

Notes: Differences in total value of percentage is due to removal of "All Stages" and 'Non applicable', hence figures do not round up to 100%.

However, such tools have the highest percentage (51.8 per cent) with building services system (Dm3) at the design development stage. Decision-making on new and renewable energy systems in the building (Dm4) (36.2 per cent) and integrated low carbon design principles (Dm5) (37.5 per cent), are also at the concept design stage. Hence, it can be inferred that decision-making by architects, are mostly at the concept stage of the design process.

8.6.3 DSTs and Decision Making

To assess the association between the act of making decision (Dm1-Dm5) in Question 9, and use of simulation tools (DSTs) in Questions 3.3 and 3.4 at different stages of the design process, a Chi square test of the cross tabulation function in SPSS 19 was further used to test the following hypothesis:

- H_0 : There is no association between decision-making and use of detailed simulation tools;
- H_1 : There is association between decision-making and use of detailed simulation tools.

Table 8.10 illustrates the summary output of the Chi square tests to show the association between various matrixes of the different types of DSTs in Questions 3.3 to 3.4 and different categories of decision- making (Dm1-Dm5) in Question 9. The p values of all associations in Table 8.10 are less than 0.05 on all decision-making. This infers that decision-making (Dm1 and Dm2) has relationships with the use of BPES tools in Question 3.3; dynamic simulation tools for modelling the effect on performance of the thermal capacity (thermal mass) of the building fabric and energy simulation tools such as IES, eQUEST and Energy plus in Question 3.4.

Table 8.10: Chi square Statistical Test on level of association between DSTs and Decision making (Dm1-Dm5)

Tools	Decision Making	Chi square Value	Degree of Freedom (Df)	Critical value of Chi square at Df	P Values	Association
All DSTs	Dm1 Dm2	78.053	6	12.59	0.000	Significant Association
Dynamic and Energy Simulation Tools	Dm3 Dm4 Dm5	42.75	9	16.92	0.000	Significant Association

There is also a significant association of the p value of 0.000 (column 6, row 3) between decision making (Dm3-Dm5) and dynamic simulation tools for modelling the effect on performance of the thermal capacity (thermal mass) of the building fabric in Question 3.3, and energy simulation tools, such as IES, eQUEST, Energy Plus in Question 3.4. Hence, the hypothesis H_0 that there is no association between decision-making (Dm1-Dm5) and use of detailed simulation tools (DSTs) can be rejected. The alternative conclusion is that there is association between decision-making (Dm1-Dm5) and use of DSTs at the later stage of the design process. The foregoing conclusion is that DSTs are used to take decisions on Dm1, Dm2, Dm3 and Dm5.

8.6.4 DSTs and Decision Making at different Stages of Design process

The percentage distribution of the cross-tabulation function of questions on all BPES tools from Question 3.3 to 3.4, and decision-making in Question 9, at different stages of design process, was further carried out. The use of BPES tools, as shown in Table 8.11, has the highest percentage (57.4 per cent) for decision-making on thermal implications on building forms (Dm1) at concept stage of the design process. However, decision-making on building services system (Dm3) is at design development stage ‘D’ (53.8 per cent) while that of thermal characteristics on building performance (Dm2) (50.0 per cent), is also at the concept stage of the design process.

Table 8.11: Percentage distribution of DSTs and Decision making (Dm1 -Dm5)

Tools	Decision Making	Stage A and B (%)	Stage C (%)	Stage D (%)	Stage E (%)	Total (%)
DSTs	Dm1	18.5	57.4	13.0	5.6	94.5
	Dm2	13.0	50.0	18.5	11.1	92.6
	Dm3	5.8	21.2	53.8	13.5	94.3
	Dm4	7.4	35.2	37.0	11.1	90.7
	Dm5	11.5	34.6	38.5	7.7	92.3

Notes: Differences in total value of percentage is due to removal of “All Stages” and ‘Non applicable’, hence figures do not round up to 100%.

All the findings, in relation to decision-making from the percentage distribution and Chi square tests of the cross tabulation, provide further evidence in support of assertions made in Chapter Five, from the analysis on the case-based documents on integrated design process(IDP). This infers that decisions made from the concept stage of the design process, have greater benefits for the construction industry and especially low carbon housing design and delivery in the UK.

8.6.5 The Green Guide to Specification and Decision Making

The Green Guide to Specification, discussed in section 2.3.4, provides easy-to-use guidance on how to make the best environmental choices when selecting construction materials and components. To assess the association between decision-making (Dm1-Dm5) (Question 9), and the use of Green Guide to Specifications (Question 3.10), at different stages of the design process, a Chi square test of the cross-tabulation function in SPSS 19 was used to test the following hypothesis:

- H_0 : There is no association between decision-making and use of The Green Guide to Specification;
- H_1 : There is association between decision-making and use of The Green Guide to Specification.

Table 8.12 illustrates the summary output of the Chi square tests to show the association between The Green Guide to Specification (Question 3.10), and the different categories of decision-making (Dm1-Dm5) (Question 9). The Chi-square statistics in Table 8.12, suggest that there is an association between the two variables. The cross-tabulation of Dm1 and Dm2 in Table 8.12 with The Green Guide to Specification has a p value of 0.001(< 0.05).

Table 8.12: Chi square Statistical test between green guide to specification and decision making

Tools	Decision Making	Chi square Value	Degree of Freedom (Df)	Critical value of Chi square at Df	P Value	Association
Green Guide to Specification	Dm1	27.467	6	12.59	0.001	Significant Association
	Dm2					
	Dm3	10.68	9	16.92	0.298	No Association
	Dm4					
	Dm5					

This infers that there is a significant relationship between The Green Guide to Specification with decision-making (Dm1 and Dm2), in contrast to decision-making on Building Services System (Dm3); New and Renewable Energy Systems for use in the building (Dm4), and Integrated Low Carbon design principles (Dm5). However, decision-making (Dm3-Dm5) has a p-value 0.298 (greater than 0.05), thus has no association with The Green Guide to Specification. This infers that The Green Guide to Specification can be used to make decisions on Dm1 and Dm2, but not necessarily on Dm3 to Dm5. However, no sufficient data exists to support the claim.

8.6.6 Green Guide to Specification and Decision Making

The percentage distribution of the cross-tabulation function (Question 3.10) on The Green Guide to Specification with decision-making (Question 9) at different stages of design process, produce the percentage distribution shown in Table 8.13. The highest percentage of all decision-making (Dm1-Dm5) is at the design development stage D of the design process. The foregoing conclusion is that the use of The Green Guide to Specification with decision-

making (Dm1-Dm5) is at the design development stage D, more than any other stage(s) within the design process.

Table 8.13: Percentage distribution in Green guide to specification and Decision Making

Other Information	Decision Making	Stage A and B (%)	Stage C (%)	Stage D (%)	Stage E (%)	Total
Green Guide to Specifications	Dm1	5.4	17.9	37.5	16.1	76.9
	Dm2	5.3	17.5	36.8	15.8	75.4
	Dm3	5.5	18.2	38.2	14.5	77.7
	Dm4	5.3	17.5	36.8	15.8	75.4
	Dm5	5.6	18.5	35.2	16.7	76.0

Notes: Differences in total value of percentage is due to removal of "All Stages", and 'Not Applicable', hence figures do not round up to 100%.

8.7 Reliability

The meaning of reliability is that a scale should consistently reflect the construct it is measuring (Field, 2009). In this study, the test for reliability of the data analysed was carried out using the Cronbach test for reliability of the SPSS 19. Table 8.14 shows the reliability statistics of Cronbach's Alpha to be 0.852.

Table 8.14: Reliability Test

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.852	.854	25

However, Field (2009) states that all items should correlate with the total for the data to be considered reliable. Since Cronbach's Alpha, shown in Table

8.14 is above 0.8, all values in the column labelled ‘*Cronbach’s Alpha if item deleted*, in table 8.15 should also be around the same value of 0.8 for the condition of the reliability test to be fulfilled. Only then, can the data be considered to be reliable.

Table 8.15: Reliability Analysis

Tools	Scale	Scale	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
	Mean if Item Deleted	Variance if Item Deleted			
Early Tools	37.5778	328.977	.310	.588	.849
Simulation Tools	37.7333	319.155	.445	.654	.845
Dynamic Simulation Tools	39.2667	298.609	.634	.796	.837
Energy simulation tools	39.7111	306.119	.544	.894	.841
BIM	39.0000	312.545	.348	.661	.850
Green Guide to Specification	38.1111	322.737	.353	.644	.848

If any items result in substantially greater values of α than the overall α , the item(s) concerned may need to be deleted from the scale to improve its reliability. In this case, all α are slightly above 0.8 and is certainly in the region indicated by Kline (Field, 2009) to indicate good reliability.

8.8 Summary

This chapter has evaluated the data collected on a wider scale to fulfil the quantitative part of objective two in Section 1.4. A frequency distribution of the SPSS 19 was used to evaluate the data collected from the UK architectural practices, while percentage distribution of the cross-tabulation function in the SPSS and Chi square tests were used to test the association. The responses from the questionnaire survey came from individuals with different maturity levels and varying years of experience. Almost 80 per cent of the subjects who

represented the architectural practices have over 10 years of experience, with more than half having over 20 years. Thus, it is assumed that the wealth of architectural experience held by individuals in this study is such that the data they have provided can be recognised as credible.

More than half of the respondents (64.1 per cent) use BPES tools at the design development and technical stages, which are the later stages of the design process. However, the early phase of the design process, comprising the preparation stages A and B and the concept stage C, are the stages considered by more than half of the architectural practices, as the phase that needs focus for further development on BPES tools. Hence, for all existing BPES tools, embracing both the ETs and DSTs in this study, it is the concept stage of the design process that needs the most focus, followed by the preparation stages A and B. On other information such as the Green Guide to Specification and Building Information Modelling (BIM) software, such as Autodesk Revit and ArchiCad, to deliver low carbon housing design in the UK, the concept stage C of the design process is also the stage that needs focus over the preparation stages A and B within the early design phase.

Nevertheless, decision-making on thermal implications on building forms (Dm1); thermal characteristics on building performance (Dm2); building services system (Dm3); renewable energy systems for use in the building (Dm4) and integrated low carbon design principles (Dm5), have relationships with the use of BPES tools at the concept stage of the design process. The Green Guide to Specification has relationships with decisions made on thermal implication on building forms (Dm1) and thermal characteristics on building performance (Dm2), but not on building services system (Dm3), renewable energy systems for use in the building (Dm4) and integrated low carbon design principles (Dm5). The Chapter finally established the later phase of the design process as the stage that architects use existing BPES tools. It further establishes the concept stage as the most important stage within the design process, where major decision are taken, but poor support exists for the stage.

Chapter Nine: BPES Tools and Development of the Decision Support Framework

9 Introduction

Chapter Eight provided some deep insight into state-of-the-art on BPES tools and their application in decision making. It showed how the majority of UK architects do not use such tools, while the small numbers that do use it, only do so at the later stage of the design process. Hence, support for architects at the early design stage remains poor.

Inference from the interview analysis on required characteristics of BPES tools, coupled with the DIR within the IBDP from the case-based documents in Chapter Five are used to develop the DSF. The Chapter thus discusses the framework by which, the outline is:

- Existing BPES Tools and Stages of the Design Process;
- BPES tools and their Critique;
- Developing the DSF;
- Design Process in the DSF; and
- Summary

9.1 Existing BPES Tools and Stages of the Design Process

From the analysis in Chapter Eight, the most popular stages of design identified for use of BPES tools by the architectural practices are, the design development stage 'D' and the technical design stage 'E' of the RIBA Outline Plan of Work. The concept stage of the design process, followed by preparation stages A and B, are the stages that need the most focus for further development of software, to deliver low impact housing design in the UK. Hence, as shown in Table 9.1, the ten BPES tools, within the scope of this study, are categorised based on the degree of complexity in information requirements of the tools. The assumption is that, the less the required

complexity in input of information requirements of the tools, the simpler it is to use as the design develops.

Thus, only two out of the ten, are recognised for each of the stages, within the early design phase. Four BPES tools are recognised for the design development stage, while five are recognised for technical design stage. Thus, in Table 9.1, the tools that have close and interrelated functions are grouped together, based upon the complexity and information requirements of the tools. For the preparation stage, such tools include: MIT Design Advisor and Autodesk Green building studio. At the concept stage, are the Autodesk Ecotect (AE) and Energy 10. However, for the design development stage, such tools include: Autodesk Ecotect; Building Design Advisor (BDA); eQuest and IES-VE (Table 9.1).

Table 9.1: Existing BPES Tools at Stages of Design Process

Early Design Phase		Detail Design Phase	
Stages A and B (Preparation Stage)	Stage C (Conceptual stage)	Stage D (Design Development)	Stage E (Technical Design)
Early Simulation Tools		Detail Simulation Tools	
Autodesk Green Building Studio	Ecotect	Autodesk Ecotect Analysis	Energy Plus
MIT Design Advisor	Energy 10	Building Design Advisor	ESP-r
		eQUEST	DOE-2
		IES-VE	e QUEST
			IES-VE

9.1.1 Preparation Stages

- ***Autodesk Green Building Studio (AGBS)***

Autodesk asserts that AGBS seamlessly links architectural building information models (BIM) and certain 3-D CAD building designs with energy, water, and carbon analysis, to enable architects to quickly calculate both the operational and energy implications of early design decisions. The claim is that, the web service automatically generates geometrically accurate, detailed input files for major energy simulation programs. It uses the DOE-2.2

simulation engine to calculate energy performance and creates geometrically accurate input files for Energy-Plus (Autodesk, 2012a).

- ***MIT Design Advisor***

Architects and building designers are supposed to use computer modelling to improve indoor comfort and energy performance of conceptual building designs. The Massachusetts Institute of Technology claims that MIT Design Advisor can be used at an early stage of design and optimisation to provide quick and visual comparisons. It allows the description and simulation of a building in less than five minutes without any technical experience or training and runs an annual energy simulation in less than a minute, with graphical results immediately available for review (Massachusetts Institute of Technology, 2009). The functions include energy, comfort, natural ventilation, day lighting and a life-cycle optimiser.

9.1.2 Concept Stage

- ***Ecotect***

Autodesk claims that Autodesk Ecotect (AE) is a sustainable design analysis software which offers a wide range of simulation and building energy analysis functionality to improve performance (concept-to-detail analysis), both of existing buildings and new building designs. Online energy, water, and carbon-emission analysis capabilities integrate with the tools, to enable visualisation and simulation of a building's performance within the context of its environment to perform the following functions:

- **Whole-building energy analysis:** calculate total energy use and carbon emissions of a building model on an annual, monthly, daily, and hourly basis, using a global database of weather information;
- **Thermal performance:** calculate heating and cooling loads for models and analyses effects of occupancy, internal gains, infiltration, and equipment;
- **Water usage and cost evaluation:** estimates water use inside and outside the building;
- **Solar radiation:** visualise incident solar radiation on windows and surfaces, over any period;

- **Day lighting:** calculates daylight factors and luminance levels at any point in the model;
- **Shadows and reflections:** display the sun's position and path relative to the model at any date, time, and location (Autodesk, 2012c)

- ***Energy-10***

Energy-10 is a software tool developed at National Renewable Energy Laboratory (NREL) for conceptual design. It is used to make whole-building trade-offs during early design phases for buildings that have less than 10,000 ft² floor area, or buildings which can be treated as one or two-zone increments. It performs whole-building energy analysis for 8,760 hours/year, including dynamic, thermal and day lighting calculations (Balcomb, 1997). The software has been licensed to the Sustainable Buildings Industries Council (US Department of Energy, 2012). The claim is that it is specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process.

9.1.3 Design Development Stage

- ***Building Design Advisor (BDA)***

The BDA is from Lawrence Berkeley National Laboratory (LBNL) in the US. LBNL claims, that BDA is a comprehensive design theory computer programs to support the concurrent, integrated use of multiple simulation tools and databases, through a single, object-based representation of building components and systems. It acts as a data manager and process controller to allow building designers to benefit from the capabilities of multiple analysis and visualisation tools throughout the building design process (Lawrence Berkeley National Laboratory, 2012). The BDA is implemented as a windows-based application for personal computers. In addition to the schematic graphic editor, the current version of the BDA is linked to DCM (day lighting computation module), ECM (Electric lighting computation module), and DOE-2 (energy analysis module) (Lawrence Berkeley National Laboratory, 2012).

- *eQUEST*

eQUEST provides two design wizards: the Schematic Design (SDW) and Design Development Wizards (DDW); both to represent well-known stages during design that differ significantly in the level of detail they contain. Both wizards can be used to simplify data input through usage of default parameters as illustrated in Figure 9.1 (Maile *et al.*, 2007). eQuest claims, it is possible to convert from wizards with less detail to more detailed descriptions of the building.

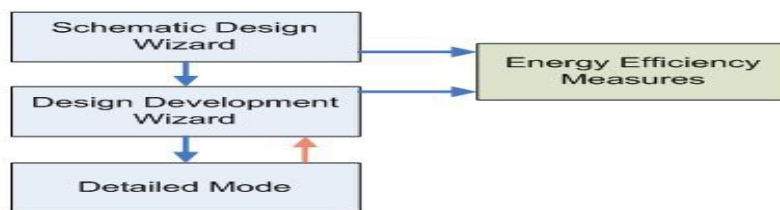


Figure 9.1: Wizards in eQUEST

Source: Maile *et al.* (2007)

eQUEST wizards contain several wizard screens which lead the user to input and/or change data. These screens include predefined default to which the user can make appropriate changes to location, weather, geometry, construction types, space types and usage, schedules and HVAC systems and components as the major input categories in Figure 9.2 (Maile *et al.*, 2007).

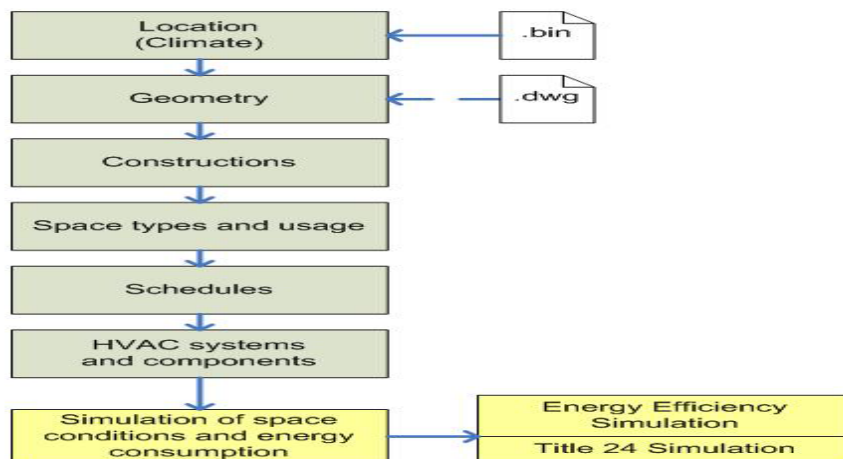


Figure 9.2: General workflow in the schematic design wizard of eQUEST

Source: Maile *et al.* (2007)

- ***IES-VE (Integrated Energy Simulation- Virtual Environment)***

Dr. Don McLean, is the Managing Director of IES-VE; he formed the company in June 1994. The company is primarily in the UK, with locations in Glasgow, Dublin, Boston, San Francisco, Melbourne, Penang, London, Dubai, Abu Dhabi, Qatar, and Pune. Their mission is to advance the sustainability of the world's buildings with integrated building performance modelling technology (Integrated Environmental Solutions, 2012).

Their claim is that, IES-VE is used by many of the world's leading building design and consultancy firms, the majority of which are specialists in green buildings to provide a general purpose simulation environment with software such as VE Pro, VE Gaia, VE toolkits, and VE Ware. Their functions include:

- **Geometry Editing:** To modify the design by adding additional windows to the model and creating shading overhangs (VE-Pro Module = Model-IT).
- **Solar Analysis:** To create images and movie files to visualize the sun's path and solar gains inside the building and quantify the impact of solar control features such as overhangs and vertical fins (VE-Pro Module = Sun-Cast).
- **Thermal Analysis:** To perform several simulations and assess variations on the design, and review the results in tables, graphs, and 3D visualizations (VE-Pro Modules = Sun-Cast, Apache Sim).
- **Daylight Analysis:** To perform simulations and create a foot-candle map on the floor plan as well as a photo-realistic 3D renderings (VE-Pro Modules = Flucs Pro, Flucs DL, Light Pro, Radiance).
- **Natural Ventilation Analysis:** To assess the performance of natural ventilation using operable windows. Results will demonstrate effectiveness of natural ventilation through a full year simulation. Additionally a detailed "snapshot" will show the complex air movement and temperature distribution using an advanced computational fluid dynamics (CFD) model. (VE-Pro Modules = Macroflo, Microflo, ApacheSim).

- **HVAC Systems Simulation:** To introduce the component-based HVAC system modelling interface for advanced energy simulations (VE-Pro Modules = Apache HVAC, Apache Sim) (Integrated Environment Solutions, 2012)

IES-VE's latest development is the plug-in support with the aid of a toolbar within Google Sketch Up, aimed at architects, in the early design stages (Ellis *et al.*, 2008). These are IES VE Sketch Up plugin (Sketch Up, 2008) and IES VE Revit plugin (Integrated Environment Solutions, 2012). Although this approach resolved interoperability issues and same building model can be used for energy performance evaluation in IES -VE, the building geometry requires to be defined in a way that it is only IES- VE that understands it (Mirani and Mahdjoubi, 2012).

9.1.4 Technical Design Stage

- **DOE-2**

The Lawrence Berkeley National Laboratory (LBNL) developed the DOE-2.1 engine. Their claim is that it is one of the most widely used thermal simulation engines, designed to study energy performance of the whole building during the design phase (Birdsall *et al.*, 1990).

The DOE-2 engine simulates thermal behaviour of spaces in a building, where heat loads, such as solar gain, equipment loads, people loads, lighting loads, and air conditioning systems can be modelled and simulated with the engine. The geometry for the simulation needs to be fairly simplified from the real geometry of the building (Birdsall *et al.*, 1990). Figure 9.3 illustrates the dataflow of the DOE-2.1 engine. The user input is combined with the materials, layers and construction library into the Building Description Language (BDL) input processor.

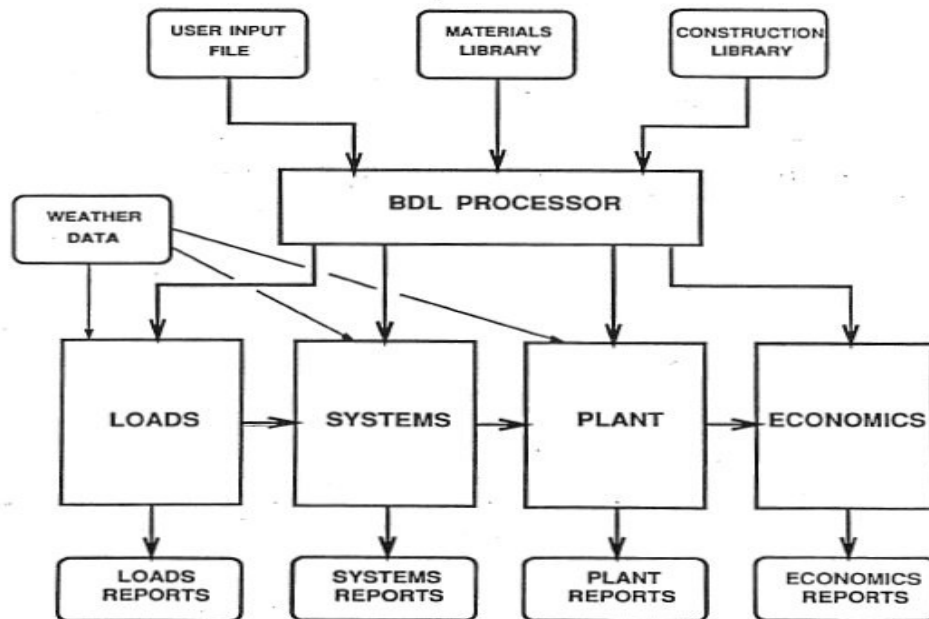


Figure 9.3: Data Flow of DOE -2.1 engine

Source: Birdsall *et al.* (1990)

The Building Description Language (BDL) processor transforms the input into a computer readable format that is later used by the four subprograms (simulation modules), Loads, Systems, Plant, and Economics, which are executed sequentially (Birdsall *et al.*, 1990).

- **Energy Plus**

Energy Plus is also from Lawrence Berkeley National Laboratory (LBNL) with incorporation of U.S. Army Construction Engineering Research Laboratory (CERL), the University of Illinois (UI), Oklahoma State University (OSU), GARD Analytics, Florida Solar Energy Centre, and the U.S. Department of Energy (DOE) (Crawley *et al.* 2002). The claim from LBNL is that, Energy Plus is a thermal simulation software tool used by engineers, architects and researchers, to model the performance of a building and optimise the building design to use less energy and water. It simulates models for heating, cooling, lighting, ventilation, other flows of energy and water use.

Based on a user's description of a building from the perspective of the building's physical make-up and associated mechanical and other systems, Energy Plus calculates heating and cooling loads necessary to maintain thermal

control set points, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment. Simultaneous integration of these and many other details, verify that the Energy Plus simulation performs as would the real building (Ellis *et al.*, 2008).

- ***ESP-r (Environmental Systems Performance – research)***

This is a simulation tool from University of Strathclyde, U.K and is majorly a European tool. It offers a general purpose simulation environment to support in-depth appraisal of the factors, which influence the energy and environmental performance of buildings. The ESP-r system has been the subject of sustained developments since 1974, converted in 2002 to the GNU Public License (US Department of Energy, 2012). ESP-r has the objective of simulating building performance in a manner that: a) is realistic and adheres closely to actual physical systems; b) supports early-through-detailed design stage appraisals, and c) enables integrated performance assessments in which no single issue is unduly prominent (Clarke *et al.*, 1998; Hensen and Clarke,2001).

The claim is that, ESP-r attempts to simulate the real world as rigorously as possible and to a level which is consistent with current best practice in the international simulation community. By addressing all aspects simultaneously, ESP-r allows the designer to explore the complex relationships between a building's form, fabric, air flow, plant and control. It is based on a finite volume, conservation approach in which a problem (specified in terms of geometry, construction, operation, leakage distribution, etc.) is transformed into a set of conservation equations (for energy, mass, momentum, etc.) which are then integrated at successive time-steps in response to climate, occupant and control system influences. ESP-r comprises a central Project Manager around which are arranged support databases, a simulator, various performance assessment tools and a variety of third party applications for CAD, visualisation and report generation (Clarke *et al.*, 1998; Hensen and Clarke, 2001; US Department of Energy, 2012).

9.2 BPES Tools Appraisal

All the ten BPES tools discussed in Section 9.1, however, do not fit the intrinsic way of architects' decision-making, hence are used at the later stage of the design process, revealed in Chapter Eight. Also discovered in Section 8.6, is that most decision made by architects are at the conceptual stage of the design process. Consequently, the DSF is to have BPES tools that fit each stage of the architectural working practice, in terms of degree in the required flexibility, approximation, accuracy and other characteristics in Table 9.5.

For the purpose of clarity, the ten BPES tools discussed in Section 9.1 were identified after the interview analysis. Hence, their categorisation in Table 9.2 is based on their specific functions, which include energy, renewable and code standard applicability. From Table 9.2, it can be seen that all ten of the BPES tools are used for energy simulation, while DOE-2; Autodesk Ecotect Analysis; Energy10; Energy Plus and ESP-r, also perform the function of decisions on renewable choices. Nevertheless, Autodesk Ecotect Analysis fulfils all the functions referred to in Table 9.2, and is the most common to architects in the UK. It can also be linked to Autodesk Green Building Studio for early design stage analysis. Table 9.3 shows the analysis of the BPES tools, based on their contrasting capabilities such as, energy simulation characteristics, relationship to CAD, ventilation function, weather data, results, and validation.

Table 9.2: Functions of Tools and Application

Tools	Energy Simulation	Renewable Energy	Code Standards	All types of buildings	UK-Application
Autodesk Green Building Studio	*			*	
Autodesk Ecotect Analysis	*	*	*	*	*
Building Design Advisor	*			*	
Design Advisor	*			*	
DOE-2	*	*		*	
e-Quest	*			*	
Energy 10	*	*		*	
Energy Plus	*	*		*	
ESP- r	*	*			*
IES<VE>	*			*	*

*Functions of Tools and Application

Table 9.3: Contrasting Capabilities of existing BPES tools

Simulation Tools	Relationship to CAD		Energy On Site energy emission	Major Green House Gas emissions (CO ₂ , CH ₄ , CO,NOX,	Energy and Demand charges	Ventilation Natural ventilation	Windows openings for natural ventilation Controllable	Weather Data With Programme (CD,DVD ,distribution download)	Separate	Results Standard	Users Define	Visual Surface Output (Walls, Window floors and roofs)	Validation	
	Import building geometry form CAD program	Export building geometry form CAD program											IEA ECBCS Annex1	IEA SHC Task 12 Empirical (Lomas <i>etal.</i> 1994)
DOE -2			x	x	x					x				
Ecotect	x	x	x	x	x			x	x	x	x	x		P
Energy 10			x	x	x			x		x	x	x		
Energy Plus	x	x	x	x	x	x	x	x(d)	x(d)	x	x	x		x
e-Quest	x		x	x	x	P(c)		x(e)	x(e)	x	x	x		
ESP-r		x	x	x	x	x	x	x	x	x(a)	x	x	x	x
IES	x	x	x	x	x	x	X(b)	x	x	x	x	x		x
<VE>														

- x: Feature /Capability of tools
- P: Partially implemented feature
- a: Performance data is written in binary forms at four levels of detail
- b: Simulation variables to control same zone, other building zone,co2 concentration, external conditions(wind speed and direction, temperature)
- c: Simple schedulable operation window models
- d: Five weather files provided with more than 900 location available for down load in energy plus
- e:Automatically download weather files from web site
- f;More than 1000 locations word wide

Note: The table dimension were derived from Crawley *et al* (2005) classification of Tools

In Table 9.3, ESPr-r and IES-VE fulfil almost all the functions, hence they are the most applicable to deliver low carbon housing design in the UK. However, they are also too complicated for architects' way of making decisions at the early design stage. Based on this, Tables 9.4 and 9.5 detail the strengths and weaknesses from the review of BPES tools, within the focus of this study.

Table 9.4: Strengths and Weaknesses of BPES tools in the UK

Tools	Strength	Weakness	UK Application
Autodesk Ecotect	Allows the user to "play" with design ideas at the conceptual stages and provide essential analysis feedback from even the simplest sketch model.	As the program can perform many different types of analysis, the user needs to be aware of the different modeling and data requirements	UK, Australia, USA and whole world
ESP-r	Flexible and powerful enough to simulate many innovative or leading edge technologies including daylight utilization, natural ventilation, combined heat and electrical power generation and photovoltaic façades. An active user community and mailing list ensures a quick response to technical issues.	It is a general purpose tool and the extent of the options and level of detail slows the learning process.	Hundreds of users, primarily in Europe and Asia.
IES-VE	Recent development of the software include plug-in support within Google Sketch-Up and IES VE Revit plugin aimed at architects, in the early design stages. (Ellis et al., 2008). This approach resolved interoperability issues, and the same building model can be used for energy performance evaluation in IES VE	Building geometry requires it to be defined in such a way that only the IES VE understands it.	Applicable in the UK

Table 9.5: Strengths and Weaknesses of widely used BPES tools

Tools	Strength	Weakness
DOE-2	Detailed, hourly, whole-building energy; high level of analysis of multiple zones in buildings of complex design; widely recognized as the industry standard for residential and commercial buildings.	Not very user friendly; high level of user knowledge required.
Energy Plus	Detailed simulation including time steps of less than an hour; interfacing to obtain geometries with CAD; input output data structures tailored to facilitate third party interface development; free	Text input may make it more difficult to use than graphical interface
Energy 10	Fast, easy-to-use conceptual design tool focused on making whole-building trade-offs during early design phases in residential and small commercial buildings.	Limited to smaller buildings.
Design Advisor	Accuracy within 10-15% used as an approximate tool for comparing early building design concepts. The tool can be quickly mastered by non-technical designers, and runs fast enough to allow them the scope to experiment with many different versions of a design during a single sitting.	Difficult to fine-tune when a building is beyond early design concepts

9.3 The DSF Conception and Development

Based on these reviews in Section 4.6, this study adopts a holistic approach to develop a DSF for architects to achieve low carbon housing design in the UK. It cross references the RIBA Outline Plan of Work (Chapter Four) with sustainability and environmental design decision tasks from the DIR (Chapter Five), coupled with the required characteristics of BPES tools (Chapter Seven) that fit the intrinsic way of architects' decision-making for the different stages of the design process.

The development of the DSF was conceived from the gap in knowledge observed from the literature review chapters, especially from the critique in section 3.4.2 on the applicability of BPES tools by architects, further discussed in Section 9.1 and 9.2. Consequently, the RIBA Outline Plan of Work, familiar to architects and the general construction industry in the UK, was explored in Chapter Four, based on the recommendations of some authors therein. Thus, case-based documents on IDP were appraised in Chapter Five to arrive at the sustainability design information requirements (DIR) in Figure 9.4. The interview findings on the required BPES tools characteristic in Section 7.3,

along with the design process in Section 7.3.1, contributed to the design of questionnaire survey, based upon the RIBA design stages, that was subsequently analysed in Chapter Eight.

9.3.1 Developing the DSF

The fourth objective in this research is to develop the DSF (Figure 9.5). A number of requirements similar to those of Dibley *et al.*, (2012) for development of a framework for intelligent-sensor-based building monitoring, guided the development of the DSF in this study. This includes the following:

- The framework should not be developed from scratch, but should make use as much as possible of the established and recognised framework in the construction industry;
- It should be flexible and comprehensive enough to accommodate different domestic construction projects across different disciplines that have the aim of sustainability;
- The framework should be user-friendly, easy to use and provide a conceptualisation of the discipline/domain of the stakeholders (architects). That is, it should embed the technical jargon used in the architectural sector;
- The framework should allow for future expansion.

Hence, the framework was developed in this chapter. It defines the sustainability and environmental design decision support tasks along with the required characteristics of BPES tools, for architects to achieve the low carbon housing design in the UK. It is different from the RIBA Green Overlay, because it integrates the use of simulation tools into the whole design process, and especially from the early design stage. Thus, the outcome from this study is unique, in the sense that, it can effectively integrate with BIM (discussed in section 3.2.2) towards delivery of the low impact design required of the UK architectural practices.

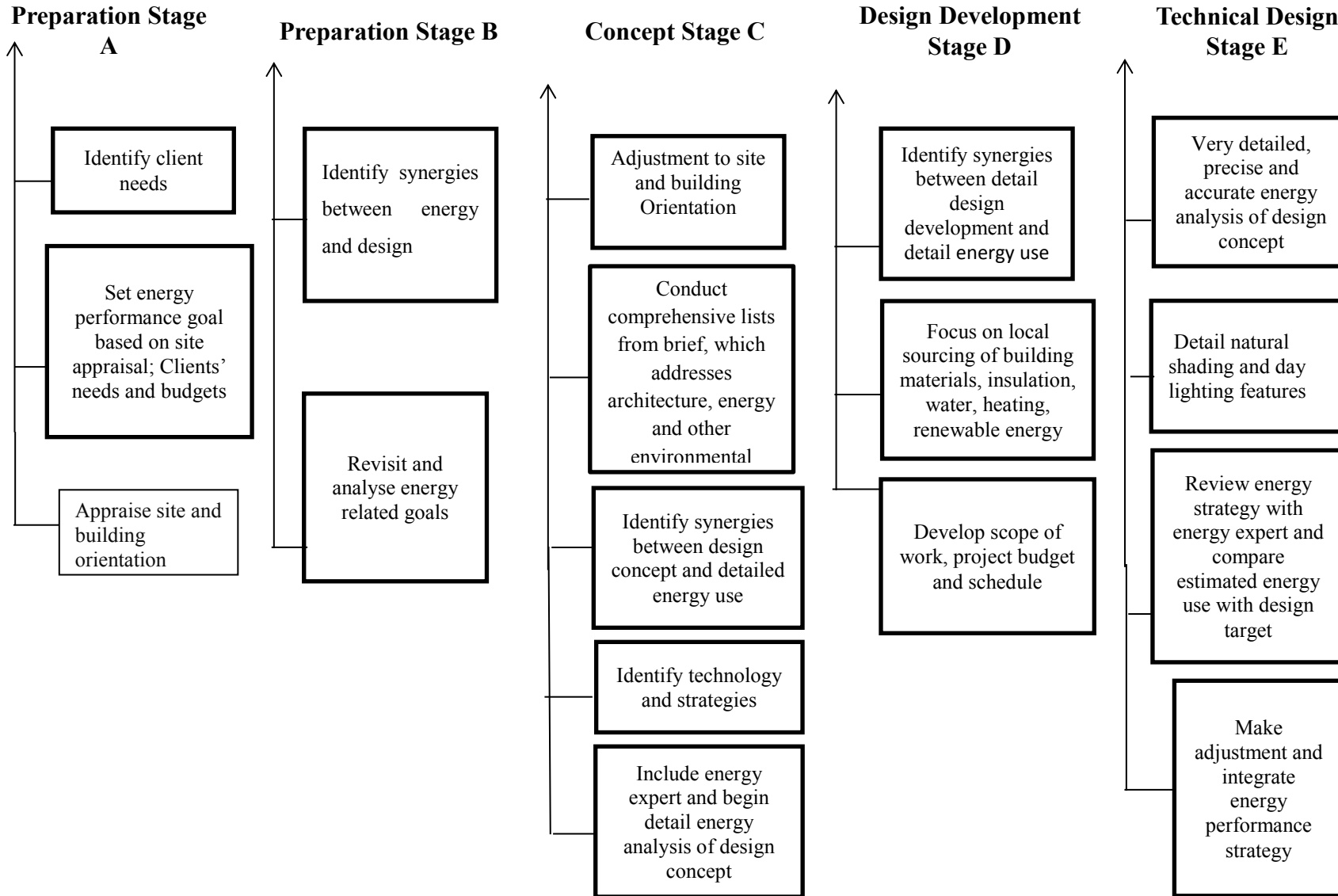





Figure 9.4: DIR from the IBDP

Stages of design process		Some Design Decision Tasks		Characteristics of BPES Tools
Earlier Design Stages	A and B	<p>Building orientation (appraisal); Topography (appraisal); Site usage (appraisal); Sun path (appraisal); Air change rate (appraisal); Building Shape; Insulation of building envelope; and glazing (optional)</p>	<p>A typical site analysis in the design process, the interplay of the building mass and natural features, such as trees, sun path, wind patterns, and the form of the land are important items to consider. It helps to ensure that the site is utilised to maximum advantage.</p> 	<p>Flexibility of BPES tools to accommodate rapid design changes, and to avoid hampering design creativity;</p> <p>Low input to minimise disruption to design creativity;</p> <p>Fast output in a language that designers understand primarily based on approximation;</p> <p>Interoperability to seamlessly integrate BPES tools with design tools;</p> <p>Interactive to enable designers to interrogate the design model performance;</p> <p>Intuitive and easy to use</p>
	Stage C	<p>Shape of building; Orientation (small adjustment); Insulation and mass; Attribution of building zone; Window size in different façade and orientation; Solar control requirements; Summer ventilation requirements; Glazing and Types (detailed analysis); Air change rate (detailed analysis); Materials selection and adjustment; Artificial lighting strategy, daylight utilisation, visual comfort and cooling; and Fuel Type/ Renewable Considerations</p>	<p>During this early stage, designers rapidly explore and refine ideas by engaging in free-flowing, collaborative brainstorming sessions, during which a wide range of designs- in the form of sketches, 2D drawings and layouts, and 3D models and renderings- are considered and evaluated until a final concept design is chosen</p> 	
Later Design Stages	Stage D	<p>Finalised material definition; Finalised building orientation; Finalised ventilation strategy; Finalised window properties (size, type, solar control); Lighting strategy, daylight utilisation, visual comfort and cooling.</p>		
	Stage E	<p>Detailed technical analysis such as: Assessment of passive cooling system (Ground cooling); Assessment of passive heating systems (solar preheat of air); Ventilation studies; and Test and refinement of heating and cooling control strategies</p>		

242 **Figure 9.5: Decision Support Framework**

9.4 Design Process in the DSF

9.4.1 Preparation and Design Phases in the DSF

- **Preparation Stages**

The RIBA Outline Plan of Work is divided into eleven stages and five main phases, explored in Chapter Four towards development of the IBDP in Chapter Five. These are the preparation phase; design phase; pre-construction; construction phase and use. However, only two phases, the preparation and design phases, out of the five, are captured in this study. The other three phases are not included as they are not within the scope of the research. The two phases are not included, as they are not within the scope of the research. The two phases within the scope are divided into five stages discussed in Section 4.1.5, and adopted in Section 5.5. The preparation phase is the basis of the whole design, as revealed in various literature reviews, such as Beadle (2008), along with the case-based documents. Consequently, a submittal would have to be performed at the end of this phase, before proceeding to the design stage that follows it. Although the phases and stages are interrelated and at the same time interdependent, it is necessary to divide them for simplification and for development of the required DSF. It is also important to note that the preparation phase is the most basic of all the phases involved in the whole design process.

However, changes may disrupt at any phase within the process, by which this may affect the design, or even the project. For example, a change in design requirements at the later stage of the design phase from the client, or due to available technology, may ultimately affect the design, or even the construction process. Alternatively, change may occur during construction phase, meaning that the work may not be performed according to the original designs. For example, due to time constraints, a decision may be made on site, which may affect the original concept of the design, especially when budget/costs are being considered (as discussed in Section 7.3.2 of the interview analysis). Hence, the IBDP and use of BPES tools by architects from the early design stage, as proposed in this study. Based on the analysis from the interview on the required characteristics of BPES tools for architects'

decision making at this stage, the tools used should: be flexible; low input and quick results; easy to master; interoperable as well as interactive.

- **The Concept Stage**

The preparatory stage discussed above involves all activities that are required to be performed before the start of the actual design. Appraisal and design brief within the preparatory stage serve as the basis for all works required for the concept design phase, the first stage in the actual design process. BPES tools at this stage are recommended to have the same characteristics as in the preparation stage, but with slightly greater degree of all characteristics required of the BPES tools at the preparatory stages.

Thus, the characteristics of BPES tools at this stage in the DSF, support the assertion made from the rationale in Section 1.3 that architects should have appropriate BPES tools that are in tune with design decisions (Mahdavi, 1998; Soebarto and Williams, 2001) at the various stages of the design process and especially at the conceptual stage, where major decisions are made. While there is no magic number of concept models that should be evaluated prior to moving proposed designs forward, designers should have the tools and the time to evaluate as many designs as possible (Schmitz, 2011). This will prevent bad design decisions that carry hefty downstream costs when design issues arise during later stages. In order to prevent such disasters, there is the need for architects to really take their time with the necessary and appropriate decision support tools during this crucial phase, to evaluate multiple environmental and sustainability design decisions.

- **Design Development Stage**

This phase is referred to as the sketching phase (Hansen and Knudstrup, 2005). It is at this phase that professional knowledge of architects and engineers is combined to provide mutual inspiration in the IBDP, in order for the demands and wishes for the building to be met. This also applies to the demands for architecture, design, working environment and visual impact, as well as the demands for functions, construction, energy consumption and indoor environmental conditions.

At this stage, detailed information would have been procured about the client's demands for space, functionality and logistics, as well as criteria for architectural qualities. It is also very important at this stage to decide principles for targets such as: energy use; heating; cooling; ventilation; lighting and indoor environmental quality such as thermal comfort; air quality; acoustics; lighting quality of the new building; criteria for application of passive technologies as natural ventilation, day lighting, passive heating and passive cooling. These criteria should be developed in consideration of local climatic conditions and the local energy distribution facilities. At the end of the analysis in this phase, a statement of aims, along with a programme for the building is set up, which should include a list of design criteria and target values. Focus should also be on: local sourcing; specification of building materials and elements; water consumption; insulation; lighting; heating and hot water systems; renewable energy, technology and ventilation.

- **Technical Design Stage**

In this phase, the various elements used in the project should be optimised, and the building performance documented by detailed calculation models, referred to in this research as detailed simulation tools (DSTs). All analyses in this stage must be detailed. The BPES characteristics for this stage, recommended in Figure 9.5, as well as the design development stage, include use of BPES with detailed and accurate input to produce comprehensive results, very close to reality (Appendix 4).

9.4.2 Post Design and Pre-Construction Phase

Once the design phases are completed, there are other processes to follow prior to the delivery of working documents for the construction phase. This is the approval and distribution processes, known as the pre-construction phase of the design process. As soon as the documents are distributed to those concerned with the execution of the project, the pre-construction phase may *formally* start. The phase is mainly concerned with the physical transformation of the project. The pre-construction phase is not included in the scope of this research. However, it is necessary to mention it in this chapter since it is an

important phase between the design phase and the construction phase. Those mostly concerned with this phase are the contractors and site personnel.

It is at this stage that the approval process takes place to ensure that the documents submitted by the contractors reflect the original project documents. The process should also ensure that there is no unacceptable deviation from documents, including quantities and costs. The process is long, has many interruptions at this stage, and involves almost all parties that are involved in the project. The receipt and distribution of the documents are the main concern to all the relevant parties, and thereby, each has a document control unit. This ensures that each party has a traceable record of documents, which is contractually important to all parties.

9.5 Summary

The Chapter reflects on the existing BPES tools and how they do not fit into the intrinsic way of architects' decision-making. It reviews the strengths and weaknesses of existing BPES tools, as applied both to the UK and internationally. Based on the observed gap in the existing BPES tools, the Chapter discussed past models and frameworks and justifies the need for this particular framework.

The DSF was finally proposed and discussed in this Chapter. Recommended within the framework are the requirements that BPES tools fit the various stages of the design process. This is also one of the recommendations of the research findings in Chapter Eleven, to fulfil part of objective six of this study. The DSF will be presented at workshops and conferences to test for its effectiveness and appropriateness at later dates. This chapter fulfils objective four of the research. Discussions to determine the adequacy between design decisions, taken at the various stages of the design process and Building Performance Energy Simulation (BPES) tools to fulfil objective five of the study is in chapter ten. This is followed by conclusions and recommendations in chapter eleven, which concludes the whole thesis.

Chapter Ten: Discussions of Research Findings and Implications

10 Introduction

Chapter Nine was used to fulfil objective four as well as the aim of the study; to develop a DSF that will help UK architects achieve low carbon housing design. This chapter is consequent to Chapter Nine. It discusses the research findings to determine the adequacy between design decisions taken at the various stages of the design process and existing BPES tools, fulfilling objective five of the study. The Chapter further discusses the implications and validation of the findings. The outline of the chapter is thus:

- Design and Decision Support Tools;
- Statutory Regulation: Code for Sustainable Homes;
- Implications of the Study;
- Validation of Research Findings;
- Summary

10.1 Design-Decision and Support Tools

10.1.1 State- of- the- Art on Existing BPES Tools

This study has revealed the characteristics of all the ten BPES tools within the scope of this research (Section in 9.1). The general critique (Section 9.2) is that the simulation tools are too complicated for architects' decision making, especially at the early design stage. To use any of the tools, the building's geometry must come from the architects' model, including: the number of rooms; the connections between rooms; their relationship to the exterior; exposure and aspect to the sun along with the shape and total area of built surfaces or openings. Hence, the design process needs to be advanced before any of the BPES tools can be applicable, even the one marketed for the early design stage.

Although, there has been some advancement in form of interoperability, where data can be transferred, however, there is the problem in the process of transferring data from tools such as BIM software, to the energy analysis software (Schlueter and Thesseling, 2009). Different methods of modeling are used in the different types of software, thus efficient exchange of geometric data is difficult and sometimes there is inconsistency in the geometry transfer between software packages. Hence, data may be lost or overwritten in the process of transfer between models or has to be re-entered.

Consequently, only a small minority of architects use the existing simulation portfolio to perform the evaluation of energy efficient strategies and technology options, at the crucial formative stages of the design process and the project at large. On this note, De-Wilde *et al.*, (1998) observed that computer-based energy analysis tools play a minor role in the selection of energy-saving technology. Thus, simulation tools should adapt to the design process, and not vice versa.

Researchers such as Soebarto and Williams (2001) have concluded that the current generation of energy analysis tools is not concerned in supporting the design strategies. There are barriers to the use of simulation tools; this agrees with Ellis and Mathews (2002). They attributed the failure of existing tools to influence energy performance outcomes, to the fact that they do not accommodate architects, nor do they fit into the design processes. Building simulation design is not fully integrated into the design process; hence the limited use of simulation tools, especially at the early design stage. Moreover, architects are seen as visual people and simulation being too abstract, thus, the role of energy analysis has been simply to give endorsement to a completed design, rather than to assist the designer during the design process (Morbitzer, 2003).

Considering the findings from the current study, the probable explanation in support of this is that, architects tend to follow an essentially iterative process. This is parallel to findings in Soebarto and William (2001) and Soetanto *et al.*, (2001), who argued that energy performance has traditionally not been the concern of architects, but has been seen as a subsequent responsibility of

service engineers, who are tasked with implementing an already formulated design.

To deliver low impact buildings in UK, the loop between building design, operation and performance must be closed (Technology Strategy Board, 2009). Most of the existing tools, as revealed in this research, perform one specific function or another. The BPES tools, discussed in Table 9.2, perform the specific function of energy simulation, renewable energy or code standards. Also, it was discovered that although most of the BPES tools are marketed for use for the whole design process, the tools are mostly used by architects in the later phase of the design process. Hence, there exists poor support for the early phase (preparation and conceptual stage) of the design process, in comparison to that of the later design phase (Table 9.1).

A plausible explanation for this is the higher level of accuracy and detail of data input required by most of these tools, which make them more appropriate for detailed design. Hence, their unsuitability for the early design stages, especially the conceptual stage of the design process. Moreover, most of the tools are designed for engineers and poorly reflect architects' professional needs, which are visual or fit into the intrinsic way of architects' decision-making.

The contrasting capabilities of existing BPES tools (Table 9.3) illustrates that IEASHC Task 12 empirical validation (column 14 and 15 of Table 9.3) has been carried out on some BPES tools such as Energy Plus, ESP-r and IES-VE (Lomas et al., 1994). However, the user of the tool is not necessarily able to estimate the reliability of the results, yet, these features are essential. On the other hand, the user may choose the tool based on the results which are most suitable for their purpose. If one tool gives better results for a certain type of building, there is a risk that users start promoting the tool in question. If the users' selection criteria are based on the desired results, then the reliability of the assessments vanishes. Hence, strengths and weaknesses of some of the BPES tools were analysed in Tables 9.4 and 9.5 towards achieving the sixth objective of the research, which is the recommendation from the research findings in chapter eleven.

These findings are consistent with the deductions of Hopfe (2009) and Attia (2010) on BPS tools. Hopfe (2009) states that there is no independent evaluation and classification of a tool's usability and functionality in practice; Tools developers rarely state the capabilities and limitations of the tools (Attia, 2010). Consequently, a potential user is faced with the difficulty of choosing a suitable program among the growing BPS landscape of tools. For example, the tools will rely on different databases, guidelines and questionnaires. Hence, the BPES tools referred to in Table 9.1, and analysed in Tables 9.2 to 9.5, are the findings on the state-of-the-art on existing BPES tools, within the scope of this study, to deliver low carbon housing design. There is therefore the need for further development on all the ten tools to fit into the way architects make decision in terms of flexibility, required data input and quick results output.

10.1.2 BPES Tools and Decision Making in the Design Process

The first major finding of this study suggests that within the design process, architects are more concerned with design issues, such as: geometry; orientation; comfort; aesthetics; natural ventilation and day lighting. However, engineers are more concerned with mechanical systems and control; hence, the difference in the type of tools important to each profession and, in their requirements. In this study, the findings on BPES tools have revealed that the tools are mostly used at the later stage of the design process by architects, in, for example, the design development or technical stage of the RIBA Outline Plan of Work stages. This is, in spite of their attribute to cater for the whole design process specified by most of the software developers and the various marketers. Furthermore, they are used majorly only in one discipline, such as engineering.

This finding is parallel to Donn (2001), who emphasised that most BPS tools are still easier to use in only one phase, which is the design development phase and, thus, the function becomes to help designers in the improvement of their basic concepts, but not to create the basic concepts. In relation to building modelling software, the study has revealed, how most simulation software is

not even intended for design. Nevertheless, design decisions stem from building simulation, by which the right tool should be chosen to optimise the design.

Decisions made at the early stages of the design process are of paramount importance and can strongly affect the later stages. Mirani and Mahjoubi (2012) argued that decisions made by the designer during the design process vary greatly in accuracy. In the early design phases, design decisions are rough and concern only the parts of the building at a global scale and without any detail. However, decisions in the later phase of the design process are precise, and concern detailed parts of the design. Despite the established role of simulation at the design development stage, De-Wilde (2001) posits that simulation is usually undertaken by specialists or simulation experts; very often designers do not have the time and resources to involve simulation, as the design is experiencing constant and rapid changes.

Consequently, Hong *et al.*, (2000) classified building performance simulation (BPS) into six main groups, as discussed in section 3.3.3, while Ellis and Mathew (2002) classified the BPS tools used during the design process mainly into two groups. The first is the advanced design stages evaluation tools, mainly used by engineers. The second is the guidance tools mainly used by architects.

Early Simulation Tools (ETs) for architects' decision making are supposed to be more purpose-specific BPES tools, used at the early design phases because they require less and simpler input data. They can also be very useful in the compliance checking of prescriptive building standards. However, as found out in this research, the existing ETs are not fit for architects' decision making, because of the large input data required by most of them. On the other hand, detail simulation tools (DSTs) often incorporate computational techniques, such as finite difference and elements, state space and transfer function for building load and energy calculation. Besides design, DSTs used at the later stage of the design process are also useful in compliance checking of performance based building energy standards (Hong *et al.*, 2000; Ellis and Mathew, 2001).

Nevertheless, for architects use, BPES (ETs and DSTs) tools, as recommended in this research, should be adaptive to the design process. This is in line with the findings of Mendler *et al.*, (2006) and De-Wilde and Prickett (2009), who argued that tools should be centric to the design process. With the growing importance in bridging this gap and integrating simulation tools for the whole building design process for architects to achieve low impact housing design, it should also be used as an integrated element (Augenbroe, 1992; Mahdavi, 1998). There are ranges of BPES tools (discussed in Section 9.2) currently available, which are proficient in performing predictive energy assessment. The relatively low level of adoption of these tools by architects, as revealed in this study, and by Dunsdon *et al.*, (2006), suggest that there are some significant barriers to their successful application, especially at the critical early design stages. This is consistent with findings from the questionnaire survey, by which most of the tools referred to in Question 3; (with the exception of BPES tools categorised as ETs and DSTs) have the majority of the subjects responding: 'Not *applicable*'. The finding is also similar to other studies, such as Morbitzer (2003), Attia (2009) and Hopfe (2009).

A plausible explanation is that in spite of the availability of tools, they reflect little of architects' way of making design decisions, coupled with complexity, and the detailed geometrical information required to use the tools. Time of result output and the training required for the use of these tools further contribute to their limited use by architects. Morbitzer (2003) observed that most tools require the creation of time-consuming models, which often led to their rejection by designers.

Consequently, architects' use of existing BPES tools, as confirmed in this study, is confined to optimisation and verification of the design, late in the design process, rather than at conceptual design stage, where most of the important decisions relating to energy efficiency components are made. De-Groot and Mallory Hill (1999) acknowledge that the conceptual stage of the design process is the point where a small number of people make decisions that have far-reaching implications on both the efficiency and effectiveness of projects. Decisions made during conceptual design are considered to have the greatest influence on project performance and have the least associated cost

(Beadle, 2008). According to Bishop (1996), 80 per cent of the overall cost of a project is determined by the first 20 per cent of decisions. Bass *et al.* (1998), also state that the early design decisions are important, since their ramifications are felt in all subsequent phases. In this sense, architecture forms a bridge between a system's definition and its design.

BPES tools, such as Autodesk Green Building Studio and MIT Design Advisor (marketed for early design stage), are used at the technical design stage by 32.8 per cent of architectural practices, while 31.3 per cent use them at the design development stage of the RIBA Outline plan of work stages. Further, 13.1 per cent use such tools at the conceptual stage C and 8.2 per cent use it at the preparation stages A and B. However, 11.7 per cent specified that they use such tools at all stages of their design, while 3.3 per cent responded that they have not used them at all in their design of low carbon housing in the UK.

On the other hand, BPES tools marketed for detail design, such as IES, eQUEST and Energy Plus (Table 9.1), more than half (64.9 per cent) of the architectural practices acknowledge that they have not used them in the design and delivery of low carbon housing in the UK. However, 15.8 per cent of the architectural practices had used it at the technical design stage, with 7.0 per cent responding that they had used such simulation tools at all stages of the design process. Thus, the findings on ETs and DSTs in this research confirm that when BPES tools are used, if at all by architects for decision making, their use is confined to late in the design process.

10.1.3 Ambiguity and Limitation of Design Tools

The findings of this study suggests that computer-based simulations tools, if used at all by UK architects, are usually employed at the later stage of the design process to determine loads and predict system's performance, typically in terms of energy use. This way of working, however, has been known to create an interruption in the design process flow for the architects. This is because the architect has to transfer his/her design from the computer-aided

design (CAD) specifications employed at the early design stage, to the computer-based simulation system at the later stage of the design process.

The geometric precision and large number of detailed selection requirements at the later stage, make such systems not well suited for early design. The required level-of-detail, although necessary for the operation of the programs at the later stage, is often largely irrelevant and tends to distract from the design activity itself at the early design stage. In order to get proficient with such systems, i.e. to reduce the cognitive load imposed by their operation, users also require extensive training and frequent practice.

Moreover, loss of data had been reported, when transferring data from the design tools such as BIM software, to energy analysis software and vice versa. Sometimes there is even the need to re-enter data. Hence, this research has revealed the need to reduce time spent on transition from the early design stage to the more precise stages. This is supported by Aliakseyeu *et al.*, (2006), who emphasised that more architects had started to use programs like AutoCAD, ArchiCAD, Arc+ in all stages of their design. They noted that the use of paper and pen or scale models, especially at the early design stage, is still preferred by most architects, because it enables the required flexibility, speed, and natural (intuitive) interaction between the architects and the design at hand.

10.2 Statutory Regulations: Code for Sustainable Homes

Based on the findings from the interviews in this study, the Code for Sustainable Homes (CSH), though the latest tool in the UK for the design and delivery of low carbon housing, cannot produce a credible route to the zero carbon target for new homes by 2016. This finding complements that of Osmani and O'Reilly (2009), who investigated the feasibility of building zero carbon homes in UK by 2016 from the house builders' perspective. The Core Strategy-Supporting technical paper also posits that the definition of zero carbon is currently being developed, as it was considered that the earlier definition of a Zero Carbon Home was too difficult and expensive to achieve across the board and by the year 2016.

The deduction on CSH in Section 7.4 of the interview analysis is consistent with findings of Goodbun (2008), Sodager and Fieldson (2008), Osmani and O'Reilly (2009) and McManus *et al.*, (2010). Goodbun (2008) stated that there exists a broad lack of informed discussion around new policy like the CSH. Sodager and Fieldson (2008) outlined the challenges facing the construction industry to meet requirements of the Code for Sustainable Homes and other standards, introduced by UK government to reduce carbon emissions of buildings. However, McManus *et al.*, (2010) evaluated the situation with a preliminary analysis of how the CSH may not be able to deliver its '*sustainable energy*' goals, due to the ways in which 'low and zero carbon technologies' are assessed and how they behave in real world situations. This was further confirmed from interview findings in this study.

Uncertainties over the detail of planned legislation further contribute to the perception that regulation is an increasing maze for designers. On a practical note, one might question the need for the tightening of Part L (discussed in Section 2.3.2) on British designs, given that 'sustainability' and 'carbon-neutrality' have already become such '*buzz words*' in the industry. Some interviewees in this study remarked that they had already specified buildings to higher energy-efficiency standards than the regulations required. This was done as a matter of routine and in order to foster their architectural practice's green or sustainable credentials, as building to minimum requirements was seen as insufficient. The government has hinted a zero carbon home could rely on on-site micro-generation of electricity through technologies such as wind turbines and photovoltaic cells. This suggestion is now facing criticism. Banfill and Peacock (2007) also doubted the efficiency of such arrangements; they argued that technologies are often best deployed outside the urban centers.

10.2.1 Cost of Low Carbon Housing Design and Delivery in the UK

Analysis from the interview identified cost as one factor, which serves as the major barrier to low carbon housing design and delivery in the UK. The other common barrier relating to cost from the interviews with architects is the way that housing is being delivered in the UK housing sector. An interviewee stated

that house builders are more interested in the profit and want cheaper buildings for them to realise more profit.

In addition, while highly energy-efficient homes are seen by some as a growth sector, it is widely acknowledged that many or even most clients are still reluctant to afford the costs associated with energy-efficient technology, whether it is more insulation, greener materials, controlled ventilation systems or renewable energy sources. In particular, speculative housing developers were still seen to favour bare-minimum solutions with regard to environmental performance. This can be typically explained by the fact that developers expect to sell their houses or flats to individuals who will be unaware of or unconcerned with the energy performance of their new property.

10.3 Implication of the Study

This study was conducted to explore the effectiveness of design and decision support tools, along with other information needs of architects to deliver low carbon housing design in the UK. The research is an addition to the body of existing knowledge related to the adaptation of low carbon action to impact climate change, energy efficient buildings, carbon emission reduction and the zero carbon agenda for new housing in the UK from 2016 and beyond.

10.3.1 Implications for Practice

The findings of this study have a number of significant implications for future practice, especially for software developers and those seeking to bridge the gap in the use of tools by architects. Throughout the cycle of an architectural project, numerous decisions are made in relation to: design issues (geometry, orientation, aesthetic, natural ventilation and day lighting); cost; quality of design; building environmental performance amongst many other decisions. Decisions vary as the project progresses from the early design phase to the technical stage of the design process, which in turn affects the level of information required. At the early design stages, decisions are broad, as there is

little concern for detail. However, as the project progresses, the decisions become more refined as the focus changes to the detailed aspects of the design and realisation of the project.

The core tools in the building energy field are the whole building energy simulation programmes that provide users with key building performance indicators such as energy use and demand, temperature, humidity and costs. The major benefit of energy simulation in design should be in their ability for comparison of architectural design alternatives. This will allow the alternatives to the original building design to be validated for functions such as thermal comfort and energy usage. However, despite the availability of sufficient technology and the landscape of tools, existing energy simulation tools have proven to be incompatible with the design process (Lowe, 2000; Morbitzer, 2003; Hensen and Augenbroe, 2004).

Similar to past researchers (Papamicael *et al.*, 1997; Attia and Beltran, 2009; Technology Strategy Board, 2009), this study has revealed that conventional tools were developed in research domains by specialists, software developers and manufacturers, to address a particular specialism (discipline or phase of design process) of building design. In addition, there has been little or no regard to the whole building design process, by which most tools are rigid and do not facilitate the consideration of building energy performance, incrementally, over the whole design process. Based on this, there is the need for a new generation of tools, which fits into the various stages of the design process.

Findings from this study suggest poor collaboration and communication between users (the architectural practitioners) and the specialists (software developers and manufacturers). Evidence from this research, in terms of weaknesses of BPES tools further submits the following:

- Conventional decision support tools, in form of BPES tools, do not effectively communicate the environmental impact of design decisions, especially those that are required at the early design stage;

- Subsequently, this constrains architects in evaluating the energy performance of building design when it matters most. This implies a lack of understanding of the design process by the software developers;
- Thus, to use BPES tools, external specialists are usually contacted by architects, towards the end of the design to evaluate the results;
- Consequently, an information delay arises that hampers the optimisation of design solutions.

Hence, this study will provide significant background to researchers, as well as a resource for future software developers, on the needs of architects. To enable BPES tools to influence the design of buildings, further development is required. Thus, the study implies that the use of simulation exercise, from the early design stage, by simulation experts and non-experts such as architects, will influence better design for energy efficient buildings.

The study further discussed how existing design tools are for drafting, drawing and computer programming of new buildings, but not for decision making. On the other hand, most of the existing BPES tools, if used at all by architects for decision support, have their use mostly confined to late in the design process after many important decisions had been taken. Thus, for software developers, this implies the need for better interoperability between design tools used for drafting and the BPS tools used in decision-making at various stages of the design process.

In this study, the observed weaknesses of BPES tools, further implies the need for more research and focus on tools that will fit into different stages of the design process. The accuracy and prediction of the tools should increase as the design progresses. To amalgamate this issue and fill the observed gap, there is need for new generation of tools to simulate design decisions from the early design stage, which need to be adequately informed.

At the early design stage, there is little information on the project to support designers. Hence, at this stage, it is important for tool to have: flexibility; approximation; a low level of detail; quick feedback; low level of input and output in a language (such as visual, graphical, design process) architects can

understand. On the other hand, at the later stage of the design process, when detailed information on the project has become available to support designers in a more realistic evaluation, the characteristics of tools should exhibit: a high level of accuracy; detailed information input; more detailed output and realistic evaluation of the performance of the design. This may or may not require larger user time or detailed training on the part of architects. Thus, the research implies that better integration across disciplines and feedback of the impact of design-decisions, will improve understanding of the relationship between design-decisions and environmental impact. Better-informed design from the earliest conceptual stage will improve the design of individual buildings.

Also, revealed in this research is that regional specific software packages, such as CAD, BIM, energy analysis and visualisation software, are almost totally developed in the USA. However, in the UK, the BRE (Building Research Establishment), although at the forefront of the development of assessment and building code checking software, has not been part of the early design process. Hence, within UK, the results of this study can provide a resource for UK researchers and developers, about the needs of architects for future software development, applicable to UK architects' way of practice.

10.3.2 Implication for Theory

A driving principle behind this research was the desire to deliver low impact housing design in the UK, in the face of the future zero carbon housing target and designation of changes to the building regulations Part L1a. Findings from this research for the need for design decisions to be taken at the early stage of the design process, has impact on the design, and indeed the life cycle of the project. The theoretical basis is consistent with studies by De-Groot and Mallory Hill (1999); Dunsdon *et al.*, (2006); Boddy *et al.*, (2007) and Beadle (2008).

De-Groot and Mallory Hill (1999) acknowledge that the conceptual stage of the design process is the stage when a small number of people make decisions that have far-reaching implications for the efficiency and effectiveness of the

entire project. Dunsdon *et al.*, (2006) concur that the most cost effective carbon reduction measures and decisions are those introduced at the early design stage. Failure to embed low carbon considerations from this stage is likely to result in a building with higher carbon emissions. Boddy *et al.*, (2007) stated that critical decisions, which influence the sustainability of a construction project, are made in a pressurised, time-critical environment. Decisions made during conceptual design are considered to have the greatest influence on project performance and have the least associated cost (Beadle, 2008).

Architects' use of BPES tools for decision support, as discovered in this research, have had little influence on the decision making process. However, if people can draw on accurate knowledge, they will react differently to information and data than if they have no prior experience and learning to guide them (Boddy *et al.*, 2005). Thus, the findings from this study should serve as the basis for future environmental and energy-related tools researchers, predominantly at universities and other research establishments.

10.4 Validation of Research Findings

Reliability of the analysed data has been confirmed in Section 8.7. However, the validation of negative findings, that is, those that have failed to measure an impact, is not so straight forward. There are several factors which will lead to confidence in the conclusions from the analysis of the findings from this research. These are in form of external and internal validation.

10.4.1 External Validation

The findings from this research are within the range of previous published studies on the use of BPES tools by architects. The maximum impact discovered from this study is that tools are used at the later stage of the design process, instead of the early design stage, when important decisions that will have major impact on the life of the project are made. The study has also confirmed that support for architects at the conceptual stage of the

design process needs focus. This is similar to an investigation into design and decision support tools made by TSB (2009). They made the following observations, parallel to the results of this research:

- Design support at the conceptual stage is particularly poor;
- Design professionals work in different ways, through sketches, physical models, 2D and 3D computer representations, analytically and thus have different requirements for representing and communicating design developments;
- Current tools only address the needs of one specialism or specific phase of the design process.

Mora *et al.*, (2006) laid emphasis on how computer support for conceptual design of building structures is still ineffective, mainly because existing structural engineering applications fail to recognise that structural and architectural design are highly interdependent processes. Hopfe (2009) also emphasised that the uptake of BPS in current building design projects is limited. She stated that, although there is a large number of building simulation tools available, the actual application of these tools is mostly restricted to code compliance checking or thermal load calculations for sizing of heating, ventilation and air-conditions systems in detailed design.

This, as much of the literature referred to in this study has suggested, may be due to: the required geometric precision; the large number of required detailed selections; and the required level-of-detail. Other researchers with similar findings include: Soebarto and Williams (2001); Ellis and Mathews (2002) and Morbitzer (2003). The findings of these authors, similar to this study, serve as external validation. Their arguments validate the findings in Chapter Eight, by which the use of BPES tools by the targeted architectural practices are at the design development and technical stages of the design process.

10.4.1.1 Internal Validation

The most compelling internal validation in this study is observed by the way that more than one approach within the cross-tabulation function of the descriptive analysis is used to test similar hypotheses to reach the same broad conclusions. This is not uncommon, as demonstrated by Meng (2008) and Henjewe (2010). It also adds confidence to the interpretation of the findings. This means that within the foregoing comparison from the analysis, validation was being carried out to achieve the broad conclusions, which in this study are:

- Use of tools by architects is at the later stage of the design process rather than at the early stage where it is supposed to be more useful;
- Decision support for the early design phase is extremely poor;
- The conceptual stage within the early phase, is the stage that needs the most focus for further development of tools to achieve low impact design;
- Most design decisions by architects are made at the conceptual stage of the design process.

10.5 Summary

The Chapter has discussed the research findings to determine the adequacy between design decisions taken at the various stages of the design process and BPES tools, to fulfil objective five of the study. It establishes the ambiguity and limitation of computer-drafting and design tools, along with the critique on the existing BPES tools. The Chapter further discusses the research findings in relation to CSH and cost as the major barrier to low carbon housing design and delivery in the UK. Conclusively, the implications of the findings on practice and research were discussed in this Chapter, coupled with validation of the research findings, based on past research studies.

Chapter 11: Conclusions and Recommendations

11 Introduction

This chapter presents the general summary of the research. It brings together discussions on findings from Chapters Two to Ten and draws conclusions to cover achievement of the original objectives and the research questions in Chapter one. The Chapter finally make recommendations to software developers, practice, research communities, and policy makers prior to highlighting contribution to knowledge, research limitations, suggestion for future research and conclusion to the study. The outline of the Chapter is:

- Achievement of Research Objectives and Questions;
- Recommendations from the research findings;
- Contribution to Knowledge;
- Limitations;
- Scope for future research;
- Summary and Conclusion.

11.1 Achievement of Research Objectives and Questions

The aim of this study has been to achieve the research objectives set out in Chapter One (section 1.4, p.6); the objectives are restated in this section and the extent to which they have been met are summarised along with the research questions used to achieve them.

Objective 1: *To review low carbon housing design in the UK, along with design and Building Performance Energy Simulation tools for the design.*

Chapter Two was used to address this objective. It provides the background study and overview of information on low carbon housing design, which are from different sources. Conversely, Chapter Three was used to finalise objective one, through a review of design and drafting tools in Section 3.2, and decision support in form of BPES tools in Section 3.3. The findings from these reviews, especially the one on BPES tools, show the need for the integration of

simulation tools into the working practice of architects, from the early design stage.

Objective 2: *To evaluate the effectiveness/state-of-the-art of decision support tools and other support for architects to deliver the design in the UK.*

Chapter Three serves as a background study to achieve objective two. Investigating effectiveness of decision support tools, towards categorisation of BPES tools characteristics was done through qualitative, in-depth interviews with architects, analysed in Chapter Seven. The evaluation was achieved through questionnaire survey, analysed in Chapter Eight. The research questions being answered by this objective include:

- What are the requirements of architects in decision support tools, at different stage of the design process?
- Why are UK architects not using the existing design -decision support tools?
- If at all they do, what stage of the design process do they use the tools;
- What stage of the design process do architects make major design decision?

The analysis from the interview, established the required BPES tools characteristics along with the reason why architects are not using the existing design-decision support tools. The questionnaire survey analysis confirmed the later phase of the design process as the stage that architects make use of existing BPES tools, and the concept stage as the stage, where architects make major design decision to deliver the low carbon housing design.

Objective 3: *To design and develop a theoretical model of design information requirements to deliver low carbon housing design in the UK.*

Chapter Four gives the background study towards achieving objective three in Chapter five to answer the research question: What are the design decision tasks for architects to deliver the design?

Chapter Four shows the differences between various types of design processes especially that of the conventional design process and the RIBA Outline Plan

of Work. Consequently, the RIBA Outline Plan of Work stages of design process were recognised, as a familiar design process to the working practices of UK architects, and in fact the general construction industry in the UK.

Nevertheless, the findings from the research suggest that sustainability requirements were not encouraged in the original RIBA Outline Plan of Work before the introduction of the Green Overlay. Hence, a new model of the design process for low carbon housing would be helpful, along with guidance in the form of checklists. To address this, five case-based documents on integrated design process were analysed in Chapter Five towards the development of the theoretical model of IBDP, which consists the design decision tasks that make up part of the DSF.

Objective 4: *To develop the decision support framework that defines the characteristics of design- decision-support tools.*

This was achieved in Chapter Nine to answer the research question: How can UK architects achieve low carbon housing design?

This is the aim of the study, by which the developed DSF will contribute towards the design and delivery of low carbon housing in the UK. The categorisation of the required characteristics of BPES tools that fits the intrinsic way of architects' decision- making was developed as the result of BPES tools requirements from the interview findings. This, combined with application of the DIR from the IBDP in Chapter Five, was used to develop the DSF.

Objective 5: *To determine the adequacy between design decisions, taken at the various stages of the design process and Building Performance Energy Simulation (BPES) tools.*

The literature review in Chapter Three, as well as the data analysis in chapters seven and eight, serves as the background study for this objective. The objective was realised in Chapter Ten through comparison of findings in this research with past research works. It discusses the findings from the research questions. The findings from this study are similar to earlier researchers, and hence serve as external validation to the research findings. It identifies the gap

in the use of BPES tools by architects for decision- making support, especially at the early design stage towards fulfilling objective six of the research.

Objective 6: *To outline the implications of research findings on practice, policy and research communities.*

Chapter Seven and Chapter Eight (discussion of results), serve as background to this objective. They provide a great deal of new knowledge and understanding about the research findings towards recommending the implication of the study for: software developers; practice; research; development communities and policy makers (Section 11.3).

11.2 Recommendations

This research has led to some practical and statistical results to conclude this thesis, as well as to summarise and make recommendations for software developers; practice; research; development communities and policy makers. The recommendations emerge from synthesis of the research findings from various stages of the research and provide suggestions for improving the practice and delivery of the design.

11.2.1 Recommendations for Software Developers

1. Developing BPES tools that fit into working practice of architects

The findings in this study have a number of recommendations for future software developers, particularly those targeting architects' needs for various stages of the design process. The study has established how building performance simulation by architects is mostly executed late in the design process, and thus, does not sufficiently integrate with design and decision-making. Hence, for future development of BPES tools that fit into architectural ways of practice, as well as the delivery of new generation of tools to achieve low impact housing design in the UK, this study lists the requirements recommended for each family of BPES (ETs and DSTs) tools at different stages of the design process.

Early Phase of the Design Process

Enough flexibility and low input information schema, amongst other requirements, are identified as being necessary in BPES tools for the early stage of the design process.

- **Flexibility**

This stage is largely an informal process where changes occur frequently. For amalgamation of these changes, as well as decision making at this stage of the design process, a useful decision support tool does not need to be highly accurate. Hence, enough flexibility is required and recommended in this study for software developers aiming to address architects' need of tools for this early stage. The tools should be able to adapt to any situation, or change in design according to clients' needs or different design alternatives.

- **Low input information and quick result**

Available BPES tools are particularly ill-adapted for the early stages of the design process and are generally labour intensive. They require designers to input detailed information that is only available when a project is well in advance. Consequently, they are restrictive, since they allow only minor changes to be made. In addition, the detail of data input required by many of these tools is inconsistent with the nature of the design information available at the early stage.

Hence, it is recommended to software developers, that tools for this stage should have a resource for relatively small information input to produce quick and fairly accurate or approximate output of results. This is because the need at this stage is to allow the description and simulation of a building in seconds or minutes without any training on the part of the architects. Consequently, the results should meet immediate needs of the architects, rather than in accordance with a high standard of design input.

Other requirements of BPES tools that will fit into the intrinsic way of architects' decision making at this stage of the design process include: *training and easy to master* (requiring little or no training on the part of architects); *a*

low level of detail (producing a small, or relatively small degree of details for the design, no matter how low the input); *interactive* (communicating with the user and computing operations based on input data entered by architects); *visual* (producing a picture representative of data input rather an abstract); and interoperability (being able to transfer data from it to other software, applicable to building design). The end-result of the preparation stage process is usually the sketch design, which initiates the design process into the concept stage. However, the continuous change by the architects in the sketch design is a natural process and can occur at any point throughout the design process.

The Concept Stage of the early design phase

BPES tools used at the concept stage are also referred to as part of early simulation tools (ETs). The recommendations for software developers targeting this stage of the design process, are more or less like that required for the preparation stage, but with greater accuracy and more detailed output results. They include:

- **Flexibility** (able to adapt to clients demand or change in design with greater degree than that required for the preparation phase);
- **Fairly accurate input and quick output** (input of information should be slightly greater than that required at the previous phase). It should be able to produce result immediately. That is, results that will meet the immediate needs of architects as required of the concept stage;
- **Slightly more input of design information**, but greater detail and accuracy than that required for tools at the preparation stage;
- They should give architects quick, but more accurate output, with ability to allow the description and simulation of building in minutes, rather than hours;
- They may require training but not so extensive, on the part of architects.

Late Phase of the Design Process

At this stage, the design development and technical stages of RIBA Outline plan of work, the architect had reached a point in the design process where all parameters considered in the previous stages must flow together or interact at higher level. These include: architecture; plans; the visual impact; functionality; aesthetics; the space design; working environment; principles of construction; energy solutions and targets, and indoor environment technology to form a synthesis of the design.

In general, data exchange at this stage needs to become more sophisticated, reliable and less error prone, so that practitioners can integrate the decisions made by the tools more smoothly into practice. Requirements of BPES tools targeted for this stage need to be more user-friendly, more capable, more robust, better documented, with minimal time for result output. The specific requirements include: *detailed and accurate input* (accurate results from detailed and accurate information input); *detailed results* (fast or give detailed results to meet detailed needs of the architects in accordance with high standard of design input); *a high level of detail* (produce high level and degree of details for the design); *photorealistic* (produce an artistic output, accurate, detailed representation and close to reality as much as it can be, without attempt to conceal any feature whether attractive or not and *training* (may or may not require training, but not an intensive one for architects' use

2. Quality software with simple interfaces

Existing BPES tools require a significant amount of time, both to learn and to achieve expertise. Although there have been significant progress since the early days, potential still exists for better software to be developed; that is, simpler and easier to use tools, with interfaces that are more natural. This is because most tools require the creation of time consuming models, which often lead to their rejection by designers. Hence, the emphasis for quick turnover times in simulation model creation.

3. Open source solutions for cheaper software

Most BPES tools are extremely expensive. More than one package may be required in any one project. Although, a number of large architectural practices exist with excellent IT resources, and their own in house energy analysts who can afford this range and scope of software, there are still significant numbers of smaller firms who cannot afford this. These set of architects will struggle with both the knowledge and data demands of designing to low carbon standards. Open source software is therefore recommended to provide solution to this challenge.

4. Regional specific software packages

Most BPES tools are almost totally developed in the USA by large and well-resourced companies. In contrast, in the UK, BRE (Building Research Establishment) is at the forefront of the development of assessment and building code checking software, which is not part of the early design process. Hence, country-specific software developers are recommended to integrate their products with building codes and legislation, for use in supporting early design decisions, as opposed to retrospective design validation.

5. Integrated energy analysis and design software

At present, there is no software that ‘does everything’. Currently, models are moved between analysis and modeling environments, with a significant time loss, or a corruption of data. Hence, it is recommended that software developers produce tools that will better integrate this scenario.

6. Interoperability of data to reduce market dominance

Interoperable standards, such as the ifcXML (Industry Foundation Classes eXtensible Markup Language) specification and gbXML (Green Building eXtensible Markup Language) enable the movement of models between various types of software. However, the take up has been slow and incomplete, thus loss of data has been reported. It is of recommended that software developers refine these schemas.

7. Sustainable Building Design Advisory Systems

This research has shown that the demand for sustainable practices goes beyond low carbon buildings. Architects will be required in the future to handle new and demanding knowledge, relating to the design of low and possibly, zero carbon housing. Recommendations are made to software developers to create advisory systems that will more effectively examine how to better integrate BIM software and energy simulation tools. This would provide timely, appropriate, relevant and understandable data to architects, in relation to support in design and decision- making.

8. Tools training cost, learning curve and future development

Software developers should create avenue for: proper training; an easy learning curve; reduced cost of programs for students; tutorials and help menu courses as well as video guidance on how to use the software. They should also provide adequate help either at the beginning of the tool, or wherever necessary while performing simulation/calculation use.

11.2.2 Recommendations for Practice

9. Demand for working data exchange solutions

Inconsistencies have been reported in data exchange between different applications. Thus, finding and correcting data to exchange becomes time-consuming. This limits the theoretically possible benefits from the commercial software applications being used. Hence, simplification of true building geometry for building energy performance simulation is recommended as mandatory for meaningful simulation.

This regularly leads to the need to recreate the building thermal view geometry from the more complex architectural view geometry. The increasing demand from practitioners and building owners for working building geometry exchange solutions is likely to improve the reliability of data exchange and enable successful geometry data transfer. Thus, practitioners should stress the need of solutions based on BIM to encourage software vendors and researchers

to improve such solutions. A functional and reliable data exchange from a model based CAD to energy simulation will reduce data inconsistencies and increase the number of projects where energy simulation can be productively used and produce reliable results.

10. Communication and Collaboration with researchers and developers

Practitioners should improve communication and collaboration with both researchers and software developers in order to get a better understanding of current limitations of software tools and their data exchange capabilities. Additionally, practitioners need to gain access to, and use, the expert knowledge and experience of researchers and software developers, so that they can more successfully use the technologies.

Furthermore, practitioners should commit to developing BIM and the spread of standards. They should also commit to testing emerging technologies, thus providing their valuable insights to the research and development community. Only then, perhaps will we witness on-going and continuous development and improvement of tools that support practical needs.

11. Integrated Building Design Process

Towards encouraging architects to use BPES tools, it is recommended that practices should encourage integrated building design process (IBDP) to allow the adaptive use of tools for different purposes, by different users and at different design stages of the design process. The IBDP should include: building's owner; building users; government regulatory and advisory agents and engineering, construction and facilities management agents. Due responsibilities to specialist should be assigned within the IBDP so that they can contribute their specific knowledge to the design process.

12. Architects trained in low carbon concepts

Training opportunities exist, both in learning to use BIM and energy analysis software and in learning the new skills and knowledge required by designers. For successful use of simulation software, training is required. Professionals,

such as architects and engineers, should be able to work with the software at both the conceptual and detail design levels, when output information would be particularly beneficial. This requires the knowledge of the capabilities of simulation, along with specific application knowledge by all the design team.

Hence, lectures, workshops and seminars should be organised to increase the knowledge of architects about the different aspects of low carbon housing to enable them make better-informed decisions about reducing the environmental impact of the project.

13. Experience and Knowledgeable Design Team

Individual and organisations that have had experience of low carbon housing design should be involved in the design team, as these people would have experienced a learning curve through involvement in past projects. They would also have experienced challenges, difficulties and barriers that are associated with the use of the tools and the low carbon delivery. Experience and feedback to team members, after completion of a project, should also be addressed at the beginning of subsequent design processes within the '*setting of principles phase*', so that mechanisms for design implementation can be put in place.

11.2.3 Recommendations for Researchers

The research has discussed functionalities, strengths and limitations of some BPES tools. It is important that the development of the tools is continuous and on-going. More advanced functionality to simulation engines, such as event driven simulation architecture, along with statistical methods for defining input parameters, will increase the strengths of BPES tools, and hence the use of them by architects.

14. Proper integration of simulation with the design process

Evidence from this research has shown that most existing BPES and design tools are not integrated with each other. Computer-Aided Design packages and existing BPES tools see building design differently. They are further

characterised with barriers in data exchange and/or interoperability. Hence, architects are conditioned to reiterate building design within energy simulation tools at later stages. This inevitably leads to rework, waste of time and effort and, above all, widens the gap between design disciplines.

This can also be attributed to the complexities of the design process and the advanced technology now applied in the building industry. Integration of different performance domains and tools at the early stage should have enough flexibility to provide basic information during pre-design and more complex information in later design phases.

There is therefore the need for integrated tools, which produce automatic graphic output (plots and graphs) of simulation results at the early phase, as well as for design and decision-making at the later phase of the design process. It is recommended that future research studies explore effective ways of integrating tools. Example is: the integration of modelling to raise awareness of energy and environmental issues, as well as giving adequate status in decision making. The results of this research clearly suggest that such a development would be a desirable one.

15. Event-driven simulation tools

The architecture of all energy simulation tools in this study is based on a fixed or variable time step simulation concept. While there has been improvement to more variable and smaller time steps, event-driven simulation would eliminate approximations that result from time steps that are longer than the characteristic time intervals of thermodynamic processes. Event driven simulations would be useful to perform change-of-status calculations only when changes in the building actually occur and would thus provide a more flexible methodology that can account for changes only when they occur. Researchers are recommended to look into this; it would be more flexible to adjust to different time characteristics of processes that usually cannot be reflected in time-step-based simulation.

16. More advanced data exchange based on BIM solutions

Today, several data formats exist to exchange building-related information between applications. While some limited solutions exist to exchange data among a small number of applications (such as CAD to energy simulation via DXF), future researcher should focus on more sophisticated and thorough solutions, such as BIM- based approaches, that account for data needs over all disciplines and life-cycle phases. The view definitions are also necessary to ensure successful data exchange, based upon the same implementation in all participating software.

17. Implementation of model servers

Researchers should also focus on the realisation of model servers based on BIM. The current file-based data-exchange process provides some benefits to the users, but can be cumbersome if design changes happen often. Model servers would be able to support these changes, so that they can be easily transmitted to, and updated in any relevant application. Model servers would also allow collaborative work on the same building project without major time delays between the party making the change and the party affected by it. Server-based BIMs would also allow users the flexibility to access the data from anywhere, given an internet connection.

18. Changes to industry processes

In conjunction with model server development, research needs to change and redefine current industry business processes. This change is necessary to leverage benefits from advanced data-sharing over the internet. Especially, change management could benefit dramatically from BIM-based model servers, where changes can be implemented in real-time or close to it. Changes would become more transparent in any given BIM and could improve change-related communication between different industry disciplines. Model servers, and their software, need to support new emerging business processes in order to be adopted by the industry. When data -exchange becomes more reliable and expedient, more timely feedback to different design alternatives or changes should provide valuable insights earlier in the process than is currently possible.

11.2.4 Recommendations for Policy Makers

The policy makers were discovered in this research as not doing enough to support the delivery of low-carbon housing. Hence the following recommendations:

19. Planning policy should be more stringent in both content and enforcement;
20. Direct funding by the government to improve the necessary technology in the sector would be beneficial. Government should spend money on technology advancement to reduce cost and encourage more client and end users. It will also leave room for profit margins and incentives;
21. Funding and training related to low carbon housing design and developments could also lead to significant improvements within the industry.

11.3 Contribution to Knowledge

Insights identified from addressing the research objectives in Section 11.1 represent part of the original contribution to knowledge made by the present thesis. The following are itemised as key contributions of the study:

- Major design decisions taken early in the design process can have far-reaching environmental impact later on. A great deal of effort has been made to improve energy simulation tools to support the design of low-carbon buildings. This involved the integration of energy simulation tools with Computer Aided Architectural Design (CAAD) tools, to better inform the design process. Despite these advances, integrated tools did not have a significant impact on the way architects work to deliver the design. Thus, the finding from this research has revealed architects require that BPES tools are fit for purpose at the different stages of the design process. At the early design stage, there should be

enough flexibility, but higher levels of accuracy and detail of data are required at the later stage of the design process.

- Implications of findings on research and practice, as well as recommendations to software developers, practice, research and policy makers have been highlighted in this study. These will be most important to those who are interested in low- impact housing design and development and especially those with the aim to bridge the gap in the use of BPES tools to deliver the design in the UK.
- The recommendations made in this study will be specifically useful for future research, especially in the UK, to develop tools that will address architects' needs. It will also be useful in the development of software, and other more accurate analysis features, to strengthen the functionalities of the existing BPES, hence their use within the building design industry and especially by the architects.
- The extensive details on the case-based documents on integrated design processes in Chapter Five illustrate the complexities of the design process. Hence, the factors identified in the theoretical model of the IBDP, provides a unique insight into sustainability and environmental design information requirements, at different stages of the design process, to achieve energy Level 5 of the CSH.
- A decision support framework (DSF) was proposed in Chapter Nine, for architects to deliver low-impact housing design in the UK. Nevertheless, the framework is still tentative, because it has not been empirically tested. However, it reflects elements derived from the empirical work reported in the present thesis.

11.3.1 Dissemination of Research

The key aim of dissemination of research is to reflect multidisciplinary nature of the thesis by publishing in the widest range of sources. Hence, both theoretical and empirical findings within the scope of this research have been published in peer reviewed journals, as well as being presented at international conference(s) as the research was progressing (Abstracts of publications is attached in Appendix 5). More publications are also in preparation and in review.

Nevertheless, information and findings from the study will further be communicated to all those involved in achieving low-carbon housing. This includes: RIBA members; Building Research and Establishments (BRE); Energy Savings Trust (EST); National House Building Council (NHBC) and many more. The findings will also be of particular interest to software developers, research communities and those working on the government's zero-carbon homes initiative, as well as other future low-carbon and zero-carbon housing developments.

11.4 Limitations

This research, like any other type of research, will be expected to have a number of strengths and limitations. The strengths of the research have been highlighted in Section 11.3, in form of contribution to knowledge. The limitations are hereby listed for future consideration and further research.

The findings on low carbon housing design, design and decision support tools, along with CSH and its implementation in the UK, are expository. The process of developing the methodology was therefore faced with critical issues that have made the author of this research change the direction of the methodology and its objectives so many times, in order to achieve the aim of the research.

As uptake to low-carbon housing design is still relatively low. This, coupled with the way that houses are being delivered in the UK, serves as a limitation in this research; thus the number of academic publications on the topic is low.

On the other hand, there were many publications from the internet in the form of reports from various organisations, companies and software developers. The study therefore had to rely on the most current reports from the different and various organisations and their web pages. This brought about the need for continuous checking, comparison and updating of the available information; hence, a limitation to the research.

Most BPES tools are almost totally developed in the US, this also serves as a limitation because the majority of the existing BPES tools are US applied. Finally, it would also have been more beneficial to widen the sample group to more than one field of designers in the construction industry. This too, serves as limitation, as the opinion is that, involving more fields within the construction industry in the survey would probably have increased the number of respondents; hence increasing the validity of the research findings.

11.5 Scope for Future Work

From this research, topics for future work to enable the delivery of low-carbon housing are identified. These lead on from the limitations to the research in Section 11.4, and could form a programme of research for the next ten years. The following areas of investigation are therefore recommended for future research:

- Since low-carbon housing as a term, is relatively new, it would be beneficial if other sectors within the construction industry would provide an extensive vision of what is taking place, such as, ‘ *An evaluation of the differences that exist in the use of decision support tools in other fields of study that relates to the design.*
- A study of the available information on cost of low carbon housing in UK;
- Investigating the state- of- the- art in the use of decision-support tools for the construction, and other phases, of housing projects;

- Developing a Decision-Support Framework for the construction and management phase of the design; and
- Investigating the hierarchy that existed when decisions were made to better understand the decision-making process.

11.6 Reflective Summary

This chapter concludes the present thesis. It summarises the extent to which the study has achieved its various objectives through the set of research questions in Section 1.5. The answers to the questions were achieved through: a comprehensive literature review, encompassing low-carbon housing, and related information in Chapter Two; design and decision support delivery tools in Chapter Three and design process in Chapter Four. Some consensus were identified from the reviews, which were then used to cover the theoretical aspect of the research and fulfil objective one of the study, towards realisation of objective two and three. Thus, the theoretical aspect was finally concluded in Chapter Five to fulfil objective three.

Consequently, Chapter Six was used to describe and explain the various methodologies and specific methods used in the research. The adopted mixed-method of research comprises of: qualitative interviews to get the perspective of practicing architects, as well as those in academia, on the theme of the research; and quantitative questionnaire survey, to draw out the experience of sustainable practicing architects to cover all regions in the UK. The qualitative and quantitative aspects of the research to fulfil objective two were covered in Chapter seven and eight

Thus, the summary of the research methods in a systematic order consist of: the literature review (chapters two to four); case-based documentary study (Chapter Five); interviews (Chapter Seven) and questionnaire survey (Chapter Eight) to achieve the aim (Chapter Nine) and objectives of the research in section 1.4. The discussion of research findings, to determine the adequacy/inadequacy between design decisions and the various stages of the

design process, is in chapter Ten, along with implications on research and practice.

The reflective summary of findings from each methodology portrays the way that the results have emerged from various stages of the research methods. The approach provides the study with the necessary data to make recommendations in sections 11.2.1 to 11.2.4 respectively, for software developers, practitioners, researchers, and policy makers, to fulfil objective six. Contributions to knowledge, limitations, and scope for future study to better enable the design and delivery of low- carbon housing in the UK, towards zero-carbon housing delivery from 2016 and beyond, finally conclude the thesis in this Chapter Eleven.

11.6.1 Conclusion

The principal aim of the study was to develop a decision- support framework for architects to enable them to deliver low-carbon housing design in the UK. This particular research focussed on BPES tools as decision-support for architects to achieve the design. It sets out to find the effectiveness and state - of - the - art in the use of existing BPES tools. It asks questions such as, the stage(s) of the design process that need more focus in terms of decision-support for architects to deliver low-impact design in the UK, and stage(s) of design that architects make more efficient use of the tools already in existence.

From the findings, it can be conclusively posited that when BPES tools are used (if at all) in design and decision-making by architects, their use is usually confined to optimisation; verification, and late in the design process. Consequently, the role of energy analysis has been simply to give endorsement to a completed design, rather than to assist architects at the early stage of the design process, where most of the important decisions relating to energy efficiency components are made. Thus, the support at the early design stage is poor.

To achieve low-impact design in the UK, there is need for new generation of tools, by which early design decisions, especially ones at the conceptual stage,

must be adequately informed. Hence, the study makes recommendations to software developers, practitioners and research communities that there is need for BPES tools, which fit into the intrinsic way that design-decisions are made by architects, at the various stages of the design process.

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Appendix 1

Case Based Documents

- *Hansen and Knudstrup (2005)*

The first step of the building project is the description of the problem or the project idea to an environmental or sustainable building. The analysis phase encompasses analysis of all the information that has to be procured before the designer of the building is ready to begin the Sketching process (Figure 5.2). Information about the site, municipality and local plans, the architecture of the neighbourhood, topography, vegetation, sun, light and shadow, predominant wind direction, access to and the size of the area and neighbouring buildings. Moreover, it is important to be cognisant of the special qualities of the area and the sense of the place before the design.

Analysis Phase

At the analysis phase, detailed information is procured about the user's demands for space, functionality and logistics. Criteria for architectural qualities are also discussed. Various architectural demands and a chart of the functions and a company concept which can lend inspiration to the design of the building are done at this stage. Here, it is also important to decide principles for targets, such as: energy use; heating; cooling; ventilation; lighting and indoor environmental quality, as well as criteria for application of passive technologies as natural ventilation, day lighting, passive heating, passive cooling. These criteria should be developed in consideration of the local climatic conditions and the local energy distribution facilities. At the end of the analysis phase, a statement of aims and a programme for the building is set up including a list of design criteria, target values.

Sketching Phase

The Sketching Phase in Hansen and Knudstrup (2005) can be referred to as the design development phase of the RIBA plan of work stages. It is at this phase, that professional knowledge of architects and engineers is combined to provide mutual inspiration in the Integrated Design Process in order for the demands and wishes for the building to be met. This also applies to the demands for: architecture; design; the working environment and visual impact; the demands

for functions; construction; energy consumption and indoor environmental conditions.

During the Sketching phase all defined criteria and target values are considered in the development and evaluation of design solutions. As well as demands for logistics and other demands by which new creative ideas and solutions are produced in this phase. The phase involves a complex mental process, to visualise ideas on paper or in physical models, and by using computer designed models e.g. programmes like Auto Cad” or “Autodesk VIZ 4”. As mentioned above, in this phase the professional parameters of both architects and engineers are flowing together in the Integrated Design Process in interaction with each other.

In summary, the preconditions for designing an energy saving building in an Integrated Design Process are as follows. In the Sketching phase, the designer must repeatedly make the plans, the orientation of the building, the construction and the climate screen influence the energy consumption of the building in terms of heating, cooling, ventilation and daylight – and how these choices inspire each other. Typically the different solutions have different strength and weaknesses when the fulfilment of the different design criteria and target values is evaluated. In this phase the designer makes a lot of sketches to solve the various problems in order to optimise the final and best solution that hopefully will appear in the next closely connected phase, the synthesis phase.

Synthesis Phase

The Synthesis Phase in Hansen and Knudstrup (2005), is the phase where the new building finds its final form, and where the demands in the aims and programme are met. This relates to the technical design stage of the RIBA plan of work stages. Here the designer reaches a point in the design process where all parameters considered in the Sketching phase flow together: plans, the visual impact, functionality, company profile, aesthetics, the space design, working environment, room programme, principles of construction, energy

solutions and targets and indoor environment technology form a synthesis. In the synthesis phase, the various elements used in the project should be optimised, and the building performance is documented by detailed calculation models.

Presentation Phase

The Presentation Phase is the final phase, which Hansen and Knudstrup (2005) regard as the presentation of the project. The project is presented in such a way that all qualities are shown and it is clearly pointed out how the aims, design criteria and target values of the project have been fulfilled for the new building owner.

- ***Pearl (2004)***

Early Design Stage

1. Establish performance targets for a broad range of parameters, and develop preliminary strategies to achieve these targets. This sounds obvious, but in the context of an integrated design team approach, it can bring engineering skills and perspectives to bear at the concept design stage, thereby helping the owner and architect avoid a sub-optimal design solution.

2. Minimize heating and cooling loads and maximize day lighting potential through orientation, building configuration, an efficient building envelope and careful consideration of the amount, type, and location of fenestration.

Detail Design Stage

3. Determine heating and cooling loads through the maximum use of solar and other renewable technologies and the use of efficient HVAC systems.

4. Iterate the process to produce at least two, or preferably three, design concept alternatives, using energy simulations as a test of progress, and then selecting the most promising of these for further development.

Since numerous clients are now putting energy performance and green marketing ahead of design aesthetics, it is now imperative for the design team to understand and incorporate energy and structural systems within their building design aesthetics, if they do not want to be limited to specifying

colours and materials. Integrated Design Process (IDP) is not a mechanised design approach that stunts creative iterations. In fact, it can help evaluate the potential of numerous schematic design approaches with corresponding bi-climatic strategies at the earliest design stage possible. More specifically, it is the realization that more than 80 per cent of the poetic, economic and ecological potential of a design approach is defined at the earliest stage, and thus it is crucial to have as much input from as wide a cross section of disciplines as possible, involved even at the most embryonic design stage.

- *Reed and Gordon (2000)*

Master Plan Phase

a. Site Procurement, Due Diligence, and Initial Concept Design: The owner, and if possible with the architect, evaluate sites for efficient design opportunities, secure the site, and address and environmental issues.

b. Team Selection: The critical members of the team are selected to address the general building and site issues. This team usually includes the architect, landscape architect, civil engineers (if needed), building energy specialist, general contractor, and the owner. This is the time for planning the first conceptual design session.

c. Full Design Team Selection (sometimes referred to as, Design-Construction Team Selection): This is the kind of design team where an architect is selected who then selects the other consultants, otherwise called the *Top level team selection*. Contractor selection is usually left to the bidding process. A Design/Build team can be selected as well.

Concept Stage

d. Conceptual Design Refinement Session: Functional, aesthetic, environmental, general specifications, budget, and scheduling (with milestones) goals are established and

e. Conceptual Design Iteration – The team works to a defined schedule and communicates as necessary. The owner may be involved in ‘on-board’ reviews and general energy modelling takes place.

f. **80 per cent Conceptual Design Review** –This is the session where final comments are invited on the design from all the team members.

g. **Revised and finalize Concept Drawings.**

h. **Submit for Zoning Approval and financing.**

Development Phase

i. **Pre-planning for the Design Adjustment Work Session(s):** This stage is where the owner and the architect coordinate the team members, the venue for the work sessions and the general goals, in order to finalise the schematic design, before starting the design development.

j. **Post Zoning Approval Design Adjustment Work Session(s):** Functional, aesthetic, environmental, general specifications, budget and schedule (with milestones) goals are revisited and prioritised with the design and building team. The LEED rating system benchmarks (or higher and equivalent to CSH in UK) should be specifically targeted at this stage. This is the stage where additional team members are added. This may include the mechanical/electrical engineers, a structural engineer, a civil engineer, the property manager, the commissioning agent (if applicable), and other critical specialty consultants.

k. **Schematic Design Iteration:** The team works to a defined schedule and communicates as necessary. The owner may be involved in 'on-board' reviews. As necessary, energy and daylight modelling also takes place at this stage of the design process.

Final Schematic Design Review

l. **Design Development:** Detail design, outline specifications, and schematic engineering drawings are brought to the 50 per cent level. Energy, day lighting and moisture, are also modelled here to the necessary confidence level.

m. **50 per cent Design Development Review and Life-cycle Value Engineering:** Critical team members meet, a life-cycle value engineering session is conducted and critical subcontractors are brought in to give input.

- *Energy Star Building Guidance (2008;2012)*

Pre- Design Stage

- Conduct a comprehensive charrette that address architecture, energy, and environmental issues;
- Identify synergies between design concepts and energy use;
- Develop scope of work, project budget, and schedule and energy target.

Assemble Design Team

- Select a multi-disciplinary team;
- Adopt an integrated design approach;
- Educate the project team on goals, costs and benefit.

Set Goal

- Set energy targets to achieve the 2030 goal and ENERGY STAR—Target Finder;
- Use design guidance for energy strategies and technologies;
- Review case studies that demonstrate enhanced energy efficiency;
- Visit buildings and review energy use of past projects;
- Consider financial and environmental impact;
- Allocate sufficient funds for an integrated design process.

Schematic Design

- Include an energy expert and begin energy analysis of the design concepts;
- Select technologies and strategies that enhance energy performance;
- Analyse the site and building orientation for energy flow;
- Select technologies and strategies that enhance energy performance;

- Compare estimated energy use to the design target—Target Finder.

Design Development

- Confirm the 2030 goal and achieving ENERGY STAR—Target Finder;
- Identify energy-efficient elements which require explanations for their installation, operation, and other requirements;
- Gather manufacturers' literature for systems highlighting energy-efficient features and applications.
- ***Federal Energy Management Programme (FEMP)(2001)***

Preparation Stage

Feasibility Stage

- Conduct all required feasibility analyses;
- Review all existing directives and policies;
- Establish energy use target;
- Identify the goal for other sustainable issues.

Budgeting Phase

- Programme any special requirements into budget submission;
- Include the requirement for an energy expert;
- Conduct a design charrette before concept development.

Project Pre-Planning

- Establish low energy as core project goal;
- Establish energy use targets (Level of experience is important in selecting the consultants).

Project Planning Phase

- Establish an interdisciplinary design team;

- Develop a preliminary layout;
- Investigate renewable power sources;
- Conduct preliminary energy analysis.

Schematic Design Phase (Preliminary Design)

- Ensure Optimisation of day lighting;
- Develop material specifications that maximises performance;
- Continue energy analysis and determine best project specific options.

Design Development -1

- Continue energy analysis and ensure that performance objectives are maintained.

Design Development II

- Ensure that the construction details and specifications are consistent;
- Ensure that the mechanical equipment meets the design target;
- Conduct a final design review.

Appendix 2a

Interview Questionnaire

Section A

1. How many years of experience do you have?
2. Any experience of LCHs Design?
3. If Yes, how many years?

Section B and C

4. What design/decision support /tools do you think designers need for LCHs design? (What have you been using for your design of LCHs?)

a. Architects to List the known Support /Tools

b. Some Proposed Support /Tools

5. What type of tools do you use at the moment for your design of LCHs?
6. What type/ categories of decision support tools are essential or should be included in the decision making process?
7. What are the characteristics required of decision Support tools to deliver LCHs design (What are the characteristics of BPES tools required for different stages of the design process)?
8. What do you think are the barriers to the low-carbon housing design and delivery in the UK?
 - a. (Architects to list the barriers)
 - b. Some Common Barriers

The country's economy; real/perceived affordability costs; client economy; lack of information knowledge on design and decision support tools; limited availability of products and skills of services and technology; lack of an informed system to check for current and emerging information.

Section D: Format of DSF

9. What type of format should the DSF be presented?

. Design Stages, b. Design Tasks, c. Design Components

Section E: CSH and Other Information

10. Do you know about CSH? (CSH is a design guide produced with the aim of helping UK Housing developments to achieve zero carbon emission levels by 2016)
11. Do you think it can produce credible route map to the zero carbon target for new homes by 2016?
12. If No, What do you think are the barriers to use of CSH and Zero Carbon Housing in the UK by 2016?
 - a. (Architects to list the barriers)
 - b. Some Common Barriers

The country's economy; real/perceived affordability costs; client economy; lack of information knowledge on design and decision support tools; limited availability of products and skills of services and technology; lack of an informed system to check for current and emerging information. Others.

13. Do you think the present format for the CSH is okay?

If no, how do you think it should be presented to designers?

14. Do you think other building regulation requirements like the Building Regulations Part L1A and Eco Homes should be included in the Framework?
15. What type / categories of material and component information should be included in the DSF?

U- Value; Energy/ Carbon Embodiment

16. How do you think information on material and components should be presented?
17. Do you think it will be suitable to include case studies?

Section F: Design Information Requirements

18. What other type of information in the form of design information requirements should be presented in the DSF?

Any other comments:

Appendix 2b

Interview Transcripts

Section B and C: Design and Decision Support Tools

What design/decision support /tools do you think designers need for LCHs design? (What have you been using for your design of LCHs?)

B: *-Passive haus. Some other support / tools include: 'CSH, components/materials information are on the web but one must know how to look for it. Case studies are also needed, but I don't believe in design guides because it makes designers less responsible or one can say it is for poor designers'.*

C: *'It is more about good understanding of what LCHs. The support should therefore be educative and informative with good strategy, starting from academy level and continue to professional level'.*

Design tools: *'If energy design tools, 'Yes' but social and economic sustainability tools are very difficult'*

E: He mentioned, *'SAP, Passive House Planning Package (PHPP) and Integrated Environmental Solutions (IES) tools'* (Figure 7.1), although he does not think that these tools, will necessarily deliver low carbon housing in the UK. In his opinion, *'These are the best at the moment'*. He further stated, *'it will be good to have a tool that starts from when the client write brief to the management level'*.

G: *'We are the clients' servants: we can only do what we are asked. Very few clients want to have low-carbon homes. Those that do, (owner-occupiers, by and large, and how many 'self-builders' are there in the UK?) frequently stop wanting them as soon as the additional costs become apparent. Developers and I include many social housing providers here, unfortunately, only want to do an elegant sufficiency to comply with statutory requirements'.*

H: *'It seems PHPP is more like the tool to achieve low carbon housing because it has recipe of how to attack the problems'.*

Section D: Tools Characteristics Format of DSF Presentation

What type/ categories or requirements are essential for tools to support decision making?

A: *'It should to be layered, so that it will be useful at the different stages just like an Encyclopaedia'.*

B: Design tools, energy calculator and carbon embodiment, code compliance and checking tools. He further stated, *'Building code is easy to read and that is not even the issue, but you have to build everybody expectation and value into it. On 'U-Value Calculator, He stated, 'The architect understands this, since it is the basic thing, it is therefore definite. However, Carbon Embodiment is useful but there is not enough data to produce reliable prediction (but useful in design of the Olympic for example). He further stated that it will be good if confidence of tools can be tested against reality.'*

C: *'Enable the designers using it to understand it much better, that is to take responsibility for and understand what they (designers) are using at the different stages of the design process. U value design calculator on its own is not enough. It should be linked with ventilation strategy and air tightness, energy calculator and carbon embodiment.'* On Code compliance and checking Decision support tools, he stated, *'It should be easily accessible, less complex; you don't have to read the biggest manual in the world to understand it. It should enable the designers using it to understand it much better, that is to take responsibility for and understand what they (designers) are using.'*

C: *'An easy to use and more accessible tool than CSH (less volume)" very useful.'*

Interviewees B, D and J: *'To be represented in the form of design stages'.*

E: *'It will be good for any tool to start from the client right to the brief and finally to the management level.'*

F: *'Literature on Products'*

Interviewee I and J: *'A guideline or checklist would be useful'.*

I: *'Building Research Environment (BRE), Best practice guidance from EST, the Carbon Trust and articles in architectural press.'*

J: *'The checklists should be supplemented by questions to suggest which lists are relevant and information should guide the selection.'*

Barriers to low-carbon housing

What do you think are the barriers to low-carbon housing design?

B: Cost and Building Industry. Country Economy; Real or Perceived affordability cost/ Client Economy; Lack of information knowledge from designers' point of view (*It will help if I am aware*). As for 'Limited availability of products and skills of services and technology', He further stated, *'Everyone is capable of doing it, it is therefore not much of a barrier while an informed system to check for current and emerging information will be an advantage'*. Other barriers are cost and the building industry in the UK. He admitted that the cost to build low carbon houses is slightly more than that of a conventional house. However, he emphasised, *'Running costs would be considerably less, saving money in the long term.'*

C: The country's economy; real or perceived affordability cost (client economy). He said, *'This has to do with house builders and they think it is more expensive'*. He further added, *'Lack of Knowledge from designers 'point of view is not much of a barrier because there are lots of information which designers are aware of.'*

E: *'Skills, confidence and competence, financial structure, unwillingness to change (earlier) with more people ready to change for now. The way housing is being in the UK through the volume house modelling also makes it more difficult for the delivery.'*

H: *'Developers are the main factor; they want buildings to be cheaper so they can realise more profit. This relates more to insulation levels for the design, as it was necessary that any extra money spent on insulation should be balanced by the increase in performance.'*

I: *'One of the main key issues is probably affordability. This needed to be balanced with delivering the right product. Most of the time, the main client was worried about the commercial viability of the project and realised that some changes to the original concept needed to be made because of this. Most clients wanted to show the business case for the development, so that other house builders would see that the design could be delivered commercially. Hence, 'Most clients believe costs are more important than environmental issues.'*

J: *'One of the key barriers to low carbon housing design and delivery is to perhaps understand how much it costs at an early stage. I do not use timber for the rainwater goods but dedicated to using non-PVC wiring in the houses. I am not put off by the contractor's overestimation of the cost for this. My recommendation for most decision that has to do with renewable energy is that that no renewable energy technologies should be provided in the houses, due to cost implications but more money should be spend on making the houses 'solar ready' so that if people were willing to pay for solar thermal panels, then it would be very easy to install, hence the desired level of the CSH for marketing purpose.'*

Section E: Statutory and Non-Statutory Regulations: CSH

On CSH producing credible route map to zero carbon homes by 2016

C: *'No', by which he was further asked what he thought were the barriers to the zero carbon targets by 2016 in addition to the barriers listed in the interview templates, which were:*

- A country's economy;
- Real or perceived affordability;
- Lack of information knowledge from an architects' point of view;
- Limited availability of products and skills of services and technology;
- Lack of an informed system to check for current and emerging information.

He further acknowledge, the barriers use and implementation of CSH as: *‘Economical; Social, i.e. people not asking for it; Misunderstanding about what sustainability is and what is involved and existing housing stock needs to be retrofitted first (There is no strategy to retrofit existing housing stock)’.*

E: *‘Yes (Optimistically) and No (Worried that it won’t, because the industry has to learn too much between now and then)’.* One other interviewee’s answer to the question in addition to the provided lists was, *‘The whole concept of the route map was a brilliant idea (refers to what zero carbon hubs has done) but with problems in the code 6 achievement, which is sort of dead, definition of Zero carbon is not very clear yet. ‘Theory of route map is good but how you achieve it is the problem.’* (It is a credible route map, but it still has problems).

G: *‘CSH is a beurocratic nightmare invented by an institution, once a fully funded government research institute, to be sure, but now simply a rather piratical commercial organisation. We do TRY really we do but we have to be realistic. How many ‘tools’ can you be using when the total fee for designing a dwelling is frequently only a couple or three hundred pounds?’*

Format of the CSH

C: *‘It should be much more easily accessible, less complex (you don’t have to read the biggest manual in the world to understand it) and enable the designers using it to understand it much better, that is to take responsibility for and understand what they (designers) are using.’*

H: *‘CSH’ is fine, but it has some flaws like it not be able to deliver level 6 coupled with people spending much money on wrong technology.’* He further stated, *‘It will be good for any tool like CSH to start from when the client write brief to the management level.’*

Section F: Design information requirements

What other type sustainability /design information requirements apart from CSH do you should be included in the Framework?

B: *'A range of varieties based on what is required at stages of design. I think the design guides will be especially useful to those designers new to the field and countries'.*

C: *'Orientation, Ventilation, Air tightness'.*

D: *'I think all the three are important, that is U values, Energy and Carbon Embodiment, Insulation.'* Others include: *'Air Quality of building, how building breathe for breathing building is a better building and Air quality of building'.*

I: *'Conventional developers viewed the design process differently because, sustainability offers long term savings whereas many developers usually base their decisions on the short term.'*

J: *'The focus should be on reduction of CO₂ emissions, conservation of energy, waste recycling etc. rather than on costs, programme and density.'*

Appendix 3

Exit this survey

Developing a decision support framework for low carbon housing design and delivery in the UK

Introduction

The purpose of this research is towards designing a framework that will facilitate the progress of design decision making by architects from briefing, through concept, and detailed design.

1. How long have you been in practice?

- Less than 2 years
- 2-5 years
- 6-10 years
- 11-20years
- Greater than 20years

2. Where is your current location in the UK?

- England
- Scotland
- Wales
- Northern Ireland

*

3. What stage of design do you use the following in your design of low carbon homes in the UK?

	A and B	C	D	E	All Stages	N/A
Tools such as Autodesk Green Building Studio and MIT Design Advisor.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Simulation Tools, such as Ecotect and Energy 10 software	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	A and B	C	D	E	All Stages	N/A
Dynamic Simulation Tools(for modelling the effect on performance of the thermal capacity (thermal mass) of the building fabric	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy simulation tools such as IES, eQUEST, Energy plus	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building Information Modelling (BIM) software (Autodesk Revit, ArChiCad)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sizing Tools(for building services, including renewable energy systems)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building Environmental Assessment tool (BEA) (Envest II)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Life Cycle Assessment tool (Environmental Impact Estimator)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Life Cycle Cost Assessment (LCCA) tool (Envest II, Building life cycle cost (BLCC)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Green Guide to Specification	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify) <input type="text"/>						

4. What stage of design do you apply the following planning and building regulations in your design of low carbon homes in the UK?

	A and B	C	D	E	All stages	N/A
Merton rule' standards for renewable energy contributions as set by planning authorities and other agencies like English partnership	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building Regulations, Part L1A	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
EU- Energy Performance of Building Directives(EPBD)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

5. What stage of design do use and apply the following energy and environmental procedures?

	A and B	C	D	E	All Stages	N/A
Standard Assessment Procedure (SAP)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
National Home Energy Rating (NHER)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Domestic Energy Rating (DER)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building Research Establishment Domestic Energy Model (BREDEM)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

6. What stage of design do you carry out environmental assessment using the following?

	A and B	C	D	E	All Stages	N/A
Code for Sustainable Homes (CSH)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BREEAM	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Energy Performance Certificates(EPCs)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. What stage of design do you use the following non- statutory energy and environmental standard?

	A and B	C	D	E	All Stages	N/A
Energy Saving Trust Best Practice Standards	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Code for Sustainable Homes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Passive House Standard	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
AECB Carbon Lite	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building Research Establishments Environmental Assessment Method (BREEAM)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other recognised environmental standards such as LEED	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

*

8. Which stage of the design process needs more focus in terms of design tools and decision support for low carbon homes design in the UK?

- Preparation Stage (Stages A and B)
- Concept Design Stage (Stage C)
- Design Development (Stage D)
- Technical Design Stage (Stage E)
- All Design Stages

9. Which stage of the design process do you take decision on the following?

	A and B	C	D	E	All Stages	N/A
Thermal implication on building forms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thermal Characteristics on Building Performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building services system and their key characteristics that contribute to low carbon performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
New and Renewable Energy Systems for use in the building	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
integrated low carbon design principles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

*

10. What stage of design will you need information on the following for your design of low carbon housing in the UK?

	A and B	C	D	E	All Stages	N/A
Design Tools	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Components and Materials Information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Case Studies	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Design Guides	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Access to Manufacture Data	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

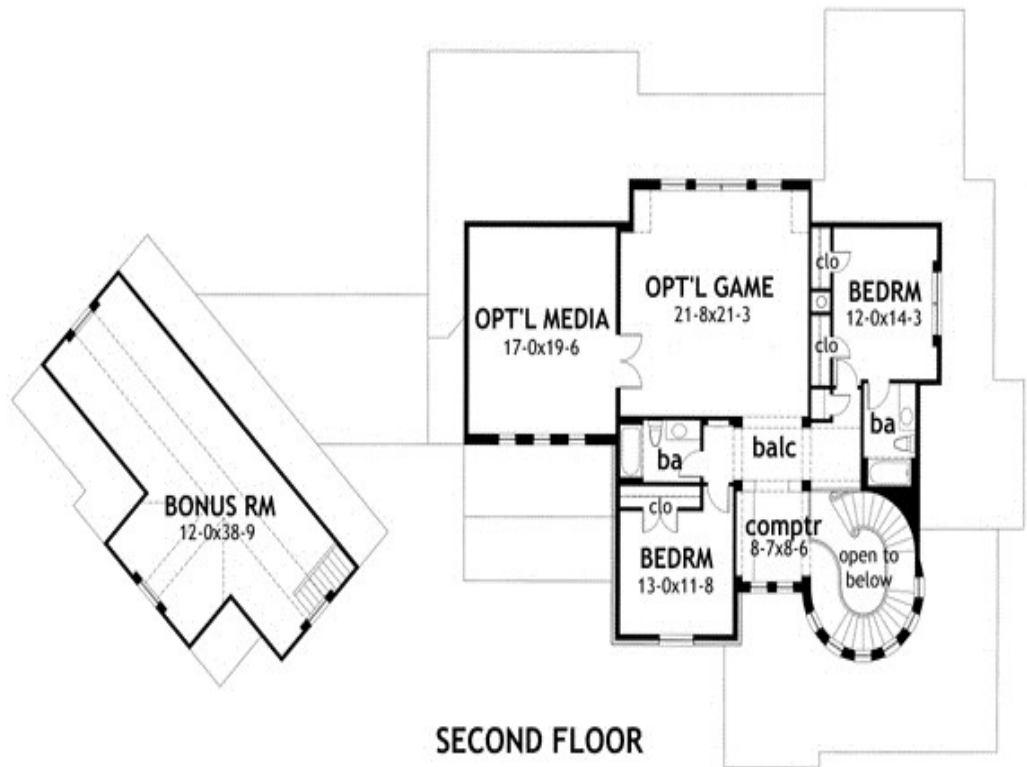
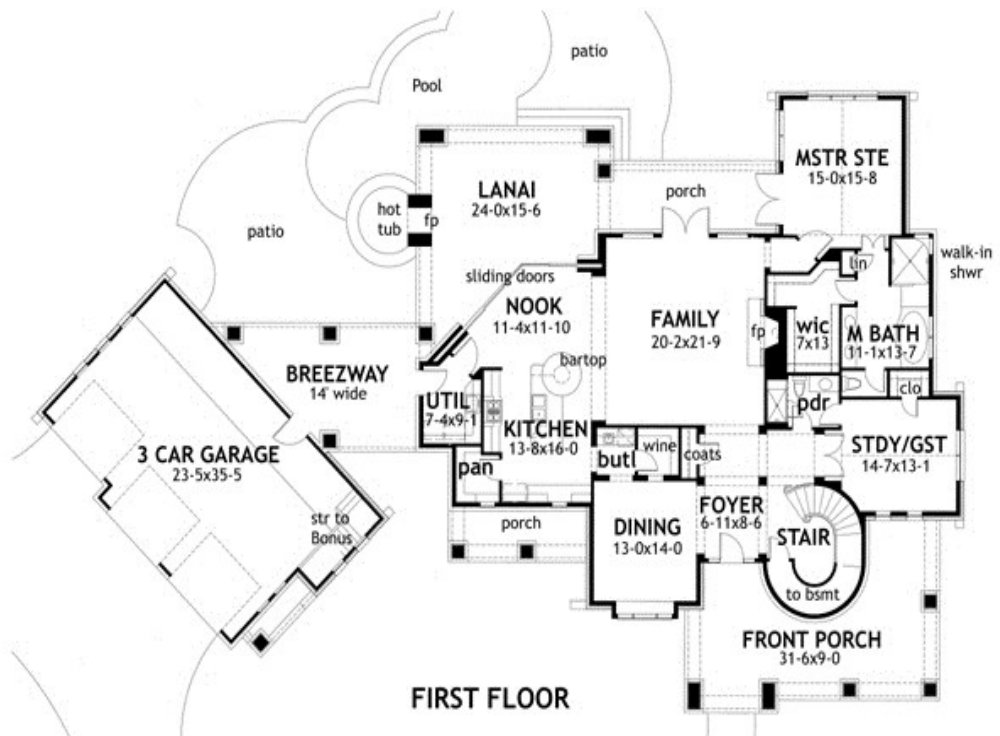
Other (please specify)

Done

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Appendix 4
Low Carbon House





Appendix 5

Abstract 1: Insights of Architects Knowledge of the Code for Sustainable Homes in relation to Low carbon housing design and delivery in the UK

Purpose-The purpose of the paper is to report research conducted to explore the insights of UK architects on the Code for Sustainable Homes (CSH) in relation to low carbon housing design and delivery.

Design/Methodology/Approach- To explore the awareness and knowledge of CSH in low carbon housing design and delivery in the UK, a mixed method approach comprising of interviews with architects in practice and academia were combined with questionnaires to UK sustainable architectural practices.

Findings-The results confirmed that, although UK architects are aware of CSH, it is only very few (11.8%), that have the expert knowledge. This is in comparison to 52.9% of those with some knowledge, and 35.3% of those who are very knowledgeable in the use and implementation of CSH to design and deliver low carbon new homes in the UK.

Research Implication-The research focused on investigating the judging criteria and opinions of architects who are strongly identified with sustainable housing design practices in the UK. It explores the insights of architects on the CSH, because their knowledge, use and implementation of it along with other information on low carbon housing design from the onset determines how soon the zero carbon homes in the UK can be achieved towards tackling energy use in the UK and on a wider level, the European commitment reduction of energy consumption.

Abstract 2: Developing an Information Support System for Low Carbon Housing Delivery in the United Kingdom

The design stage of low carbon housing in the United Kingdom (UK) is supported by varieties of information. This includes Building Regulations part L1A, Code for Sustainable Homes (CSH), information on different and various types of design and decision support tools and many more. However, varieties of the information are from different sources such as BRE, DCLG, NHBC, and Carbon Trust. As a result of this, a study comprising mixed method approach of qualitative and quantitative method of data collection was carried out.

The qualitative semi-structured interview was used to investigate the state of art in the use of Code for Sustainable Homes (CSH), being the most recent tool for low carbon housing design, construction and delivery in the UK and to identify other current information needs of architects towards development of the piloting phase of the proposed system. Past researches, journals and reports on existing low energy design processes in the UK and at international level were then identified to develop the sustainability requirements necessary to the design. This was followed by the quantitative data collection in form of an on line survey emailed to sustainable architectural practices recognised from the Royal Institute of British Architects (RIBA) directory to investigate the extent and knowledge in the use of all identified information and towards development of the proposed system.

The interview result identified deficiency of an informed support for the design while the survey recognized the Code for Sustainable Homes (CSH) as the latest tool for the delivery which architects in the United Kingdom (UK) lack its expert knowledge. The study is proposing a support system in which the sustainability requirements to achieve the design are acknowledged and CSH is presented in a simplified and easy to use format.
