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The Role of Knowledge Management in Assisting Key Stakeholders in Making Informed Decisions in Delivering Sustainable Retrofitted Building Projects

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ABSTRACT

The global attention given to climate change that led to the clamour for sustainable development in the 21st century is a laudable development. The efforts of different governments worldwide geared towards mitigating climate change effects are widespread. The construction industry has taken centre stage in driving sustainable development through sustainable construction due to its impacts on society. Nevertheless, it is widely accepted that the 80% target reduction of greenhouse gas emissions required in the UK by 2050 can only be realised if the industry recognises the need for sustainable retrofitted building projects and that this represents one of the most critical approaches to achieving sustainable development in the construction industry. However, the challenges of delivering sustainable retrofitted building projects are enormous and complex, mainly due to key stakeholders' lack of knowledge in making informed and appropriate decisions. This has arguably made decision-making difficult for key stakeholders because the lessons learned from sustainable retrofit projects are not captured. This can improve if the industry recognises the need to adopt knowledge management (KM) to enable key stakeholders to make informed decisions in the delivery of sustainable retrofitted building projects. This research conducted a comprehensive investigation of the literature followed by the collection of empirical data using a mixed-method (quantitative and qualitative) approach. An exploratory industry survey of 86 respondents was followed by multiple-case studies involving 12 semi-structured interviews, each with a representative of a different construction organisation. The survey data were subjected to descriptive, reliability, factor and correlation analysis using SPSS, while the case study interviews were analysed using NVivo and qualitative content analysis. The mixed-method approach assisted in answering 11 research questions and among the key findings were (1) 9 barriers, and 3 enabling factors to embark upon and delivering sustainable retrofits projects were revealed through factor analysis; (2) 6 critical enablers and barriers to sustainable retrofit project delivery were revealed through case studies; (3) an optimal approach is recommended for knowledge capture in retrofit project delivery as well as criteria for easy and difficult decision-making in retrofit project delivery. The research findings assisted in developing sustainable retrofitted building process (SRBP) to guide key stakeholders on the steps needed. The findings and the SRBP contributed to a proposed sustainable retrofitted building decision-support framework (SRBDSF) with knowledge management principles and procedures, and 9 objectives were employed to deliver this aim. The SRBDSF promotes the systematic management of project knowledge, thus enhancing the decision-making capabilities of key stakeholders. Finally, the SRBDSF framework was validated by industry practitioners who found that the SRBDSF was fit for purpose, easy to use and relevant to making informed decisions in the delivery of sustainable retrofit projects. Suggestions and recommendations from the validation contributed to the research recommendations and future work.

DEDICATION

I dedicate this research to the Almighty God!

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DECLARATION

I declare that this work or any part thereof has not been submitted for any other academic award. I confirm that the intellectual contents of the work are solely mine. I state that this work fully acknowledges references and/or bibliographies cited therein. The right of Nnamdi Stanley Maduka to be identified as the author of this work is in confirmation with Sections 77 and 78 of the Copyright, Design and Patents Act 1998. At this date, the author owns the copyright.

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LIST OF ABBREVIATIONS

Abbreviations	**Meaning**
AIA	American Institute of Architects
AECOM	Architecture Engineering Consulting Operations and Maintenance
APM	Association of Project Management
ARRA	America Recovery and Reinvestment Act
ASTM	America Society of Testing and Materials
BBB	Better Building Partnership
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CAQDAS	Computer Assisted Qualitative Data Analysis Software
CBE	Centre for the Built Environment
CCC	Committee on Climate Change
CEPA	California Environmental Protection Agency
CEEQUAL	Civil Engineering Environmental Quality Assessment and Award Scheme
CFA	Confirmatory Factor Analysis
CFC	Chloro-fluoro-carbon
CIB	Conseil International du Batiment (International Council for Research and Innovation in Building Construction)
CIC	United States Green Building Council
CIOB	Chattered Institute for Building
CITB	Construction Industry Training Board
CIRIA	Construction Industry Research and Information Association
CMHC	Canada Mortgage and Housing Corporation
CO_2	Carbon Dioxide
CPA	Construction Products Association
CSN	Construction Skills Network

DCLG	Department for Communities and Local Government
DTTP	Department of Transport/Transport Professional
CSH	Code for Sustainable Homes
DBIS	Department of Business Innovation and Skills
DECC	Department of Energy and Climate Change
DEFRA	Department of Environment, Food and Rural Affairs
DETR	Department of Environment, Transport and the Regions
DTI	Department of Trade and Industry
DSS	Decision Support System
EAPPG	Environment Agency Pollution Prevention Guidance
EFA	Exploratory Factor Analysis
EHER	Euler Hermes Economic Research
EHA	Existing Home Alliance
EMS	Energy Management Systems
EPA	Environmental Protection Agency
EPBD	Energy Performance Directive for Buildings
EU	European Union
FMB	Federation of Master Builders
GCB	Government Green Construction Board
GDP	Gross Domestic Products
GHG	Green House Gas
GVA	Gross Value Added
HM Treasury	Her Majesty Treasury
HVAC	Heating, Ventilation, and Air Conditioning
ICRIBC	International Council for Research and Innovation in Building and Construction
IUCN	International Union for the Conservation of Nature
IPCC	Intergovernmental Panel on Climate Change
JCT	Joint Contract Tribunal
KM	Knowledge Management
KMO	Kaiser-Meyer-Olkin
KPMG	Klynveld Peat Marwick Goerdeler

LCA	Life Cycle Analysis
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
MSA	Measure of Sampling Activity
NAO	National Audit Office
NEFUS	National Energy Foundation and the University of Salford
NGO	Non-Governmental Organisation
NPBEC	National policy for the built environment committee
NREL	National Renewable Energy Laboratory
ODPM	Office of Deputy Prime Minister
OECD	Organisation for Economic Cooperation and Development
OGC	Office of Government and Commerce
ONS	Office for National Statistics
PCC	Pearson Correlation Coefficient
PCA	Principal Component Analysis
PM	Particulate Matter
PMH	Public Medical Health
PMI	Project Management Institute
PPMV	Parts Per Million by Volume
Q	Quarter
QTA	Qualitative Content Analysis
REC	Recruitment Employment Generation
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
SB	Sustainable Building
SC	Sustainable Construction
SCRS	Sustainable Construction Road Show
SD	Sustainable Development
SPSS	Statistical Package for the Social Sciences
TNS	The Natural Step
UDE	US Department of Energy

UK	United Kingdom
UKGBC	United Kingdom Green Building Council
UN	United Nations
UNEP	United Nations Environment Programme
USA	United States of America
USGBC	United States Green Building Council
VAT	Value Added Tax
WBPS	World Bank Participation Sourcebook
WCED	World Commission on Environment and Development
WHO	World Health Organisation
WRAP	Waste and Resources Action Program

LIST OF PUBLICATIONS

International peer-reviewed conference papers

- Maduka, N.S., Udeaja, C. and Greenwood, D. (2015). The Use of Exploratory Research in Addressing Knowledge Issues in Delivering Sustainable Retrofitted Building Projects. Proceedings of ARCOM Doctoral Workshop on Research Methodology, 10th April 2015, Dublin Institute of Technology, Ireland.
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- Maduka, N.S., Udeaja, C. and Greenwood, D. (2015). Managing Project Knowledge in Delivering Sustainable Retrofitted Buildings: A Decision Support Framework. Proceedings of 12th International Post-Graduate Research Conference (IPGRC), 10th -12th June 2015, Salford University, UK.
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- Maduka, N.S., Udeaja, C. and Greenwood, D. (2015). Exploring Knowledge Management Principles for Decision-Making in Low-Energy Building for Sustainability in Construction. Proceedings of International Council for Research and Innovation in Building and Construction (CIB) of Joint International Symposium On: Going North for Sustainability: Leveraging Knowledge and Innovation for Sustainable Construction and Development. November 23rd – 25th 2015 at London South Bank University.
- Maduka, N.S., Greenwood, D., Osborne, A. and Udeaja, C. (2016). Implementing Sustainable Construction Principles and Practices by Key Stakeholders. Proceedings of Modular Offsite Construction Summit (MOC), Edmonton Alberta, Canada. September 29th - October 1st, 2016.

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Introduction

Climate change has imposed significant problems and risks worldwide. With the rapid increases in urbanisation and industrialisation, more greenhouse gases (GHG) are being released into the atmosphere. The built environment, particularly existing buildings and their operations, contribute a significant amount of GHG emissions into the atmosphere. However, delivering sustainable retrofitted building projects has posed a challenge in the industry due to the lack of managing knowledge in making informed decisions and choices in the uptake and delivery of sustainable retrofitted building projects. The need to employ knowledge management strategies in the uptake and delivery of sustainable retrofit projects is essential. Managing project knowledge is necessary due to the key stakeholders' lack of decision-making abilities in the uptake and delivery of sustainable retrofitted building projects.

This research will investigate knowledge management procedures and processes and the barriers and enablers associated with the uptake and delivery of sustainable retrofit projects. It will also investigate the impacts of construction; the benefits of retrofitted buildings; stakeholder management and decision-making tools. These investigations are designed to deliver answers to research questions and deliver the research aim, which is to develop a decision support framework with knowledge management procedures and principles in order to enhance and improve the decision-making abilities of key stakeholders in embarking on and delivering sustainable retrofit projects. Herein, the term 'uptake' refers to the aspects of 'understanding' and 'comprehension' (Merriam-Webster, 2012), while the term 'delivering' refers to the actual execution and completion to achieve outputs, outcomes and benefits (APM, 2017). This chapter presents an overview of the research, which includes the theoretical research underpinnings; justification of the research; aim and objectives; research scope; research methodology; contribution to knowledge, and a guide to the thesis.

1.2 Research theoretical underpinnings

The global attention given to climate change that led to the clamour for sustainable development in the 21st century is a laudable development. Efforts of different governments worldwide geared towards mitigating the climate change effects have been widespread and well documented (European Commission, 2007, Kapsalaki *et al.*, 2012, McManus *et al.*, 2013). Renukappa *et al.* (2013) argue that the issue of climate change is one aspect of the broader problem of sustainability. They posited (2013) that several industries, particularly the construction industry, have acknowledged the need to address climate change challenges in order to survive and grow in everchanging, entangled global business economies. Hence, key stakeholders of many organisations are now implementing various GHG reduction strategies due to mounting pressures.

The need to reduce and mitigate climate change effects was propelled by the Brundtland report 'Our Common Future' which charged national and international bodies to promote the course of sustainable development through three sustainability concepts – environmental, economic and social – in order to reduce climate change (WCED, 1987a). The report further described sustainable development as development that meets the need of the present generation without undermining the ability of future generations to meet their own needs (Brundtland, 1987). In a related view, the IPPC Fourth Assessment Report reaffirmed that climate change, which is predominantly caused by human activities, is inevitable due to an increase in GHG emissions (e.g. CO_2) in the atmosphere (IPCC, 2007). While steps are being taken to reduce carbon emissions from other areas such as road travel, reducing waste and water consumption, the building and energy sectors are becoming significant areas of attention for GHG emission reduction, which means growing potential for energy-related obsolescence in existing built environments (Butt *et al.*, 2012). These have put the United Kingdom (UK) under a commitment to champion the concepts of sustainable development in the built environment, particularly the construction industry due to its impacts on society (McManus *et al.*, 2013).

Construction activities have significant effects (both positive and negative) on the UK and worldwide (Pietrosemoli and Monroy, 2013). Some of the positive impacts include the contribution of about 7% to the UK Gross Domestic Product (GDP) or approximately £110 billion in annual income; job creation; and the production of different types of buildings and facilities to meet human needs (ICRIBC, 2002, Winch, 2010, Pietrosemoli and Monroy, 2013). The negative impacts of construction are documented due to its contribution to GHG emissions, which has affected climate change (Stern, 2006, IPCC, 2007, Weight and Rawlinson, 2007, Levin, 2008, Stolarski *et al.*, 2010). Furthermore, the built environment worldwide contributes about 30% to 40% of CO_2 emissions to the atmosphere as well as consuming about 40% of the total energy usage (Boardman, 2007, Dixit *et* al., 2010, Kapsalaki *et al.*, 2012). The European Union (EU) estimates that its member countries contribute about 50% of CO_2 to the atmosphere (Rai *et al.*, 2011). In the UK, it is documented that buildings consume over 45% of UK energy usage and generate approximately 50% of GHG emissions (Stern, 2006).

These negative impacts have made the industry come under the scrutiny of the public, regulators and government more than ever before and have necessitated the industry to increasingly recognise the need to achieve sustainable development by engaging in sustainable construction (Zuo *et al.*, 2012b). Sustainable construction is argued to be the application of sustainable development concepts and principles to construction processes and practices (Sage, 1998, Carpenter, 2001, ICRIBC, 2002, Shelbourn *et al.*, 2006, European Commission, 2007, Winch, 2010). Sustainable construction in building projects exists in new-build and retrofit building projects. In the case of new build, this involves the construction of new energy-efficient buildings while retrofit involves sustainable refurbishment of existing buildings to deliver more energy-efficient or improved buildings. The UK government had stated that by 2016 every new building must be energy-efficient or built on a carbon-neutral basis, and non-domestic buildings must be constructed on a carbon-neutral basis from 2018 (Kelly, 2009). It is pertinent to state that the government did not meet its target in 2016, largely due to lack of enforcement and lack of managing knowledge amongst the key stakeholders about embarking upon and delivering sustainable retrofitted building projects. However, the need for this has been suggested and cannot be overstressed (Menassa, 2011a, Ma et al., 2012, Maduka et al., 2015a).

In 2016, after the UK voted to leave the EU, the Government legislated the fifth carbon budget. CCC (2017) stated that the budget is stipulated to achieve at least 57% GHG emission reduction by 2030. The reduction is aimed at assisting the UK in reaching its legally binding target of an 80% reduction in greenhouse gas emissions by 2050, using the emissions in 1990 as a baseline. However, achieving 80% target reduction of GHG emission in the atmosphere by 2050 will be challenging unless sustainable retrofitted building projects are given priority attention both by the government and the construction industry (Glass *et al*., 2008, Kelly, 2009, Pietrosemoli and Monroy, 2013). This is because only about one-third or 30% of new energy-efficient buildings would have been constructed in response to the target, and this cannot contribute significantly to GHG reduction by 2050 (Glass *et al*., 2008). Hence, over two-thirds (approximately 70%) of buildings existing today in the UK will still be in use by 2050 (Glass *et al*., 2008, Kapsalaki *et al*., 2012, Stafford *et al*., 2012). Considering these facts, it is evident that embarking upon and delivering sustainable retrofitted building projects is inevitable and will contribute substantially to greenhouse gas reduction (Glass *et al*., 2008, Deloitte and Lockwood, 2008, Kelly, 2009, Jenkins, 2010, McManus *et al*., 2013, Stevenson, 2013). Sustainable retrofitting building has been defined as an improvement made to an existing building that leads to an increase in the overall efficiency of that building (Stephens *et al*., 2011, Fulton *et al*., 2012). BCA (2010) also defines sustainable retrofitted building as the provision, extension or substantial alteration of the building envelope and building services in an existing building in order to reduce CO_2 emissions. The World Business Council for Sustainable Development revealed that embarking on such projects can contribute greatly to tackling climate change and fostering the concepts (economic, social and environmental) of sustainability (WBCSD, 2008). Additionally, delivering sustainable retrofitted building projects has been acknowledged to have tremendous economic, health, social and environmental benefits (Dong *et al*., 2005, Verbeeck and Hens, 2005, USEPA, 2010, Syal *et al*., 2014).

However, while the previously mentioned benefits of delivering sustainable retrofitted building projects are well established and documented, hitherto, the delivery of retrofit projects has faced a lot of challenges and obstacles, particularly with key stakeholders' lack of managing project knowledge in making an appropriate and informed decision in embarking upon and delivering retrofit projects (Duah *et al*., 2014). Delivering a sustainable retrofitted building project remains a challenge in the industry due to a lack of managing knowledge. It has been argued that there is a possibility for substantial carbon emission reduction through appropriate approaches to sustainable retrofit; however, achieving it presents a multifaceted and challenging problem to the industry due to lack of knowledge management in delivering sustainable retrofit projects (Stafford *et al*., 2012, McManus *et al*., 2013).

Lack of knowledge management has been stated to cause key stakeholders to 'reinvent of the wheel' and make decision mistakes in the uptake and delivery of sustainable retrofit projects (Wang *et al*., 2009, Maduka *et al*., 2015b).

1.3 Justification for the research

Existing buildings are responsible for half of the total GHG in the UK which has an adverse impact on global, environmental, human health and economy. It is recognised that 80% of the energy consumed throughout a building's life cycle occurs when it is occupied and in use and where the service life of the building ranges from 30–70 years (Menassa and Baer, 2014). Thus, it necessitated the efforts of many governments and international organisations in the last decade to put significant efforts toward energy efficiency improvement in existing buildings (Ma *et al*., 2012). In 2010, the UK government made a significant contribution to upgrading the energy efficiency of around 7 million homes by 2020 with the aim of reducing GHG by 29% (DECC, 2011c); however, that target is yet to be accomplished. Thakore *et al*. (2013) posited that sustainable transformation to energy-efficient building remains very challenging. Thakore *et al.* (2013) further stated that implementing energy-efficient housing strategies remains a global challenge, particularly in Europe.

These facts compel the industry to deliver buildings that are energy efficient during their life cycle through sustainable retrofitting of the existing buildings by employing sustainability principles (UNEP, 2009). It has been suggested that significant reduction of GHG emissions can be achieved through sustainable retrofitting of existing buildings (Menassa and Baer, 2014). The critical role that existing buildings play in achieving energy reduction or GHG through sustainable retrofits can be part of a complete plan for sustainable corporate development (Hwang and Ng, 2013). According to Kubba (2010), sustainable retrofits should be designed for optimal energy efficiency and constructed with a preference for natural, reclaimed, and recycled materials. These buildings provide healthier, more comfortable and productive indoor environments for occupants by maximising the efficient use of resources like energy, water and raw materials.

ASTM (2009) maintains that sustainable retrofitted buildings provide the definite building performance necessities while at the same time minimising the disturbance to local, regional and global ecosystems, both during and after their construction and

service life. Sustainable retrofitted buildings extend the lifespan of a building while at the same time improving the building performance and preventing the early onset of obsolescence (Menassa, 2011a, Gorse et al., 2013). The need for sustainable retrofitted buildings is due to underperforming buildings impacting on energy commodities, having direct financial implications on the occupant and contributing to increases in GHG emissions (Gorse *et al.*, 2013). Retrofitting of existing buildings offers significant opportunities for reducing global energy consumption and GHG emissions. Delivering retrofit projects is considered as one primary approach to achieving sustainability in the built environment (Ma *et al.*, 2012).
However, despite the benefits of sustainable retrofitted buildings, there has been a lack of interest from key stakeholders in embarking on sustainable retrofit projects between the key stakeholders (Menassa, 2011a, Ma et al., 2012). This is primarily due to lack of adoption of knowledge management by the key stakeholders as regards to making informed and appropriate decisions and choices in the uptake and delivery of sustainable retrofitted building projects (Duah *et al.*, 2014, Maduka *et al.*, 2015a). The part played in this by the fragmented and temporary nature of the industry has already been noted, and added to this is the frequent transfer of personnel between projects, the rarity of ‘lessons learned’ project feedback, and the shortage of skilled workers in the first place (Kazi, 2005, Tan *et al.*, 2010a). Although the industry has been described by Shelbourn *et al.* (2006) as knowledge-driven, the management of project knowledge has not been fully adopted, and its absence has contributed to a lack of appropriate decision-making (Pietrosemoli and Monroy, 2013) by its key stakeholders. Thus, Duah *et al.* (2014) have highlighted the need for the management of project knowledge to underpin an appropriate and informed decision support framework (DSF). In turn, DSFs would enable the key stakeholders to make an informed and proper decision, hence solving the key knowledge issues in stakeholder engagement with sustainable retrofitted building projects.

The need to employ knowledge management strategies in the uptake and delivery of sustainable retrofit projects has been suggested and documented (Maduka *et al.*, 2015a, 2015b, 2015c, 2015d, 2015e). Managing project knowledge is necessary in order to enhance the decision-making abilities of the key stakeholders in the uptake and delivery of sustainable retrofitted building projects (Duah *et al.*, 2014, Maduka *et al.*, 2015a). Adopting knowledge management in sustainable retrofit projects will assist in breaking some of the barriers to the uptake and delivery of retrofit projects. Such barriers include: lack of awareness (NEFUS, 2015); misconception of retrofit cost (Nelms *et al*., 2005); information overload (Malhotra, 2000, Robinson *et al*., 2006); complications involved in retrofit construction (JSCE, 1999); lack of informed decision-making (Maduka *et al.,* 2015a); lack of client demand (Pitt *et al*., 2009) and insufficient expertise (Azizi *et al*., 2011); poor quality design (Winston, 2010); lack of proven alternative technologies (Pitt *et al*., 2007) and unsatisfactory building performance (Azizi *et al*., 2011). Overcoming these barriers necessitates the need to develop a decision support framework with knowledge management procedures and principles to improve the decision capabilities of key stakeholders in the uptake and delivery of sustainable retrofit projects (Syal *et al*., 2014).

1.4 Research scope

The research study focuses on sustainable retrofitted building projects in the UK. The choice for sustainable retrofitting is to contribute to the UK government's interest in achieving 80% carbon emission reduction by 2050 (Kapsalaki et al., 2012; Stafford et al., 2012). The focus on sustainable retrofitted building projects is also due to the fact that an estimated 70% of 2010 buildings stocks in the UK will still be standing and in use by 2050 as earlier mentioned (Kapsalaki *et al*., 2012, Stafford *et al*., 2012). This demonstrates the undoubted need for sustainable retrofit projects. This research attempts to determine the current practices of different construction organisations in the UK as regards the lack of adoption of knowledge management (KM) in the uptake and delivery of retrofit projects and create a holistic approach to enable them to adopt KM not just for retrofit projects, but also in all construction projects. Thus, the research focuses on key knowledge issues and stakeholders' decision-making challenges that limit the embarking upon and delivery of sustainable retrofitted building projects. In relation to that, the research explores knowledge management procedures and a comprehensive examination of the existing decision-making tools used in the construction industry. The research employed knowledge management principles and procedures in developing a sustainable retrofitted building decision support framework (SRBDSF) for key stakeholders (clients, civil/construction engineers, architects/designers; project managers; quantity surveyors; NGOs; government; material manufacturers and suppliers) in the industry.

1.5 Research questions

RQ1: Who are the key stakeholders in sustainable retrofitted building projects?

RQ2: How do the stakeholders rate the construction in improving sustainable principles and practices in delivering sustainable construction?

RQ3: Does the construction industry have a standard or regular building process and decision support framework for the delivery of sustainable retrofit projects?

RQ4: What are the social, economic and environmental benefits of sustainable retrofitted buildings?

RQ5: What are the environmental assessment methods that key stakeholders consider when delivering sustainable retrofitted building projects?

RQ6: What are the sustainable retrofit materials used in delivering sustainable retrofit projects?

RQ7: What does knowledge mean to individual stakeholders in the construction industry?

RQ8: What is the role of knowledge in delivering sustainable retrofit projects?

RQ9: How can project knowledge be captured in sustainable retrofit projects?

RQ10: How can managing project knowledge enhance decision-making in delivering sustainable retrofit projects?

RQ11: How can stakeholders avoid information overload in relation to sustainable construction?

RQ12: What criteria are used to determine the relevance of new knowledge?

1.6 Research aim

This research presents a sustainable retrofitted decision support framework (SRDSF) with knowledge management principles and procedures, the aim of which is underpinned by nine objectives.

1.7 Research objectives

1. To examine through literature review the current practices in the uptake and delivery of sustainable retrofitted building projects.

2. To determine through literature review knowledge management principles and processes.
3. To establish through a survey the barriers and enabling factors to the uptake and delivery of sustainable retrofitted building projects.
4. To ascertain options that make decision-making easy or difficult when delivering sustainable retrofitted building projects.
5. To establish a sustainable retrofit process order of application through a survey in order to assist in developing a sustainable retrofit building process (SRBP).
6. To ascertain through semi-structured interviews the critical enablers and barriers to the uptake and delivery of sustainable retrofitted building projects.
7. To determine and report the extent to which key stakeholders capture knowledge during and after retrofitted building projects.
8. To develop a sustainable retrofitted building decision support framework (SRBDSF) with knowledge management principles and procedures.
9. To test and validate a sustainable retrofitted building decision support framework.

The ensuing section summarises how the research objectives were delivered.

1.8 Research method summary

This research involves a mixed-method approach in order to deliver the aim and objectives of the research. The mixed-method approach is a combination of both quantitative and qualitative research approaches for the collection of data. The most appropriate result analysis strategies were identified and employed to analyse the research findings. Figure 1.1 highlights the research design flow and output that consists of six stages. Figure 1.1 depicts briefly how the research aim and objectives were delivered.

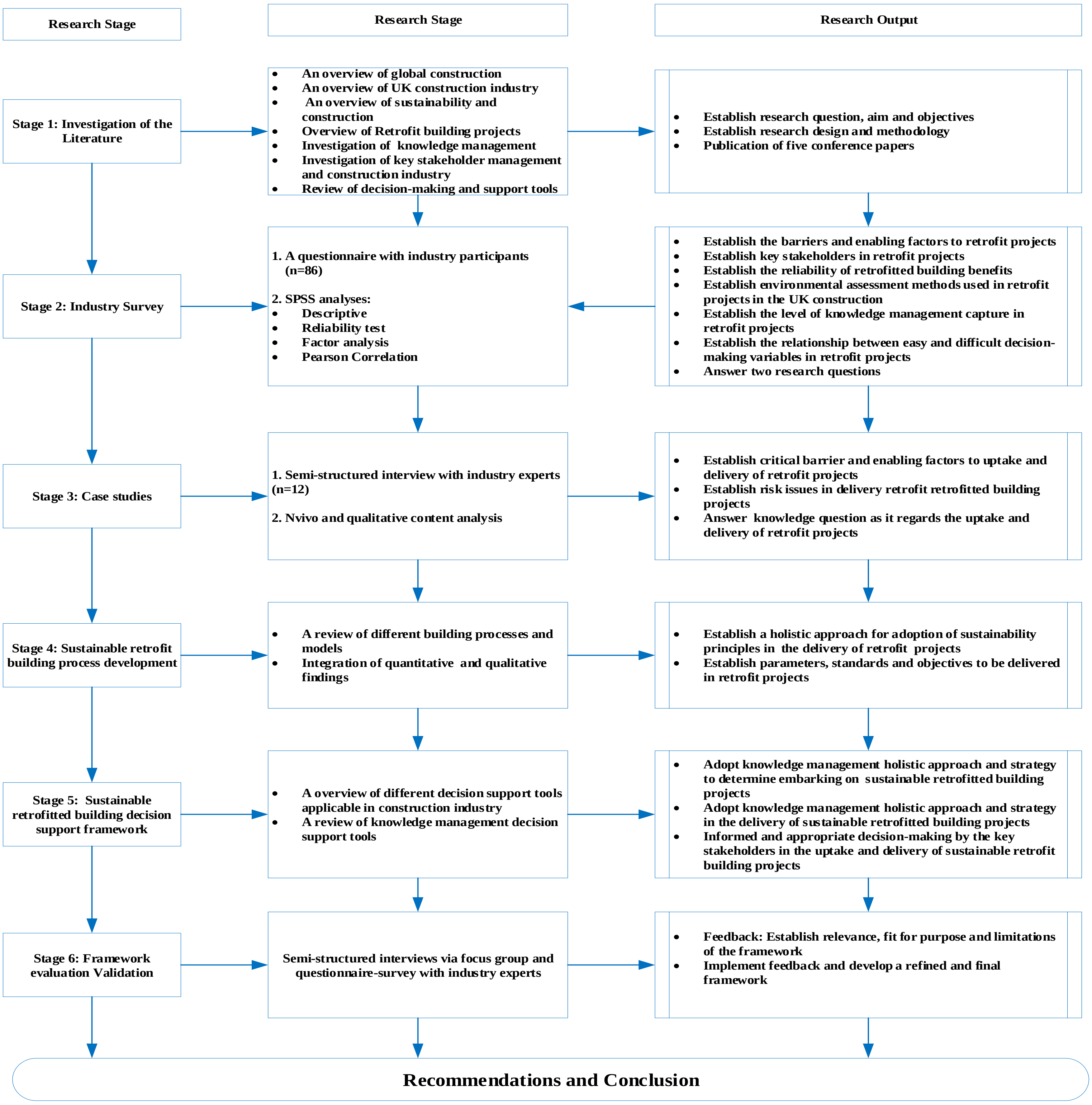


Figure 1. 1 Research design flow and output

The *first stage* is a literature review investigation of current practices and previous research in the areas of the global construction industry and UK construction; sustainability; environmental impacts of construction; sustainable construction; sustainable retrofitting; benefits of sustainable retrofitted buildings; environmental assessment methods; barriers and enablers of retrofitted building projects; knowledge management and the construction industry; stakeholder management and the construction industry; decision-making and decision support tools. These investigations set solid theoretical underpinnings that determine the research questions and research methodology of the current research.

Stage 2 involved conducting an industrial survey using a questionnaire for data gathering. The industry survey explored and determined the key stakeholders in retrofit projects; benefits of sustainable retrofits; environmental assessment methods; barriers and enablers of retrofit projects; knowledge management issues in retrofit projects; and factors that contribute to easy or difficult decision-making in delivering retrofit projects. The researcher employed Statistical Package for the Social Sciences (SPSS) to analyse the data. The statistical inferences employed in the analysis include descriptive, reliability test, factor analysis and Pearson correlation.

Stage 3 investigates and determines the critical barriers and enabling factors in the uptake and delivery of sustainable retrofit projects. Secondly, it establishes the risk factors in delivering sustainable retrofit projects. Thirdly, at this stage some knowledge management questions regarding the delivery of sustainable retrofit projects are answered. Some of the answered questions in the chapter include what knowledge and knowledge management means to stakeholders; the role of knowledge; the relevance of knowledge; access to knowledge; knowledge capture and the role of knowledge in enhancing decision-making. These were achieved through multiple case-studies using the semi-structured interview. NVivo and qualitative content analysis were employed in analysing the findings.

Stage 4 this stage involved the development of sustainable retrofitted building process (SRBP). This was developed with the output of Stages 1, 2 and 3. The development involved establishing the principles, standards and parameters of sustainability to be adopted in delivering sustainable retrofitted building projects.

Stage 5 comprises the development of a decision support framework for the sustainable retrofitted building project. This was achieved using the output of Stages 1, 2, 3, 4 and 5. It is pertinent to note that the framework development is knowledge management based. Thus, the researcher employed holistic knowledge management principles and procedures in developing the framework.

Stage 6 involves the validation of the framework by the industry experts that partook in the data collection. Validation was needed to determine the relevance and applicability of the framework in the delivery of sustainable retrofitted building projects. In addition, the validation established the limits and benefits of the framework. The feedback obtained from the validation will be useful for a future research study. The framework contributed to the recommendations and conclusions of this research.

Further details on the research design are seen in Chapter 5 of this thesis. In addition, the analysis of the research findings is seen in Chapters 6 and 7 of this thesis.

1.9 Thesis outline

The thesis consists of nine (9) chapters as highlighted in Figure 1.2.

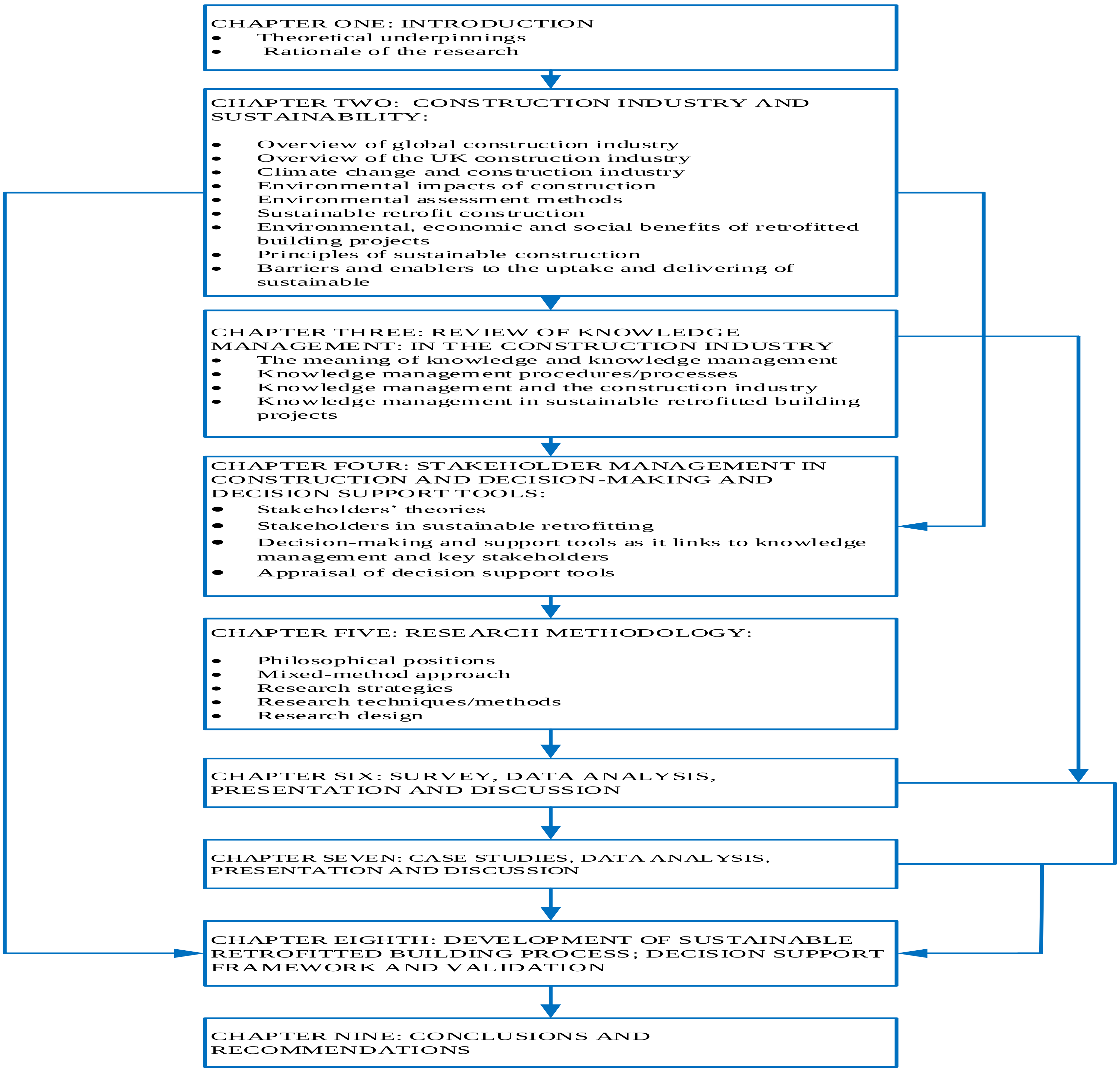


Figure 1. 2 Thesis structure framework

Chapter One: consists of the introduction of the research establishing the theoretical research underpinnings; rationale of the research; research aim, objectives and questions; research scope and research flow and output.

Chapter Two: in this chapter, a critical literature review of the global and UK construction industry is undertaken. It also consists of an investigation of the literature in regard to construction and sustainability. The investigation of the literature covers climate change and the construction industry; environmental impacts of construction; environmental assessment methods; sustainable retrofitting; sustainable principles and practices; environmental, economic and social benefits of sustainable retrofitted buildings; and barriers and enablers to embarking on and delivering sustainable retrofitted building projects.

Chapter Three: this chapter involves the investigation of the literature in regard to knowledge and knowledge management in the construction industry, which includes amongst others, knowledge management procedures and principles and the need for knowledge management in delivering sustainable retrofitted building projects.

Chapter Four: this chapter presents the review of the literature as regards stakeholder management in the construction industry. The review covers stakeholder management in the construction industry, who the stakeholders are; identification of stakeholders in construction projects; the essence of stakeholders in construction projects; roles of construction stakeholders and the key stakeholders in sustainable retrofitted building projects.

Chapter Five: this chapter presents the research methodology. Following the investigation of literature in Chapters 2, 3 and 4. This chapter provides an outline of the research methodology adopted for undertaking this research. The review of research methodologies covered the adoption of ‘research onion’ as a guiding step in the methodology. The chapter discussed the philosophical underpinnings and standings of the research which consists of the ontological and epistemological standings of the research. This chapter also consists of the literature investigation of research approaches; strategies; and techniques. In this chapter, rationales for choosing mixed-method as a research approach; survey and case studies as research strategies; and research techniques are all discussed. The research design in this chapter reflects the guide to delivering the research methodology.

Chapter Six: this chapter consists of the industrial survey findings; analysis; presentations and discussion. SPSS was employed for statistical result analysis. The statistical analysis presented in this chapter includes descriptive analysis; reliability test; factor analysis and Pearson correlations.

Chapter Seven: this chapter comprises of the case studies findinga; analysis; presentations and discussions. It employed NVivo and qualitative content analysis in analysing the multiple case study results. The rationale for the use of NVivo and qualitative content analysis can be found in this chapter.

Chapter Eight: this chapter comprises of the development of sustainable retrofitted building process (SRBP). Chapters 2, 3, 4, 6 and 7 contribute to SRBP development. Also in this chapter, the researcher developed a sustainable retrofitted building decision support framework (SRBDSF). Chapters 2, 3, 4, 6 and 7 contribute to SRBDSF development. The validation of the framework through a mixed-method approach is presented in this chapter.

Chapter Nine: this chapter consists of a discussion of the research and its outcomes, recommendations and conclusions. Inclusively, contributions to knowledge and originality, research limitations and the possibilities of further research are also presented in this chapter.

CHAPTER 2: THE CONSTRUCTION INDUSTRY AND SUSTAINABILITY

2.1 Introduction

The construction industry is vital worldwide, and particularly in the United Kingdom, in its significant contribution to GDP and job creation. The output of the construction industry, be it public buildings, commercial buildings, homes, or infrastructure is felt everywhere in society. The construction industry makes an outstanding contribution to the competitiveness and prosperity of any economy. Firms throughout the global economy are dependent on the performance of built infrastructure, such as roads, rail, power stations, and telecoms networks to remain competitive, and investors will consider the quality of the built infrastructure as one of the key considerations in selecting a location. However, the impacts of construction in society are well documented (RICS, 2005a; Pitt *et al*., 2009; Hultgren, 2011; USGBC, 2016), and these negative impacts have contributed to the climate change challenge through the emission of greenhouse gases into the atmosphere.

Shen and Tam (2002) state that construction is not, by nature, environmentally friendly. The industry, by its size, is one of the largest users of energy, material resources, water and is significant polluter of the environment. The extent of its impact is still being debated because information and data about the environmental impacts of the construction industry are still not being collected and analysed systematically (Horvath, 2004). The impacts of construction activities contribute mostly to climate change. Climate change, also referred to as global warming, has necessitated a universal need for a solution: hence, the birth of sustainability. Sustainability, which was coined into sustainable development, has three aspects include environmental, economic, and social.

However, the construction industry must not only comply with the ever-growing number of environmental rules and regulations, but must also apply principles of sustainable construction in each construction project and activity as has been globally advocated to deliver the benefits of sustainable construction, particularly sustainable retrofitted building projects. Modern, efficient construction is a key driver of productivity, and the construction industry has a major role in delivering construction projects in an innovative and energy efficient way. The industry’s productivity also depends on the efficiency and nature of the built environment. Key stakeholders in sustainable retrofitted building projects need to proactively promote the aspects of sustainable development and integrate it into sustainable retrofit projects in order to deliver the benefits of sustainable construction, essential for sustainable living and future generation. It is relevant to understand that delivering sustainable retrofit projects is essential primarily in the United Kingdom, where it is estimated, as aforementioned, that more than 75% of required buildings have been built (Existing Home Alliance, 2010; English Heritage, 2012). However, barriers to delivering sustainable retrofitted building projects exist primarily due to the lack of project knowledge management in delivering sustainable retrofit projects (Maduka *et al*., 2015a). Hence, there is a need for the industry to apply knowledge management principles and approaches when making informed decisions in retrofit project delivery.

This chapter reviews the characteristics of global and the UK construction industry. It also discusses the climate change issue, impacts of construction, the emergence of sustainable development and the construction industry, sustainable construction, sustainable retrofit, sustainable construction practices, the benefits of sustainable retrofitted buildings, and barriers to embarking on and delivering retrofit projects. This review is by no means exhaustive but demonstrates the nature of the industry and associated challenges and solutions to delivering retrofit projects.

2.2 Global construction

Construction, and the ability to build, is one of the most ancient of human skills. In prehistoric times, it was one of the talents ascribed to homosapiens aside other species. Humans struggled to survive and sought shelter from the elements and hostile environment that surrounded them by building protective structures (Halpin *et al.*, 2010). However, the construction industry, from a global perspective, has been argued as one of the oldest internationalised economic sectors, which can be traced back to more than 100 years ago (Low and Jiang, 2004). A similar review by Ngowi *et al.* (2005) points out that, in traditional societies, construction relied on the environmental resources of land and was an activity in which all members of the community participated to create shelter, which reflected a precise and detailed knowledge of local climatic conditions and a reasonable understanding of the performance characteristics of the construction materials available.

Colean and Newcomb (1952), Lange and Mills (1979) and Bernold and AbouRizk's (2010) assessment of the construction referred to it as an aggregation of businesses engaged in closely related activities. Nam and Tatum (1989) suggest that, historically, construction applies to all activities associated with the erection and repair of fixed structures and facilities. Similarly, Wells (1985) describes construction as an activity involving the creation of physical infrastructure, superstructure and related services.

However, Halpin *et al*. (2010) state that there are three sectors of construction: buildings, infrastructure and industrial. Building construction is divided further into residential and non-residential (commercial/institutional). Hapin *et al.* (2010) also state that infrastructure is often called heavy civil or heavy engineering that includes large public works, dams, bridges, highways, railways, water or wastewater, and utility distribution. Industrial construction comprises refineries, process chemicals, power generation, mills and manufacturing plants (Chitkara, 1998). In a review of statistics on construction in the United Kingdom, 'construction' was interpreted to mean the resources directly used in construction, the products of construction activity, financial and operational aspects of the building materials and construction industries (Ofori, 1991). Considering the participants in the construction process, Ofori (1991) portrayed the industry as a series of related, but discrete, activities, persons or organisations as shown in Figure 2.1

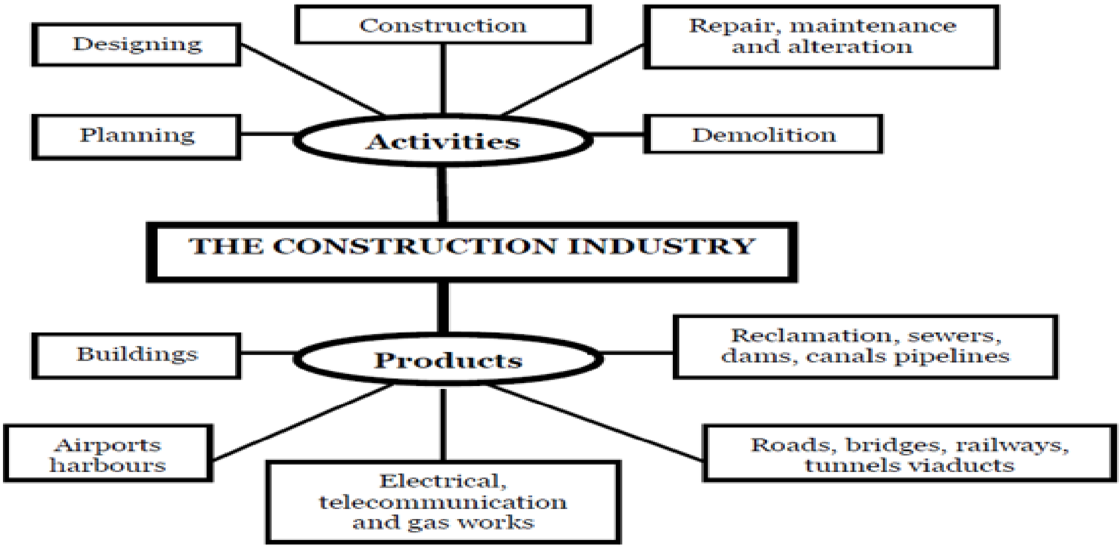


Figure 2.1 Construction industry (Ofori, 1991)

2.2.1 Global construction output and gross domestic product

The significant increase in urbanisation has generated an economic shift from west to east and changing demographics that point towards an increasing level of construction output during the next decade. CISION (2016) global construction will experience one of the most significant market growths compared to other industries in the next decade. Emerging markets and the US rebound will drive this growth. In similar revelation, CIC (2017) argued that construction is likely to be one of the most dynamic industrial sectors in the next fifteen years and is utterly crucial to the evolution of prosperous societies around the world. The construction industry is capable of creating vast numbers of new jobs and significant wealth for some countries across the globe. According to Sleight (2013) construction output accounts for 10% of Global GDP, which is estimated to be US$75 trillion; hence, global constructions are estimated at US$ 7.5 trillion. In a similar disclosure, Hook (2017) asserts that the construction sector is a vital part of the global economy and currently accounts for more than 11% of global GDP. However, a report predicts that it will account for 13.2% of world GDP by 2020 (PwC-Global, 2011), while 13.5% was predicted by 2025 (GCPOE, 2013).

However, by 2030 it has been predicted that the average global construction output growth will be about 3.9% per year outpacing that of global GDP by over one percentage point, driven by developed countries recovering from economic instability and emerging countries, which is expected to continue to industrialise (GCPOE, 2017). In its publication, IECONOMICS (2017) reported that the US is in the first position as the country with the highest GDP in construction; in second position is North Korea, and third is China. In the same publication, Paraguay was rated as the country with the lowest GDP from construction, followed by Kenya; the third position belongs to Japan. While global construction and Oxford Economics predicts that in 2025 China will lead in terms of GDP, the US will be in the second position; India, Japan, Indonesia and Russia will be in the 3rd, 4th, 5th and 6th positions, respectively. Global construction output reached US$8.8 trillion in 2016 up from US$7.9 trillion in 2012 and will stand at about US$10.1 trillion in 2021 (PwC-Global, 2017). Meanwhile, GCPOE (2013) estimated that, in 2025, the global output would be approximately $15 trillion, although this may not be realisable due to the dwindling crude oil market. The value of construction projects in the emerging market, which includes Brazil, Russia, Turkey and India, surpassed that of advanced economies as predicted in 2014, and this difference will continue to widen.

Nevertheless, in 2012, emerging markets accounted for 46.7% of global output, and this is expected to the rise to 52.8% by 2021 (PwC-Global, 2017). A study conducted by market research firms Global Construction Perspectives and Oxford Economics forecast that US$97.7 trillion will be spent on construction globally during the next decade and the sector will expand by 5.2% on average every year, outpacing global GDP growth (PwC-Global, 2011). GCPOE (2017) predicts that, globally, construction will grow more rapidly than the overall economy, with developed markets expected to rebound from their depressed levels. Explaining further, they stated that many countries would not be back to their previous peak levels even by 2030. There was an emphasis that the current environmental and financial activities in most emerging countries are likely to be temporary, with higher growth rates soon returning. The ensuing sections have further discussions on worldwide construction predictions.

2.2.2 Global construction market trend and prediction up to 2021

Global Construction 2020, a major global study into construction, predicts that global construction will grow by 67% from $7.2 trillion to $12 trillion by 2020 (PwC-Global, 2011). Growth in China, India and the US will account for over half of the predicted $4.8 trillion increase in global construction to 2020 (PwC-Global, 2011). In another publication, the CIC (2017) predicts that Asia-Pacific will continue to account for the substantial share of the global construction industry, given that it includes the vast markets of China, Japan and India. The publication further asserted that the worldwide construction output would stand at about $10.1 trillion in 2021 with the Asia Pacific at $4.8trillion (3.3%), Western Europe at $2.1 trillion (2.4%), North America accounting for $1.6trillion (1.9%), Latin America at $646 billion (2.1%) and the Middle East and Africa at $502 billion. Although the predictions are slightly different in figures, the similarities point to the apparent growth expected in the global industry from 2017 to 2020/21.

PwC-Global (2011) and PwC-Global (2013) predictions state that Canada and Australia would also lead construction growth in developed countries, boosted, in particular, by demand for natural resources and favourable demographics.

The publication further revealed that the combined expansion in construction in Canada and Australia would almost equal growth in the entire Latin American construction market, including Mexico, Brazil, Argentina, Chile and Colombia, indicating its less bright prospects. The publication further stated that China, India, United States, Indonesia, Canada, Russia and Australia would account for 65% of the growth in global construction to 2020. There has been a contrary prediction on Australia in that the expected construction boom is over-predicted mainly due to slow investment in the mining industry; hence, it will impact on construction by slowing 4.3% as at 2012 to 1.3% by 2025 (GCPOE, 2013).

Global-Insight (2017) stated that Asia accounts for 46% of the global market, Western Europe 23%, North America 18%, South America 5%, the Middle East and Africa account for 4% and Eastern Europe 4%. The pace of expansion in the global construction industry stabilised in 2016, standing at 2.4%, but there will be an improvement over the next five years, with an average growth of 2.8%. The pick-up will reflect trends in the broader economy; during the period 2017–2021, the world economy is set to expand by almost 3% per year on average (CISION, 2016).

PwC-Global (2011) and GCPOE (2013) in its publication emphasised that China and India would drive growth in emerging markets as rising populations, rapid urbanisation, and strong economic growth are key drivers for construction. China’s construction market will more than double in size over the decade to $2.5 trillion by 2020, or 21% of world construction. The report predicts that India will overtake Japan to become the world’s third largest construction market by 2018. The US will experience a sharp cyclical rebound in construction with short-term double-digit growth in both residential and non-residential building sectors. However, seven countries, which are China, the US, India, Indonesia, Canada, Australia, and Russia will contribute to the two-thirds of the growth in global construction to 2020 (GCPOE, 2013; Hook, 2017).

Considering the expected global growth, the construction industry needs to work out how to deploy skills and develop the best coalitions to benefit the industry from the exciting growth opportunities that exist and being predicted (Hook, 2017). Figure 2.2 highlights a more global outlook of construction in developed countries.

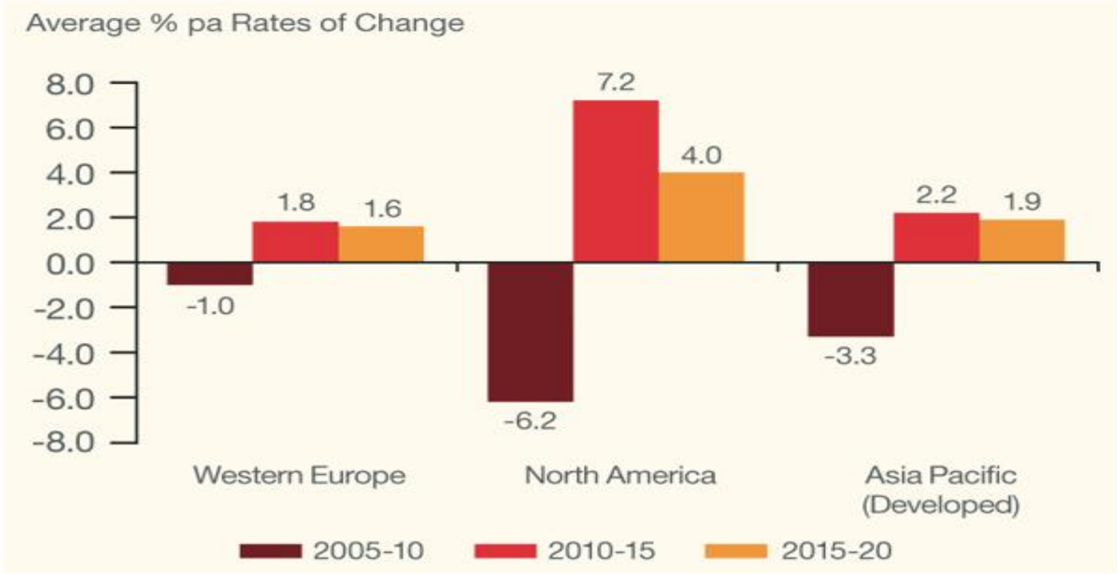


Figure 2.2 Construction output rate in developed countries (GCPOE, 2013)

Figure 2.2 explains the construction output of developed nations and the growth rate experienced between 2005 and 2020. It also highlights the downward trend of global construction during the 2008 recession that poorly affected the construction industry worldwide. It also deduces that North America will experience more growth from 2015 to 2020, followed by developed countries in the Asia Pacific and Western Europe. However, Figure 2.3 highlights construction output in emerging nations and percentage growth.

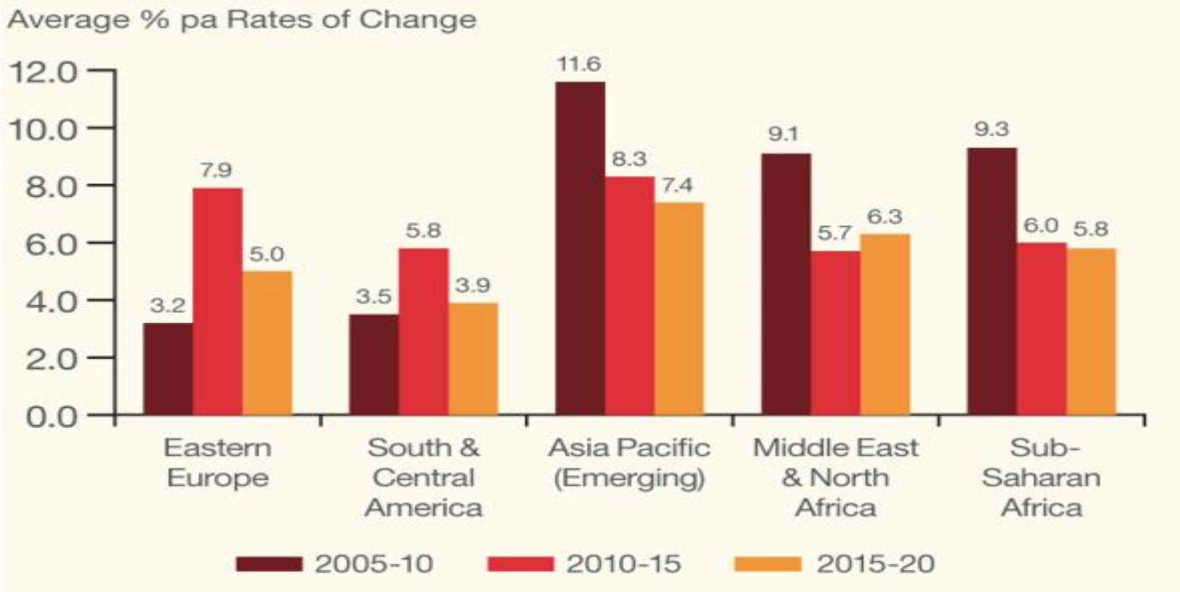


Figure 2. 3 Construction output rate in emerging countries (GCPOE, 2013)

Figure 2.3 indicates the construction output in the emerging countries, which includes Brazil, Russia, Turkey and India. In comparison to the developed countries, the 2008–2009 global recession did not have such an adverse effect. However, Eastern Europe had poor growth during the recession period. Meanwhile, emerging nations in the Asian Pacific are leading in the construction output and growth between 2010 and 2020. From 2015 to 2020, the Middle East and North America are leading after emerging Asian Pacific countries. Sub-Saharan Africa and Eastern Europe follow, respectively, for the years on view.

2.2.3 Global construction market trend and predictions up to 2030

PwC-Global (2017) describes the medium and longer-term prospects for the global construction industry, giving forecasts showing how the global construction industry will evolve as the recovery from the global financial crisis transitions into new opportunities, challenges and uncertainties by 2030. GCPOE (2017) in its publication highlights that China construction growth is too slow considerably with a slump in housing and the first ever decline in housing output, recorded in 2017. However, the report states that there is expected growth in construction in China regarding healthcare, education, and social infrastructure, including the retail market. In India, the publication affirmed that the construction market in India would grow almost twice as fast as China in 2030. The growth will be facilitated by India's urban population, which is expected to grow by an estimated extra 165 million by 2030, with an increase in population in Delhi predicted to be 10.4 million, indicating that it is the world's second-largest city, thus driving global growth in emerging markets (GCPOE, 2013; PwC-Global, 2017).

In the US, construction growth will incline towards the southern states, therefore, reflecting the region's exceptional catch-up potential and higher population growth (Global-Insight, 2017). In Europe, the UK is expected to have a significant increase until 2025, hence overtaking Germany to become the largest in Europe and the world's sixth largest construction market by 2030 (GCPOE, 2017). It is pertinent to note that while China, the US and India have been predicted to have a reasonable growth, there is an expected significant weakness in Brazil and Russia (on oil fall and sanctions), while Indonesia is predicted to have an extraordinary construction growth. Indonesia is expected to overtake Japan by 2030; however, Latin America and Mexico are expected to surpass Brazil (GCPOE, 2017).

According to GCPOE (2017) forecast, the volume of construction output will grow by 85% to $15.5 trillion worldwide by 2030, with three countries, China, US and India, leading the way and accounting for 57%, which is about $8 trillion of all global growth. The US construction market is expected to grow faster than China over the next 15 years, despite its size. The publication further asserted that India would provide a new engine of global growth for construction in emerging markets, growing almost twice as fast as that of China. Europe will not regain its ‘lost decade’, but reinstates that the UK will be continental Europe’s significant growth market, overtaking Germany to become the world’s sixth largest construction market by 2030 (CIC, 2017). China’s share of the world construction market will increase only marginally as growth slows in the world’s largest construction market by 2030. There is expected slow growth in China construction due to a slump in housing and the first ever decline in housing output recorded by China in 2016. The construction market in India will grow almost twice as fast as China by 2030, providing a new engine of global growth in emerging markets (Global-Insight, 2017; CIC, 2017; PwC-Global, 2017). In comparison, US construction will grow faster than China over the next 15 years expanding by an average of 5% per annum.

2.2.4 Potential risks in the expected global construction growth

There a number of fundamental risks to the projected global construction growth; most notably is how the Chinese authorities will rein in credit growth and manage the ensuing economic slowdown, and how investors in advanced economies will respond to the shift towards monetary policy normalisation, particularly in view of the likely pick-up in inflation as commodity prices bounce back (CISION, 2016; Global-Insight, 2017). Nevertheless, despite structural weaknesses and price pressures, the sector has become slightly less risky (PwC-Global, 2011). However, despite this current positive global trend, the industry is still one of the riskiest industries with several countries facing a negative outlook (Global-Insight, 2017; CIC, 2017; EHER, 2017). There is a possible risk for construction growth in key emerging markets including Brazil, Russia, Turkey and India, which could all suffer from significant short-term reductions in construction growth, with some of these countries potentially halving growth (GCPOE, 2013).

However, Han et al. (2010) state that much of the world’s construction, approximately 80% of the total volume, has been carried out by small-scale local builders who construct single houses or maintain roads over small areas, using very traditional materials and methods. Therefore, this implies that only 20% of the total volume of the world’s construction is considered a potential market accessible by foreign construction firms (NRC, 1988; Han and Diekmann, 2001; Han *et al*., 2010) hence, this may impact on growth. In a similar publication, PwC-Global (2011) predicted that large public deficits would constrain construction in most developed countries, austerity programmes, slow population growth, and limited economic expansion, except the US due to its growing population. EHER (2017) argues that since the construction sector remains mainly composed of small firms with very high advantage ratios, highlighted strengths and weaknesses could impact on global growth.

Strengths

- Long-term market opportunities in emerging countries for infrastructure and housing development;
- Stimulating impact of new environmental standards in mature markets;
- Global population growth and an increase in urbanisation rate; and
- Well-established major players.

Weaknesses

- Many small companies with fragile financial structures highly exposed to market fluctuation;
- Longer payment delays compared to the overall economy;
- Infrastructure investments postponed in emerging countries; and
- Dependency on national and household borrowing capacity linked to interest rate trends.

2.3 The United Kingdom’s construction industry

The UK’s construction industry is distinct; it is a large and highly diverse sector of industry activities. It has built Great Britain, and its monuments are evident. Its operations are concerned with the planning, regulation, design, manufacture, construction, and maintenance of buildings and other structures (Harvey and

Ashworth, 1997; Hook, 2017). Projects can vary from work worth a few hundred pounds undertaken by contractors, to significant schemes costing several million pounds such as the Channel Tunnel, which is an international joint venture, estimated to cost over £10bn (Banister and Thurstain-Goodwin, 2010). While the principles of execution are similar, the scale, complexity and intricacy vary enormously. The industry is viewed as having a narrow and broad definition regarding its size and structure (Pearce, 2003), Figure 2.4 explains shows the narrow definition focuses attention on the actual on-site construction activities of contractors, whilst the broad definition, which actually covers the true extent of the construction industry, draws in the quarrying of construction raw materials, the manufacture of building materials, the sale of construction products, and the services provided by the various associated professionals (Pearce, 2003).

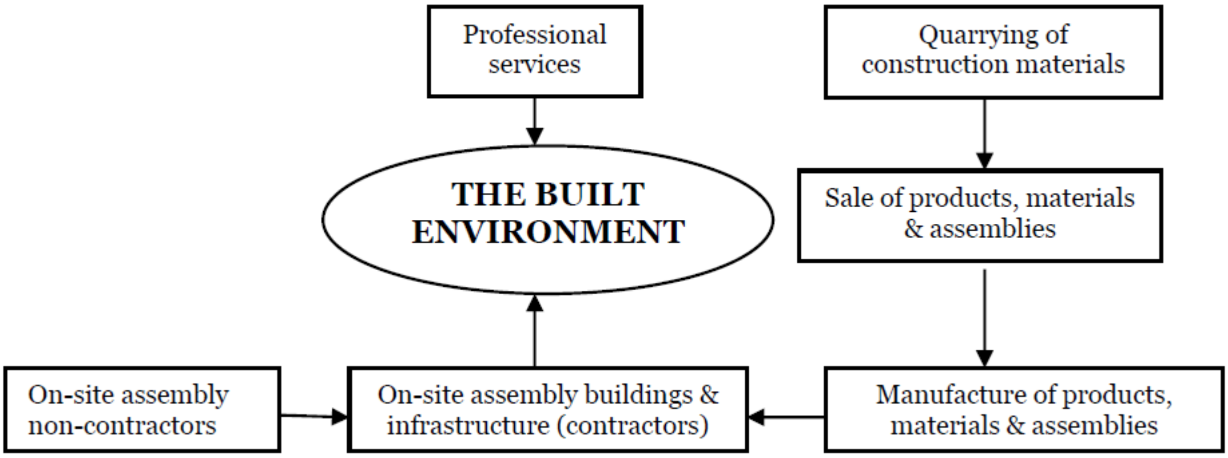


Figure 2. 4 The composition of the construction industry (Adapted from Pearce, 2003)

According to Ashworth (2006), the construction industry has characteristics that separate it from all other industries. These are:

1. The physical nature of the product;
2. The product is normally manufactured on the client’s premises, i.e. the construction site;
3. Many of its projects are one-off designs and lack any prototype model being available;

4. The arrangement of the industry, in which the design has typically been separate from construction;

5. The organisation of the construction process; and

6. The methods used for price determination.

These characteristics mean that the delivery of the built environment is project based with the involvement of numerous participants whose responsibilities are set out in contracts. There is also limited control over the production environment (Ashworth, 2006). The risk and uncertainty associated with these methods of production and price determination also mean that margins are thin, uncertain, and easily eroded, and consider the fact that an individual project can often represent a large proportion of the turnover of a participant in any year (Harvey and Ashworth, 1997; Fellows *et al.*, 2002). Hence, there is inevitably mistrust among the participants because firms are struggling to avoid making a loss, and, as a result, relationships are often very confrontational. Notwithstanding these challenges, the UK construction industry is still very economically significant, and its contribution to the economy is examined in more detail below.

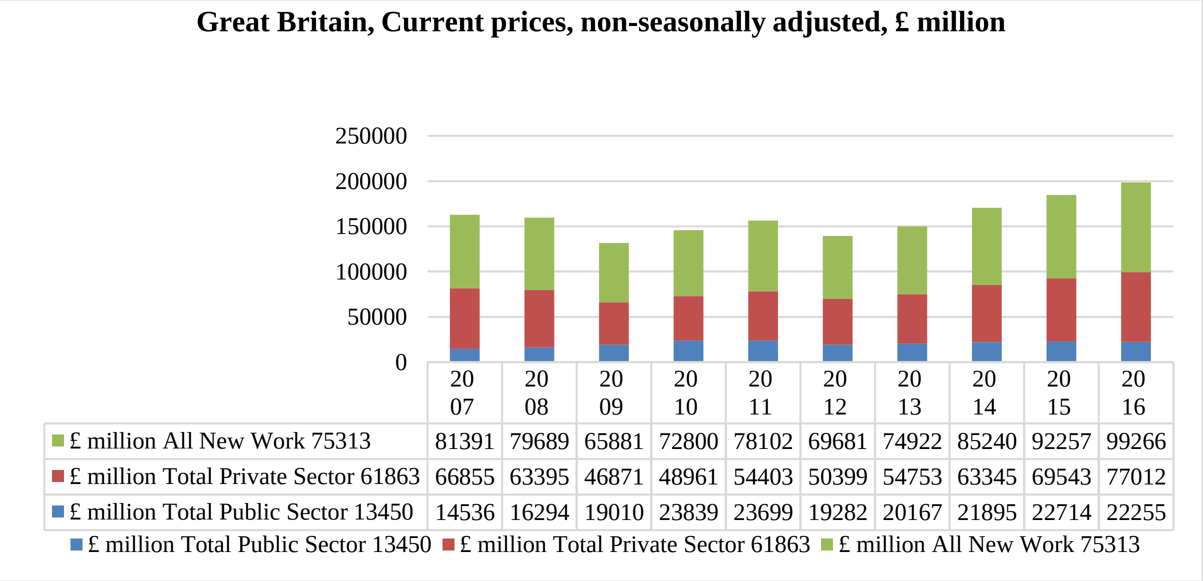
2.3.1 Economic significance of the United Kingdom's construction industry

The UK's construction industry is renowned for its intricate and dynamic industrial environment. It is highly responsive to the economy, especially regarding new construction, and is often used as a key indicator by economists (Telegraph, 2008; Morgan *et al.*, 2008). In examining the significance of the construction industry, various indicators can be employed as the basis of analysis. Among these is output, employment and skills shortage. As highlighted by Pearce (2003), each of these indicators reveals part of the story that is relevant to our understanding of the state of the construction industry. The distinction between the broad and narrow definitions also becomes very significant when examining these indicators. The construction industry is one of the supporting pillars of the UK economy. While initial thoughts may throw up images of hard hats and builder's behinds, the industry is far-reaching and covers areas such as architecture, civil engineering and manufacturing (Hook, 2017). Due to the high cost/high-risk nature of construction, the industry is a good barometer of how the broader economy is performing. A struggling economy sees a slowdown in new projects, while the UK, in recovery, will result in a surge of investment. Despite these many economic fluctuations in the UK, construction has always been a stable source of revenue and falls only behind manufacturing and the service sectors as the country's leading contributor of gross value added (GVA) (ONS, 2015).

2.3.2 The United Kingdom’s construction output and gross domestic product

Another useful indicator of the economic significance of construction is the contribution to the UK’s Gross Domestic Product (GDP). Construction is a high cost, high risk, long-term activity; hence, its performance is a good indicator of the health of the wider economy. When the economy falters, construction investment grinds to a halt, but when the economy begins to recover, the construction industry can quickly rebound (Design-Building, 2017a). Design-Building (2017a) and Trading-Economics (2017) affirmed that, in the UK, construction output measures account for the yearly change in the amount charged by construction companies to customers for the value of work. The publications explained that the value is based on the sample of 8,000 businesses, employing over 100 people or with an annual turnover of more than £60 million. Construction estimates are a component of GDP from the production approach, contributing approximately 6.4% of GDP. Pearce (2003) estimated this to be about 5% GDP since 2002 for contractors (the narrow definition) and 10% for the broader definition. Construction output in the UK is more than £110 billion per annum and contributes 7% of the GDP (Cabinet Office, 2011). In 2014, the industry generated £103 billion, a figure that equates to nearly 6.5% of the UK's total output (Agency-Central, 2017). Approximately a quarter of construction output is public sector and three-quarters private sector (Design-build, 2017). In 2009, the construction industry received total orders of around £18.7 billion from the private sector and £15.1 billion from the public sector (ONS, 2010). While manufacturing in the UK shrank as a proportion of the economy between 1948 and 2013, replaced by the service sector, construction remained approximately flat at about 6% of the economy (ONS, 2014, The-Guardian, 2014). Figure 2.5 further explains the output of the construction industry in the UK from 2007 to 2016.

There are three main sectors of construction, including commercial and social, which contribute to approximately 45% of the construction output, followed by residential and infrastructure, which account for 40% and 15%, respectively (Cabinet-Office, 2011). Nevertheless, around 60% of construction output is new builds, while 40% is refurbishment and maintenance (Cabinet-Office, 2011; Design-Building, 2017d). The construction output in the UK grew sharply by 3.5% year-on-year in August 2017, beating market expectations of 0.2% again and following an upwardly revised 2.7% increase in previous months (ONS, 2017b). All work jumped 3.7% (1.9% in July 2017), driven by an 8.5% gain in all new housing and a rebound of 4.9% in infrastructure output (ONS, 2017a). Meanwhile, all repair and maintenance went up at a softer pace (3.3% from 4.2% in July) (Design-Building, 2017d). Every month, construction output went up 0.6%, mainly boosted by a 1.7% rise in all new work. Construction output in the UK averaged 2.03% between 1997 and 2017, reaching an all-time high of 24% in March of 2002 and a record low of -19.20% in January 2010 (Trading-Economics, 2017). Figure 2.5 explains further the output of the construction industry in the UK between 2007 and 2016.



	20 07	20 08	20 09	20 10	20 11	20 12	20 13	20 14	20 15	20 16
🟩 £ million All New Work 75313	81391	79689	65881	72800	78102	69681	74922	85240	92257	99266
🟥 £ million Total Private Sector 61863	66855	63395	46871	48961	54403	50399	54753	63345	69543	77012
🟦 £ million Total Public Sector 13450	14536	16294	19010	23839	23699	19282	20167	21895	22714	22255

Figure 2.5 All new work is broken down into public and private sectors, 2007 to 2016 (Adapted, ONS, 2017)

From Figure 2.5, one can deduce that the value of all new work increased to £99,266 million in 2016, the highest level on record during the year investigated. The publication states that this increase in all new work has occurred notwithstanding the public sector output decreasing in 2016. With historically low interest rates, continuing to facilitate private sector investment in the industry, the marginal fall in public sector work has been far outweighed by the continuing expansion of the private sector, with growth coming from the housing sector in particular. The UK economy is made up of four main areas: services, production, construction, and agriculture. Construction also influences some of the leading economic indicators, including inflation and gross domestic product (GDP). In the UK economy, the service sector makes up 79.3% of GDP, construction contributes 6.1%, while production and agriculture equate to 14.0% and 0.7% respectively (these percentages sum up to 100.1% due to rounding) (ONS, 2017a). Figure 2.6 explains the GDP growth of the construction industry in the UK from 2010 to 2016.

Figure 2.6 GDP and construction output quarterly volume growth rates, 2010 to 2016: Chained volume measure, seasonally adjusted, United Kingdom (Adapted ONS, 2017)

From the ONS publication, Figure 2.6 Q1 refers to Quarter 1 (Jan to Mar), Q2 refers to Quarter 2 (Apr to June), Q3 refers to Quarter 3 (July to Sept), and Q4 refers to Quarter 4 (Oct to Dec). In Figure 2, the publication compares the growth in the construction industry in comparison with GDP as a whole in volume terms. The volatility of the construction industry is evident; expansions and contractions in construction exaggerate small fluctuations in GDP. Since 2013, growth in the construction industry has been broadly positive, with only one-quarter of negative growth coming in Quarter 3 (July to Sept) 2015 (ONS, 2015).

2.3.3 The future outlook of construction in the United Kingdom

However, the future outlook of the construction industry comes with uncertainties. in its forecast, the CPA (2017) emphasises that there is an expected increase in infrastructural activity and private house building; these will be primary drivers of growth over the next two years, which will help offset a sharp fall in the commercial and industrial sectors. The publication further highlights that growth in infrastructure would be due to significant projects in rail and water and sewerage such as HS2 and the Thames Tideway Tunnel, with an activity forecast to grow by 7.4% in 2017 and 6.4% in 2018. Growth will be reliant on the delivery of these projects, and the extent of the continued delays to major works at Hinkley Point C has resulted in it no longer being included in the Construction Product Association (CPA) prediction. The Barbour-Abi (2017) publication states that on all contracts, activities show that August 2017 witnessed an increase in the construction level, with a value of contracts awarded at £5.8 billion, based on a three-month rolling average with the London region accounting for 20% (the highest in all the regions) of the overall region.

The publication further explains that the estimates reflect a 7.4% increase from July 2017 and a 4.7% increase in the value recorded in August 2016. Hence, the number of construction projects increased by 19% in July and were higher than in August 2016. However, ONS (2017a) and the Financial Times (2017) in a closely watched business survey revealed that UK construction sector growth slowed during June 2017, as the political uncertainty of the Brexit negotiations and concern about the economic outlook deterred new orders. There were signs that UK construction firms are bracing for the easy patch to continue into the autumn, with fragile business confidence contributing to weaker trends for job creation and input buying (Financial Times, 2017). According to ONS (2017a), output in the construction industry decreased by 1.3% in the second quarter of 2017 due to a decline in new commercial work. In similar publications, CPA (2017), the Financial Times (2017) and Skynews (2017) stated that the purchasing managers' Index (PMI) showed a significant decrease in building works, and this was argued to be the weakest overall UK construction performance since August 2016.

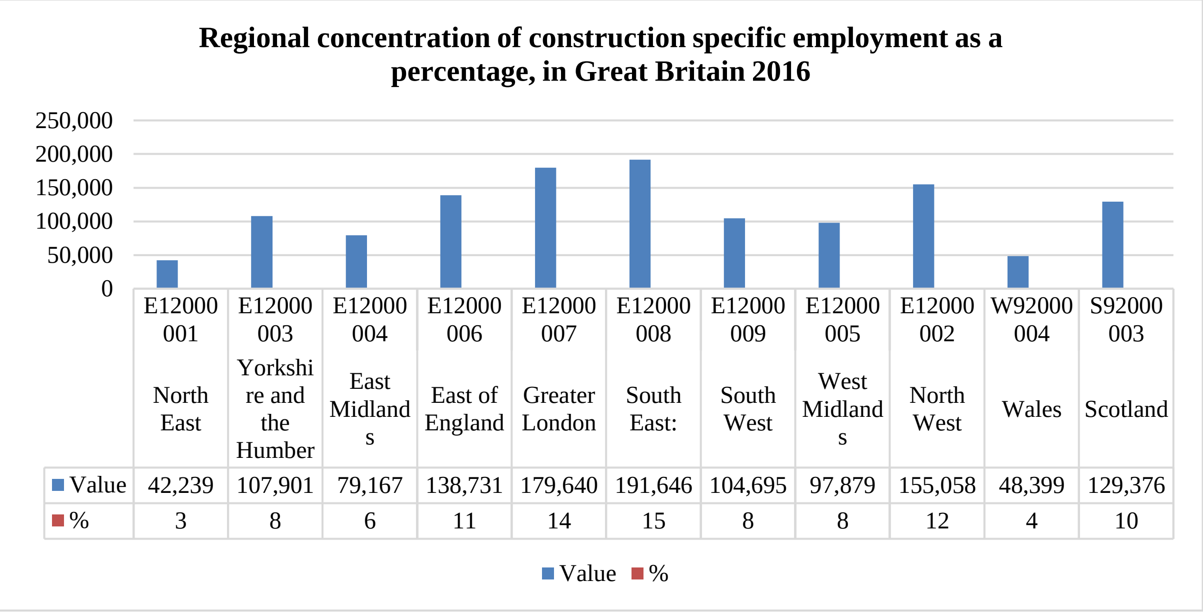
The Financial Times (2017) publication revealed that the UK construction and infrastructure market survey showed that financial constraints, due to economic uncertainty, primarily driven by Brexit, were noted as the most significant impediment to building activity. In the publication, it was revealed that ‘clients' were reluctant to invest in new projects, choosing instead to delay spending decisions, and in some cases, scaling back planned ventures. However, Sky News (2017) revealed in a survey conducted by Markit/Chartered Institute of Purchasing and Supply UK Construction, the downside of the currency plunge, with firms linking higher costs to rising prices on imported raw materials and the exchange rate, hence, affecting construction output.

In a similar study, the GCPOE (2013) states that the CPA revealed that imports largely follow construction output in the UK; however, exports fluctuate. The study further explains that one of construction industry’s key targets by 2025 is to achieve a 50% reduction in the trade gap between total exports and total imports of construction products and materials. Hence, it was asserted that closing the gap by 50% will require the industry to increase exports by about £3bn over the next 12 years. Nevertheless, it can be argued that reduced government spending and economic and Brexit uncertainty were to blame for the industry’s poor performance. In the near-term future, without considering those new orders, the poor performance of the construction industry will likely continue. Hence, a recent survey indicates that the construction industry is ‘flirting with another recession’ (Sky News, 2017).

2.3.4 Employment and labour

The UK construction industry was estimated to have about 194,000 construction companies in 2009; from that figure, about 75,400 employed just one person and 62 hired over 1,200 people (ONS, 2010). As noted in a World Bank report on the wealth of nations, it infers that the output of any country, or in the context of this study the construction industry, fundamentally depends on its human resources, thus: ‘the skill, dexterity, and judgment of its labour’ (World-Bank, 1997). Although figures vary from source to source, it is estimated that between 1.4 to 2.0 million people are employed in the UK construction industry. Pearce (2003) states that, as of 2001, contractor employment was of the order of 1.7 million, accounting for about 6% of total UK employment. ONS (2009) estimates that there are 2.6 million construction employees who represent over 8% of all jobs in the UK, from highly skilled professionals through to lower skilled workers. A more recent publication by ONS (2017b) indicates that 2.1 million people work in the industry, and despite occasional drops caused by recessions, employment figures have remained relatively constant over the last decade. The industry accounts for approximately 3 million jobs, 10% of total UK employment (HMG, 2013); this includes both manufacturing and services (Design-Building, 2017a).

According to DBIS (2013) the industry is made up as follows: (a) Contracting, 2,030,000 jobs, 234,000 businesses; (b) Services, 580,000 jobs, 30,000 businesses; and (c) Products, 310,000 jobs, 18,000 businesses. CSN (2017) state that lower-skilled workers (trades and operatives) represent approximately 63% of the UK's construction workforce. The publication revealed that the representation also varies by region, with Northern Ireland (75%) and the North East (72%) having the most substantial proportion of lower-skilled workers. Across all regions, lower skilled workers represent more than 55% of the regional construction workforce. The labour market characteristics of the construction industry are unique, with a high self-employment rate, making up approximately 40% of the workforce, the largest proportion of self-employed workers in the UK's industrial makeup (ONS, 2009, UK Construction, 2015). These levels, which are high compared to other industries, can be explained by the high rate of subcontracting in the industry, as 'main contractors use subcontractors as a means of surviving the volatility of the construction business cycle' (Dainty et al., 2001). In addition, government policies have made the setting up of small businesses fiscally attractive (Edgell, 2006; HMTRC, 2009). Regarding the proportion of the UK labour market as a whole, the percentage of construction jobs have varied slightly since 2005, falling by nearly 1% (Agency-Central, 2017). Figure 2.7 deduces the regional employment generation in the UK.



	E12000 001 North East	E12000 003 Yorkshire and the Humber	E12000 004 East Midlands	E12000 006 East of England	E12000 007 Greater London	E12000 008 South East:	E12000 009 South West	E12000 005 West Midlands	E12000 002 North West	W92000 004 Wales	S92000 003 Scotland
■ Value	42,239	107,901	79,167	138,731	179,640	191,646	104,695	97,879	155,058	48,399	129,376
■ %	3	8	6	11	14	15	8	8	12	4	10

Figure 2. 7 UK regional concentration of construction employment (Adapted, ONS, 2016)

The most substantial contributions to construction employment growth came from London and the South East, which together contributed 29% of construction employment in 2016. However, the most notable increase in 2016 came from Yorkshire and The Humber, which grew by 18.6% compared with 2015. The growth rate of Scotland increased, rising to about 13,500 in 2016 and contributing 10% of all construction employment in the UK. Irrespective of the jobs provided by private contractors in the UK, self-employment in the construction industry is becoming increasingly widespread. ONS (2017a) highlights the rise in popularity in self-employment in the economy as a whole; it is broadly reflected in the services sector, which has risen rapidly since 2008. The publication further states that the latest report on self-employment in the construction sector equates to more than the agriculture and production sectors collectively.

Furthermore, relating Figure 2.7 to the regional concentration of firms, the number of employees and companies in each region are, in most cases, directly relatable, i.e. a higher number of firms in a region results in a higher number of employees. For example, the South East and London provide the most notable contributions to construction employment. However, in some areas, such as Scotland, this is not the case. Scotland contributes 6% of all construction firms in Great Britain while contributing 10% of all construction employment (ONS, 2017b). ONS (2017b) states that the overall rise in companies was driven by increases in England, where the number of construction firms rose to about 20,136 in 2016. This increase was due to consistent reliance on London and South East, alongside growth in the East of England and North West. The number of construction firms registered in Scotland and Wales increased marginally in 2016, but the number of construction organisations operating in these regions remains small compared to the rest of Great Britain as a whole (ONS, 2015). The industry remains a vital area for employment, the economy, and social growth; however, skill gaps are threatening to derail the industry from market recovery and growth.

2.3.5 Skills shortage in the United Kingdom's construction industry

The UK's construction industry is one of the country's leading economic drivers. However, a lack of expertise is becoming a challenge for a field that relies on its workforce more than most industries. Over the last decade, the construction workforce has fluctuated, but it peaked in 2007 with about 2.3 million people (Agency Central, 2017). However, since the 2008 recession, these numbers have fallen considerably, and nearly 400,000 jobs were lost following the stock market crash (Agency Central, 2017). Following the crash, construction organisation had the most challenging times, especially in employment, leading to a vast number of skill sets leaving the UK for jobs abroad.

The UK is currently experiencing an ageing population, and the construction sector is set to see more skill sets leave the industry than in any other area of work. In addition, there is a challenge in the sector regarding the ageing population. Around a quarter of the construction workforce is now over the age of 50, while 400,000 employees over 55 are planning to retire during the next decade (CIBT, 2013); this will increase the skills gap already experienced. Furthermore, the increase in the number of workers over the age of 60 is the largest of any age group in the sector, with the most significant drop off being in the under 30s (CIBT, 2013). While work experience is vital in any working environment, current trends suggest that the construction workforce will begin to decrease as new employees are incapable of meeting the demand left behind by retiring practitioners. Furthermore, Agency Central (2017) states that employers and professional construction recruitment agencies are experiencing, at first-hand, a lack of qualified candidates. The publication notes that the trade recruitment market is always complaining about the lack of skilled workers. The study conducted by the Federation of Master Builders FMB (2015) investigated the skills shortage problems. The result of the investigation shows that bricklayers were, by far, the most difficult to recruit in the third quarter (Q3) of 2015; carpenters/joiners, supervisors and site managers were also hard to come by while construction organisations found scaffolders the easiest to hire (see Figure 2.8).

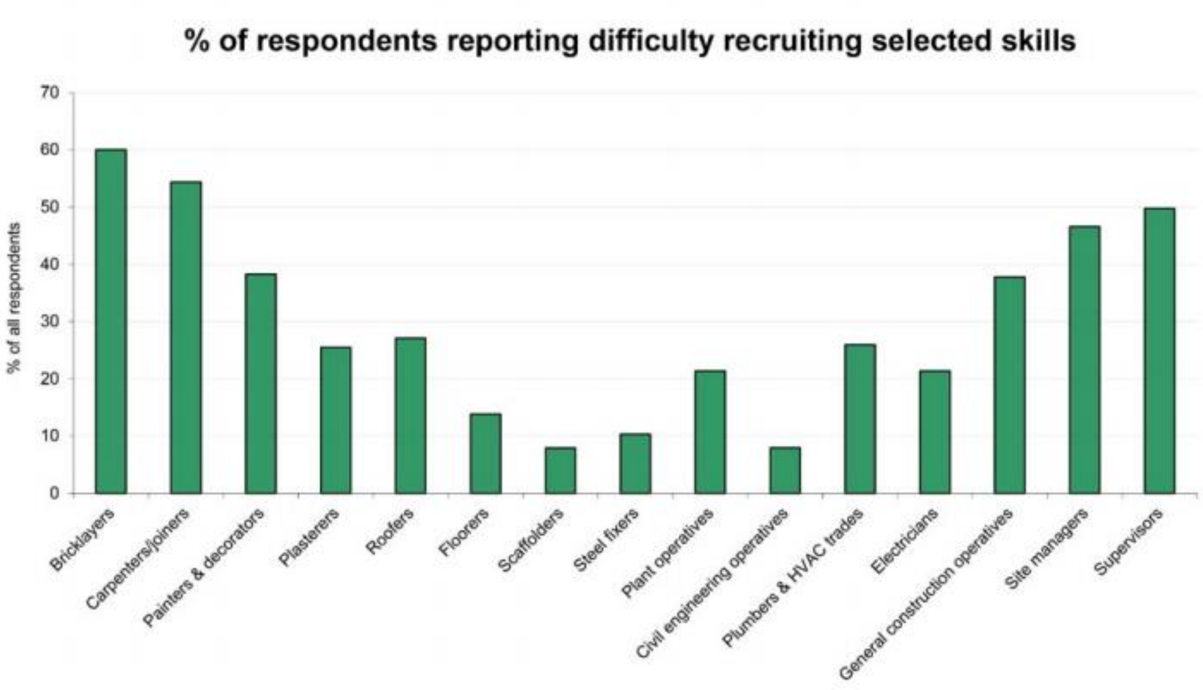


Figure 2.8 Selected skills recruitment difficulty experienced by construction organisations (FMB, 2015)

In another report by the Recruitment and Employment Confederation (REC), the skills shortage in the construction and engineering industry was described as 'critical' (Agency Central, 2017). Although the number of job opportunities is rising, the number of suitable candidates is not, and the Construction Industry Training Board (CITB) estimates that more than 36,000 new workers a year will be needed to cover current demand (CITB, 2017). The skill gap is very challenging because more than half of employers are finding it challenging to fill skilled positions as aforementioned. While current market conditions dictate any shortages, the Royal Institute of Chartered Surveyors (RICS) has predicted that this lack of skills could impact 27,000 construction projects each year until 2019 (Agency-Central, 2017). UK construction

(2015) states that the RICS survey shows that 66% of surveying firms have already been forced to turn down work due to a lack of staff and this could be set to grow over the next five years. A combination of factors can be credited with forcing open the construction skills gap, but, put simply, there is a lack of expertise to cover the demand. This is primarily due to a diminishing interest in the profession, ageing staff, and a boom in investment CIBT (2013)

Furthermore, Public Finance (2015) states that 37% of the UK construction workforce is self-employed and 23% (equivalent to 182,800 people) of those are set to retire from the industry in the next 5–10 years as aforementioned. It is predicted that 1 million construction workers are needed by 2020 to keep up with UK housing plans (Skynews, 2017). The government hopes to build 275,000 affordable homes within this time; however, the Local Government Authority warns that skills shortage could impede such progress (Public-Finance, 2015, Skynews, 2017). This has made construction staff the most in demand within recruitment circles according to the Recruitment and Employment Confederation (REC) (Agency-Central, 2017) and KMPG construction survey (KPMG, 2016).

The volatility of the construction industry is evident in the skill gaps currently trending, and construction companies' insolvencies also occur in the industry, and, thus, it can be described as intertwined. Figure 2.9 shows the number of new starter company insolvencies for the highest 10 sectors in England and Wales in 2016.

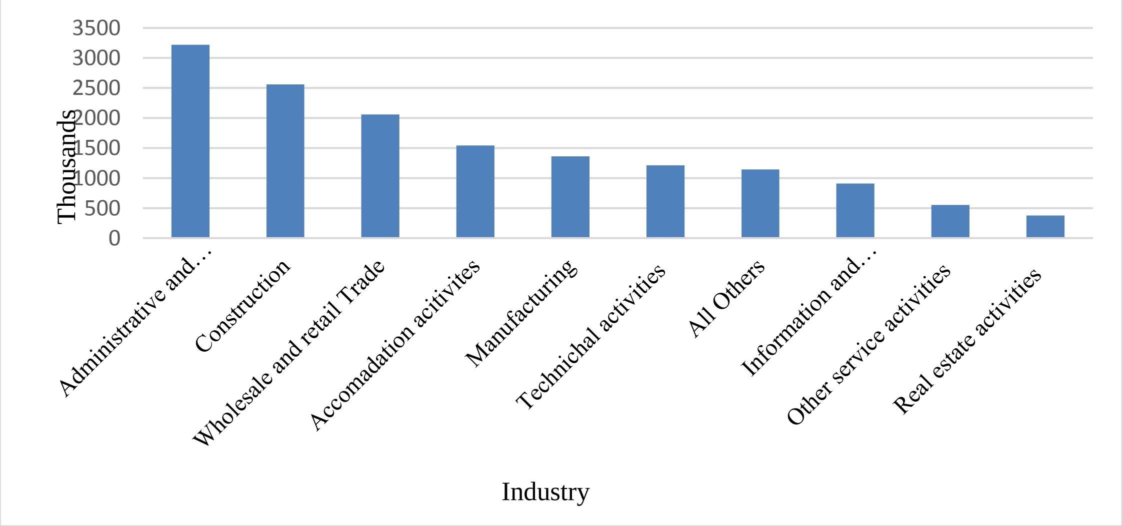


Figure 2.9 Total new company insolvencies 2016, highest 10 industries in England and Wales (Adapted ONS, 2017b)

As exhibited in Figure 2.9, across the top 10 highest industries in 2016, 14,937 new companies entered insolvency. Of these firms, 2,557 were new starter construction firms that entered insolvency in the year ending 2016, second only to the administrative services sector. The administrative services contributed more to insolvencies than construction. Alarmingly, construction had been the highest contributing sector to new company insolvencies for the five years leading up to 2016. This calls for concern and a conscious effort to address the skills gap to meet up with the predicted construction growth in the years reviewed.

2.4 Climate change and construction industry

Climate change has brought about possible permanent alterations to the Earth's geological, biological, and ecological systems (TNAP, 2011). Of the many environmental impacts of development, the one with the highest profile is currently global warming, which demands changes from the government, industry, and society (WHO, 2017a). Concerns about the local and global environment situation are increasing all over the world. Climate change, also called global warming, is the consequence of a long-term build-up of greenhouse gases (CO_2, CH4, N2O, etc.), which trap energy in the higher layer of the atmosphere (Greenwood *et al*., 2011). The average temperature of the Earth’s surface has increased by about 1.4°F (0.8°C) over the past 100 years; approximately 1.0°F (0.6°C) of this warming has occurred during the past three decades (TNAP, 2011). Similarly, Loaiciga (2009), states that the carbon dioxide concentration in 1765 was about 280 parts per million by volume (ppmv), but it increased to approximately 364 ppmv in 2009. Significant climate change over the next century is expected. The WHO (2017a) revealed that the most report from the Intergovernmental Panel on Climate Change (IPCC) concludes that the average temperature of the Earth's surface has risen by 0.6°C since the late 1800s. It is expected to increase by another 1.4–5.8°C by the year 2100 in a rapid and profound change. Global temperatures are set to rise by a further 1.1°C under a low emissions scenario, and by 2.4°C in a high emissions scenario, by the end of the century (Houghton *et al*., 2001). Even if the minimum predicted increase takes place, it would be larger than any century-long trend in the last 10,000 years.

Global warming has intensified many climatic extremes leading to a significant increase in the frequency and severity of heat waves (Glasby, 2002). These climatic changes have led to the emergence of large-scale of environmental hazards to human existence, such as extreme weather (MPG, 2013), ozone depletion, and increased danger of wildland fires (Tang *et al*., 2015), loss of biodiversity (Sahney *et al*., 2010), stresses to food-producing systems, drought (Mattson and Haack, 1987), and floods (Vigran, 2008). In a similar publication, MPG (2013) affirmed that when the carbon dioxide content of the atmosphere rises, the earth not only heats up but causes extreme weather events or environmental hazards, such as lengthy droughts, heat waves, heavy rain and violent storms, and may become more frequent if not checked. The effects of climate change on human health has been documented, and these include, Malaria (Greenwood *et al*., 2005), Dengue fever (Hopp and Foley, 2001; PMH, 2012; WHO, 2017b); mental health issues (Chand and Murthy, 2008; Doherty and Clayton, 2011), and global infectious diseases (Epstein, 2001; McMichael, 2003; Meehl *et al*., 2007), and vascular diseases (Liu *et al*., 2015). The World Health Organization (WHO) estimates that 160,000 deaths, since 1950, are directly attributable to climate change (WHO, 2017a) as a result of the mentioned sicknesses. However, Figure 2.10 highlights the relationship between global warming and human-induced hazards.

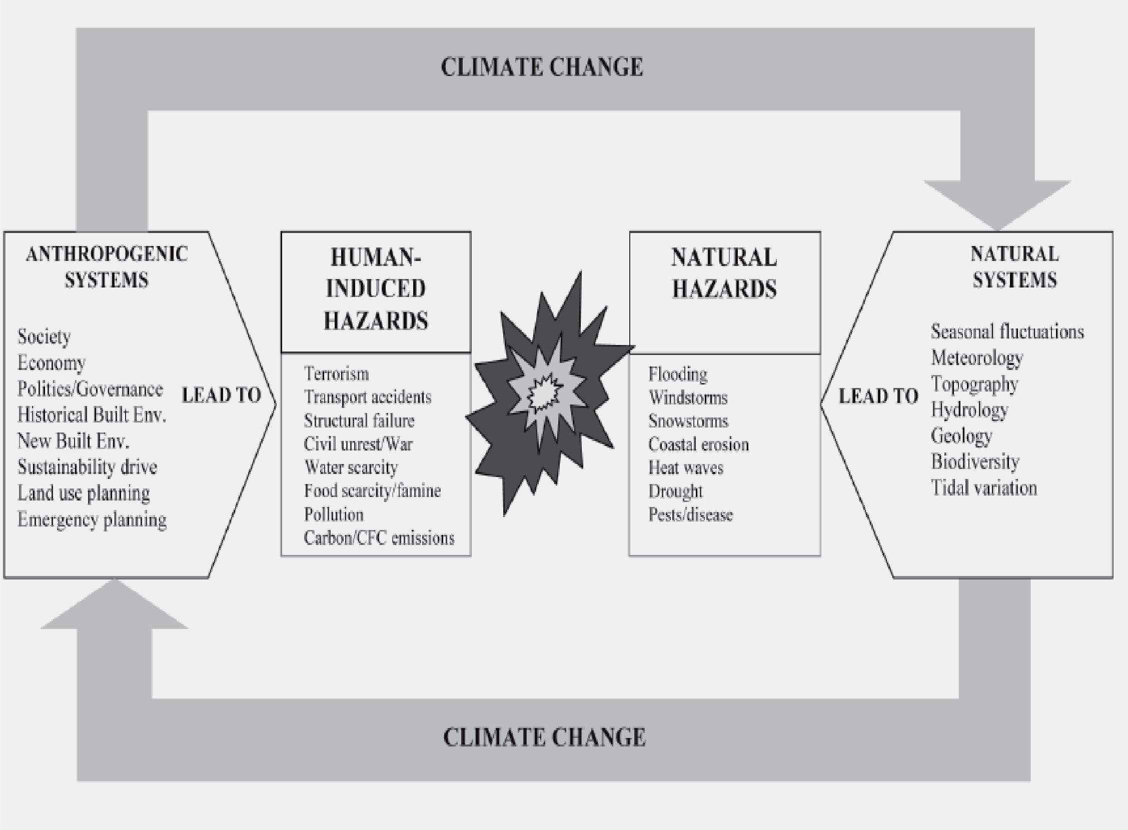


Figure 2. 10 Potential relationships between climate change and natural and human-induced hazards (Bosher *et al*., 2007)

Nevertheless, greenhouse gas is an old issue, because, as early as 1896, a Swedish chemist stated that atmospheric carbon dioxide concentration was the primary cause of global temperature fluctuations (Kininmonth, 2003), affirming that industrialisation is one of the principal reasons for a worldwide increase in temperatures due to the burning of ever-greater quantities of oil, gasoline, and coal, the cutting of forests and use of specific farming methods. In a related view, Buchanan and Honey (1994) stated that the emission of these gases is the result of intensive environmentally harmful human activities such as the burning of fossil fuels, deforestation, and land use changes. In addition, in 1985, researchers claimed that global warming was created by human activities (Kininmonth, 2003) and the claim was confirmed in 1988 at the first Intergovernmental Panel on Climate Change (IPCC). The subsequent report, published in 1990, confirmed that there is an adverse greenhouse effect and human activity has caused the increased atmospheric concentration of carbon dioxide in the atmosphere. However, a second IPCC followed in 1995 and a third in 2001; both articulated growing assurance that greenhouse gases will cause dangerous future climate change (Bala, 1998; Kininmonth, 2003; Meadows and Hoffman, 2003), having been widely believed or confirmed that human activity contributes primarily to global warming. However, the built environment, particularly construction, has been accused of contributing a huge percentage to climate change due to the impact of its activities.

It has been suggested that construction is causing environmental problems ranging from the excessive consumption of global resources, due to construction and building operations, to the pollution of the surrounding environment; these have contributed to global warming (Edwards, 2002; Greenwood *et al.*, 2011). The construction industry is a highly active sector all over the world (UNEP, 2003); hence, its immense contribution to global warming. The construction sector delivers infrastructure and buildings to society through the consumption of a large amount of unrenewable energy. Consequently, this consumption causes considerable emissions of CO_2 (Huang *et al.*, 2017). Khasreen *et al.* (2009) revealed that environmentally harmful activities differ from one industry to another, but it is discovered that the highest contributor to GHG emissions is the built environment, accounting for up to 50% of global carbon dioxide emissions (Raynsford, 1999).

The building construction industry consumes 40% of the materials entering the global economy and produces about 40–50% of the worldwide output of GHG emissions and the agents of acid rain (CEPA, 2000). Furthermore, the embodied environmental impacts generated by the building during its whole life-cycle can be of the same order of magnitude as those created during the utilisation stage (Citherlet, 2001). The construction sector is responsible for a high percentage of the environmental impacts produced by developed countries (UNEP, 2003). In the European Union, the construction and building sector are responsible for roughly 40% of the overall environmental burdens (UNEP, 2003). Homes in the UK (their construction and occupation) are responsible for the consumption of 40% of the primary energy in the country (DEFRA, 2008). If the other 30% of the building stock (non-residential) is considered, the impact of buildings is higher (Boermans, 2004).

Notwithstanding the industry has contributed to global warming as aforementioned; construction has also been identified as the sector with the most significant potential to reduce consumption (IPCC, 2007, GhaffarianHoseini *et al.*, 2013). It is essential to reduce Green House Gases (GHG) emissions by 50% or more to stabilise global concentrations by 2100 (Houghton *et al.*, 2001). The Tyndall Centre has suggested that a 70% reduction in CO_2 emissions will be required by 2030 to prevent temperature rising by more than 1°C (Bows *et al.*, 2006). Most European governments have introduced new policy instruments such as the European Community’s energy performance directive for buildings (EPBD) to reduce the negative impacts from the building sector (Bowie and Jahn, 2002). The productivity of the construction industry has a significant effect on national economic growth. Gains from higher construction productivity flow through the economy, and, like all industries, rely on construction to some extent as part of their business investment (Magee *et al.*, 2013). Hence, the industry must apply sustainable principles and practices in every construction project to achieve the much-desired greenhouse gas reduction during the next century.

Figures 2.11 and 2.12 deduce the global contribution of the construction industry to global warming. An explanation of the detailed results from the eight regions on global warming as shown in Figure 2.11 includes China, the European Union (27 member states, EU-27), India; the organisation of emerging countries (OECD) includes the Pacific (including Australia, Japan, and South Korea, OECD-P); other leading emerging economies (including Brazil, Indonesia, Mexico, and Turkey, OME), Russia, the US and the rest of the world (RoW) (Huang *et al*., 2017).

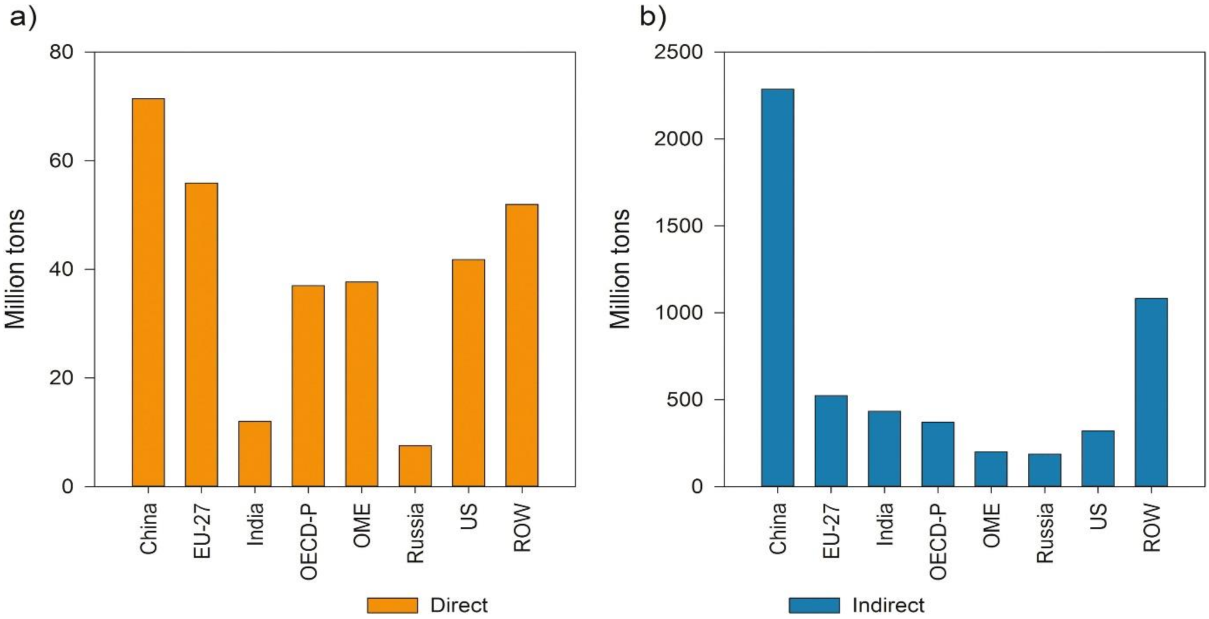


Figure 2.11 (a) Direct CO_2 emissions of global construction sector by countries/regions (million tons) in 2009, (b) Indirect CO_2 emissions of global construction sector by countries/regions (million tons) in 2009 (Huang *et al.*, 2017).

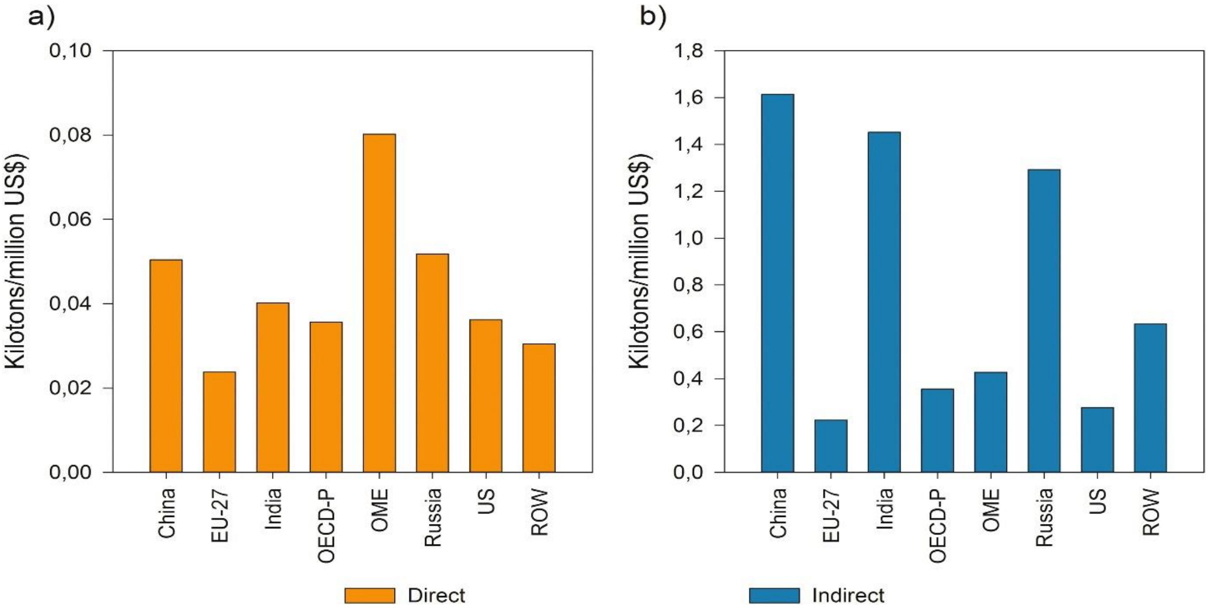


Figure 2.12 (a) Direct CO_2 emissions intensity of global construction sector by countries/regions (kilotons/millions US$) in 2009, (b) Indirect CO_2 emissions intensity of global construction sector by countries/regions (kilotons/millions US$) in 2009 (Huang *et al*., 2017)

Huang *et al*. (2017) explain that the highest CO_2 emission of the global construction sector has taken place in China. About 23% direct CO_2 emission, 42% indirect CO_2 emission, and 41% of the total CO_2 emissions of world construction activities are from China. EU-27 is the second highest immediate CO_2 emission contributor at 18%, and the US is the third at 13%. EU-27 is also the second highest indirect CO_2 emission contributor at 10%, and India is the third at 8%. Most developed countries contribute more direct CO_2 emissions than indirect ones. As a result, EU-27, India, OECE-P, OME, Russia, US and the RoW contribute to around 10%, 8%, 7%, 4%, 3%, 6%, and 20% respectively, which was added to the total carbon emissions of the global construction sector in 2009. China, India and Russia have higher CO_2 emission intensity than other regions/countries and average world value, especially indirect CO_2 emissions intensity. Equally, the magnitude of the direct CO_2 emissions, the indirect CO_2 emissions, and the total CO_2 emissions of the construction sector in EU-27 are the lowest in the world.

2.5 The construction industry and its environmental impacts

Construction projects around the world have significant implications for our environment, both on a local and a global scale. Every stage of the construction process has a measurable environmental impact: the mining processes used to source materials, the transportation of these materials to the building site from sources around the world, the construction process itself, and the waste removal and disposal process that follows the completion of the project. With a fast developing global economy, it is vital that the industry understands how construction projects impact the environment and sets standards on how to reduce that impact in the future (Hamza and Greenwood, 2009; E-SUB-Construction, 2017). Appoximately half of all non-renewable resources consumed by humanity are used in construction, making it one of the least sustainable industries in the world.

Nevertheless, mankind has spent the majority of its existence trying to manipulate the natural environment to better suit its needs, so, today our daily lives are carried out in, and on, constructions of one sort or another: we live in houses, we travel on roads, and we work and socialise in buildings of all kinds (Dixon, 2010). Human civilisation depends on buildings and what they contain for its continued existence, and yet our planet cannot support the current level of resource consumption associated with them. Globally, the construction sector is arguably one of the most resource-intensive industries. There is increased concern about the impact of building activities on human and environmental health. These impacts/concerns have put the industry under the scrutiny of the public, regulators, and the government more than ever before and has necessitated the industry to increasingly recognise the need for tenable development through sustainable construction (Zuo *et al.*, 2012b). It is clear that actions are needed to make the built environment, especially construction activities, more sustainable (Hill and Bowen, 1997a; Barrett *et al.*, 1999; Holmes and Hudson, 2000; Morel *et al.*, 2001; Scheuer *et al.*, 2003; Abidin, 2010).

The construction industry and the environment are linked, and it has found itself at the centre of concerns about environmental impact. In today's world, it is accepted that sustainable development has three foundations: environmental, social, and economic. The link between sustainable development and construction becomes clear because construction is of high economic significance, yet it has high environmental impact.

Abidin (2010) argues that buildings are enormous contributors to environmental deterioration. Buildings are long-lived, and cities have even longer lives: their impacts will stretch into the lives of many generations of our ancestors and into a future of unknown resources, pollution, and unstable climatic conditions (Dixon, 2010). Kein *et al*. (1999) and Ding (2008) describe the building industry as uncaring and profit motivated, and the members as destroyers of the environment rather than its protectors. Undeniably, the construction industry has a significant irreversible impact on the environment across a broad spectrum of its activities during off-site, on-site, and operational activities, which alter ecological integrity (Uher, 1999; Ding, 2008; Gorse *et al*., 2013).

Construction activities affect the environment throughout the life cycle of a construction project. Clearly, for the good of the environment and the survival of the planet, its myriad of interwoven and interdependent ecosystems and humanity, something has to change, and construction companies have a leading role to play in that change. It is, therefore, prudent to address environmental issues at the outset; otherwise, our created wealth of the constructed asset will be significantly be destabilised. Figure 2.13 refers to the life-cycle concept of all construction activities from the extraction of resources through to product manufacture and use, and finally disposal or recycling, i.e. from ‘the cradle to the grave’. The following sections focus primarily on the environmental impacts relevant to construction activities.

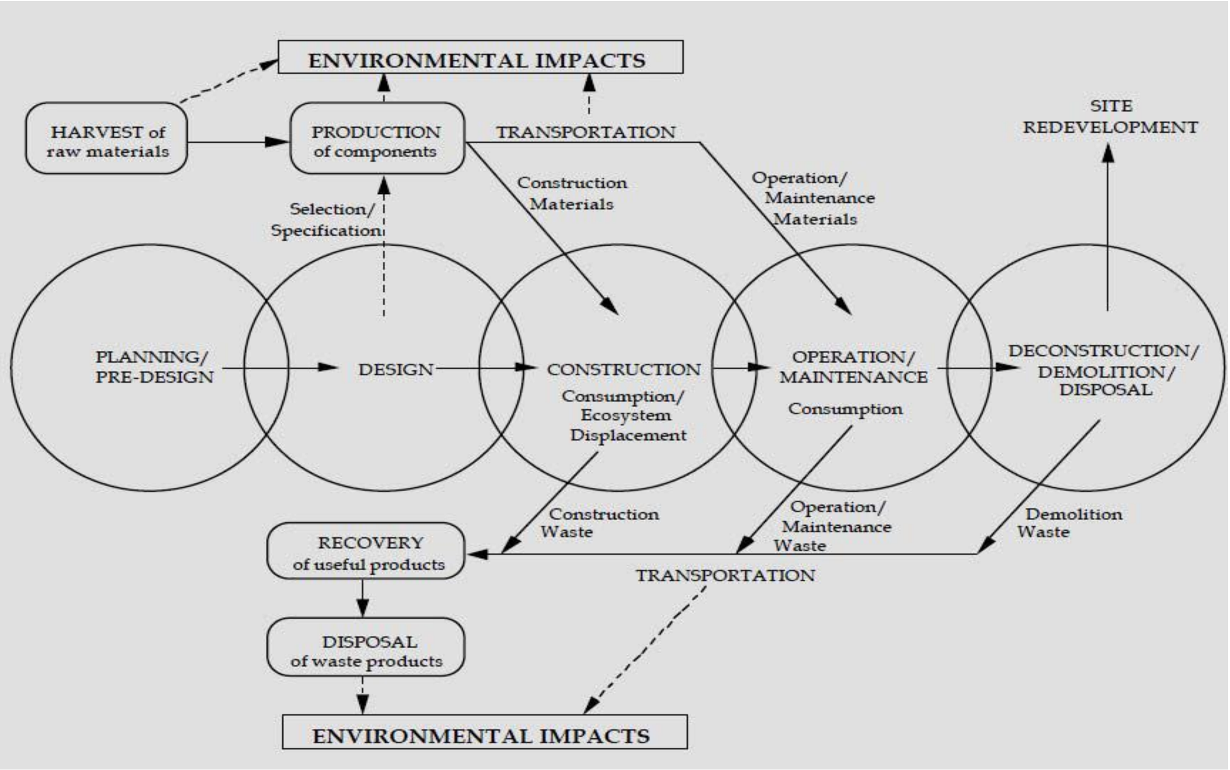


Figure 2.13 Life cycle environmental impact of building construction (Franklin-Associates, 1990)

2.5.1 Energy use and its impacts

In the last hundred years, the Earth has warmed by about 0.5^{o}C (Lenzen and Treloar, 2002). There is a global belief that this is due to an increase in the concentrations of greenhouse gases. Principal amongst these is carbon dioxide, which is produced whenever fossil fuels are burnt to obtain energy. The construction industry and the built environment is known to be the primary consumer of energy in the UK. According to Hultgren (2011), buildings account for over half of global energy use. The USGBC (2011) states that energy use in buildings contributes about 40% of all energy use forecasting that by 2030, emissions from commercial buildings will grow by 1.8%.

Global energy use is currently equivalent to 81.5 trillion barrels of oil, which would be enough to stretch to the Moon and back 100 times. Most of that energy is wasted through poor design and wasteful practices. According to the USGBC (2016), buildings account for an average of 41% of the world's energy use. Edwards (2002) study states that 50% of total UK energy consumption is from the built environment that consists of 45% of heat, light and ventilating buildings, which consumes 5% of the total energy in their construction. In the UK, buildings consume approximately 50% of the total energy sold in the country and are responsible for about 50% of the country's CO_2 emissions, while arguably, more than 50% of all UK carbon emissions have been attributed to energy use in buildings (including residential and business emissions) (DEFRA, 2008).

The building industry is rapidly increasing world energy use, and concerns have already been raised about the use of finite fossil fuel resources in terms of supply difficulties, exhaustion of energy resources, and substantial environmental impacts (ozone layer depletion, carbon dioxide emissions, global warming, and climate change (Clough, 1994; Spence and Mulligan, 1995; Ofori, 1998, Langford *et al*., 1999; Uher, 1999, Perez-Lombard *et al*., 2008; Ilha *et al*., 2009; Hamza and Greenwood, 2009). Building material production consumes energy, the construction phase consumes energy, and operating a completed building consumes energy for heating, lighting, power, and ventilation. The existing building stock in European countries accounts for over 40% of final energy consumption in the European Union (EU) member states, of which residential use represents 63% of total energy consumption in the buildings sector (Balaras *et al*., 2005, Poel *et al*., 2007).

It is essential to state that the UK government has failed to live up to expectations in championing the course of the energy review and cut down to challenge the broader and more fundamental issue as it relates to sustainable development despite the fuel poverty bill (HoC, 2006, Pitt *et al.*, 2009). This has necessitated the UK government to set a target of achieving an 80% reduction in energy use by 2050 (DTI, 2003a). The current low levels of energy efficiency in the built environment offer vast scope for improvement in energy performance, which may be accomplished through the deployment of an array of techniques ranging from plants and insulation upgrades to the implementation of advanced energy monitoring and control (Akadiri and Olomolaiye, 2009).

2.5.2 Waste production and demolition impacts and lack of recycling

The destruction and renovation of buildings results in a significant amount of waste. Building waste often includes concrete, metals, glass, plastics, wood, asphalt, and bricks. These wastes are often disposed of in landfills or incinerators. Not only does this pollute the land and the air, but the transportation required to remove such waste also has a significant impact on the environment (USGBC, 2016). Throughout the construction cycle, and especially at the end of a structure's life, large quantities of waste are produced. The construction process also generates significant amounts of waste.

Much of this waste is avoidable on site, but inattention to design detailing, inappropriate materials, dimensions, late variations, and over-ordering contribute to waste (Dixon, 2010). It has been affirmed that a substantial volume results from the production, transportation, and use of materials that are generated as a result of construction project activities (Kein *et al*., 1999, Osmani *et al*., 2008). Hultgren (2011) states that construction activities consume approximately one-quarter of global waste. According to BIMhow (2013), the construction sector globally contributes to 50% of landfill waste. Teo and Loosemore (2001) and *Mohd-Nasir et al.* (1998) state that construction activities contribute to about 29% of waste in the USA and more than 28% in Malaysia. McDonald and Smithers (1998) report that 14 million tonnes of waste are put into a landfill in Australia each year, and 44% of this waste is attributed to the construction industry. In the European Union, the construction industry contributes about 40–50% of waste per year (Stigon, 1999; Sterner, 2002).

Furthermore, Burgan and Sansom (2006) carried out a study for the European Commission in 1999, and disclosed that in the EU-15, 'core' construction and demolition waste amounts to approximatley 180 million tonnes each year and that only is about 28% across the EU as a whole is reused or recycled with the remaining 72% going to landfill. Five member states (Germany, the UK, France, Italy and Spain) accounted for around 80% of the total, broadly consistent with the share of the overall construction market accounted for by these countries. In the UK, specifically, the BRE (2006a) study affirms that construction demolition and refurbishments generate around 100 million tonnes of waste each year in the UK. According to the HMG (2008) report the percentage increased, which affirmed that construction and demolition process produces the most significant quantity of waste in the UK. The report stated that the industry is generating an estimated 120 million tonnes of waste covering one-third of all waste produced each year in the UK. In a similar study, BRE (2006) asserts that about half of this waste is recycled from the demolition sector and parts of the construction sector. This is why the Government Green Construction Board (GCB) in its *low carbon construction action* included waste control and management as one of the means of reducing environmental degradation, at the same time, achieving sustainable construction (HMG, 2013a). Figure 2.14 deduces the contribution of the construction industry in relation to waste production compared to other sectors.

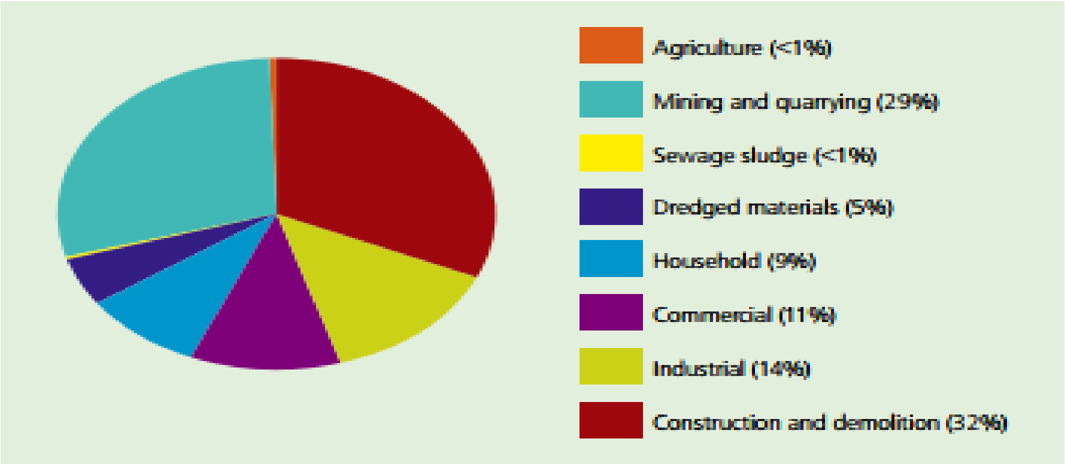


Figure 2.14 Construction and Demolition Waste in the UK (BRE, 2006a)

In a relative view, RICS (2005a) states that the construction industry produces about 40% of all waste in the UK, including greenhouse gas emissions. These have necessitated the government to project that landfill capacity will be established and fully integrated into the sector by 2017 (DTI, 2003b; Pitt *et al.*, 2009; Menassa, 2011b). The introduction of the Landfill Tax and Aggregate Levy has helped in reducing waste (OECD, 2006). This has compelled the most significant contractors in the construction industry to establish waste management procedures and practices (Group, 2004; Pitt *et al.*, 2009).

Furthermore, the need for the waste to be recycled has been suggested in line with the objectives of achieving sustainable construction. The negative impacts of construction waste to the environment remains a challenge, and this has necessitated

WRAP (2011), in their study, to propose a waste management hierarchy to help in managing construction waste, with processes including prevention, preparing for re-use, recycling, other recovery, and disposal. Nevertheless, screening, checking and handling construction waste for recycling are time-consuming activities, and the lack of environmental awareness amongst building professionals may create significant barriers to the usefulness of recycling (Langston and Ding, 2001). Sterner (2002) states that implementing a waste management plan during the planning and design stages can reduce waste onsite by 15%, and deliver cost savings up to 50% on waste handling.

2.5.3 Natural resource consumption/depletion, material use and its impacts

The construction industry is a significant user of material resources. There is a substantial environmental impact associated with the extraction and consumption of raw materials for building. Construction activities are believed to consume around half of all the resources of human extract from nature such as concrete, aluminium, and steel, which are directly responsible for 'large quantities of CO_2 emissions' due to high contents of 'embodied energy' (Hultgren, 2011). The industry is one of the largest exploiters of renewable and non-renewable natural resources (Spence and Mulligan, 1995; Curwell, 1998; Uher, 1999; Abidin, 2010). Various natural resources namely energy, land, materials and water are used during the typical construction process (Shen *et al*., 2005). The depletion of natural resources by the building industry is a concern and most recyclable material from building sites ends up in landfill sites (Morel *et al*., 2001). Moreover, several construction equipment operations are involved in the consumption of natural resources, such as electricity, diesel and petrol.

The building industry is responsible for using a high volume of natural resources and generates a considerable amount of pollution as a result of energy consumption during the extraction and transportation of raw materials (Li *et al*., 2010; Zolfagharian *et al*., 2012; Boss, 2017). According to the USGBC (2011), 40% of the world's raw materials are used in building construction. The publication affirmed that the built environment is not only responsible for a large percentage of the world's water use, but also a significant amount of wasted water. It is estimated that buildings use 13.6% of all potable water, which is roughly 15 trillion gallons of water per year. According to the Worldwatch Institute (2003), building and construction activities worldwide consume 3 billion tonnes of raw materials each year, or 40% of total global use. In a similar study, Hultgren (2011) estimated that approximately 3 billion tonnes of raw materials are used worldwide to manufacture building products and components every year. That is about 40%–50% of the total material flow in the global economy. The construction industry accounts for one-sixth of global freshwater consumption, one-quarter of global wood consumption, and one-quarter of global waste generation (Hultgren, 2011). Materials used for construction projects are derived from numerous sources and suppliers, hence, they have a severe impact on the environment; the minimisation of waste presents a particular problem. Although many of the materials in use are common to most sites, the fragmented nature of the industry constrains the practical extent of recycling. Many of the materials used in the construction of buildings are produced in a non-sustainable way. The factories that make the materials produce CO_2 emissions, which is harmful to the environment, not to mention the actual production of those materials in their final form.

According to Levin (1997), in the USA, construction uses 30% raw materials, 40% energy and 25% water. In Europe, the Austrian construction industry has about 50% of material turnover induced by society, as a whole, per year (Rohracher, 2001) and 44% in Sweden (Sterner, 2002). The UK construction industry consumes around 420 million tonnes of materials annually, the highest of any sector (DTI, 2003b; Plank, 2008); many of these materials have an adverse impact on the environment (Sourceable, 2016; BRE, 2016) as the industry relies heavily on the natural environment for the supply of raw materials such as timber, sand and aggregates for the building process.

This extraction of natural resources causes irreversible changes to the physical environment of the countryside and coastal areas, both from an ecological and scenic point of view (Ofori, 1998; Langford *et al.*, 1999; Godfaurd *et al.*, 2005). The subsequent transfer of these areas to geographically dispersed sites not only leads to further consumption of energy but also increases the amount of particulate matter in the atmosphere. Stone and primary aggregates dominate the mass of resources used in the UK construction industry: sand and gravel extraction imply significant environmental impact from the loss of habitat and ecosystems, damage to the landscape, potential subsidence problems, and release of methane. Construction has a significant effect on the environment particularly in consumption of energy as discussed, both directly and embodied in the materials that it uses. The bulk of materials used consume a great deal of energy for transport.

Furthermore, the UK water consumption rate in the last 30 years has increased to an estimated 70% (Brownhill and Yates, 2001). Consequently, with approximately 4.1 million houses needing to be built in the UK combined with the increase in population and a higher standard of living, the water use requirement will increase drastically, which might have negative impact on society (Edwards, 2002; Pitt *et al*., 2009). It has been argued that the construction industry is in a position to implement water conservation techniques into refurbishment, retrofitting, and new build projects (Pitt *et al*., 2009). In a relative view, DTI (2003b) in its report states that incorporating water-efficient technology, such as low water flush toilets, domestic appliances, and reduced flow taps can achieve about 20% water improvement efficiency. Table 2.1 highlights the resource consumption in buildings.

Table 2. 1 Estimate of global resources used in buildings (Hawken *et al*., 1999)

Resources	**%**
Energy	45–50
Water	50
Materials for building and roads (by bulk)	60
The agricultural land loss to the building	80
Timber products for construction	60 (90% of hardwoods)
Coral reef destruction (indirect)	50 (indirect)
Rainforest destruction (indirect)	25 (indirect)

2.5.4 Pollution and bio-diversity

Pollution can be defined in many ways: as that arising from the built environment (for example sewage and waste), pollution caused by the manufacturing of materials and products, pollution and hazards from the handling and use of materials or from the site itself and other construction, and operationally related activities (Dixon, 2010). The study by Kukadia *et al*. (2003) acknowledges the British Research Establishment's (BRE) definition of pollution as the introduction of contaminants into the natural environment, damaging it. It states that, in line with the construction industry, it could take the form of chemical substances, such as air, particles, noise, heat, vibration and vaporous discharges.

Pollution has been defined from a construction perspective as ‘particles, noise, vibration and vaporous discharges’ (Kukadia *et al*., 2003; Pitt *et al*., 2009). According to BIMhow (2013), the construction sector contributes to 23% of air pollution, and 40% of drinking water pollution. Raw materials extraction and construction activities also contribute to the accumulation of pollutants in the atmosphere, mostly in the processing of materials for construction. The design and construction phases involve the specification of materials, and the use of plant, processes and techniques. Pollution impacts also include large disturbances to the existing environment, whether on the greenfield or previously developed sites. Each of these activities poses a risk of introducing pollutants into the atmosphere, which can affect workers on site, the neighbourhood, or the quality of the local ground, water, and air. Similar impacts can occur during the operational phase of development. Such disturbances can also upset the equilibrium between the land, water and air and introduce the risk of pollution.

According to Holton *et al.* (2008), the UK’s construction is responsible for 40% of atmospheric emissions, 20% of water effluents, and 13% of other releases. Dust and other emissions include some toxic substances such as nitrogen and sulphur oxides. They are released during the production and transportation of materials as well as from site activities and have caused a serious threat to the natural environment (Rohracher, 2001). In its reports, the HoC (2006) affirms that global greenhouse gas emissions have increased more than four-fold in the last half of the twentieth century. Other harmful materials, such as chlorofluorocarbons (CFCs), are used for insulation, air conditioning, refrigeration plants and fire-fighting systems and have severely depleted the ozone layer (Clough, 1994; Langford *et al*., 1999). The need to identify the risks associated with pollution in the environment and the steps taken to minimise potential pollution has been emphasised (OGC, 2005). Zolfagharian *et al*. (2012), BIMhow (2013), and Sustainablebuild (2017) summarise the three significant pollutions and how they are generated during construction activities; these include:

2.5.3.1 Air pollution

Construction activities that contribute to air pollution include land clearing, the operation of diesel engines, demolition, burning and working with toxic materials. All construction sites generate high levels of dust typically from concrete, cement, wood, stone, and silica. Construction dust is categorised as a particulate matter less than 10 microns in diameter (PM10), which cannot usually be seen without a microscope. There is also the issue of transportation; materials that are not produced locally are transported often across the country and from overseas. The mode of shipment of these materials has a considerable impact on air quality.

2.5.3.2 Noise pollution

Construction sites produce a lot of noise, mainly from vehicles, heavy equipment and machinery, but also from people shouting and radios turned up too loud during construction. Excessive noise is not only annoying and distracting but can lead to hearing loss, high blood pressure, sleep disturbance, and extreme stress. Research has shown that high noise levels disturb the natural cycles of animals and reduces their suitable habitat.

2.5.3.3 Water pollution

Sources of water pollution on building sites include diesel and oil, paint, solvents, other harmful chemicals, and construction debris and dirt. When land is cleared, it causes soil erosion that leads to silt-bearing run-off and sediment pollution. Silt and soil that runs into natural waterways turn them turbid, which restricts sunlight filtration and destroys aquatic life. Surface water run-offs also carry other pollutants from the site, such as diesel and oil, toxic chemicals, and building materials such as cement. When these substances enter waterways, they poison water life and any animal that drinks from them. Pollutants on construction sites can also soak into the groundwater, a source of water for human consumption. Once contaminated, groundwater is much more difficult to treat than surface water. Table 2.2 highlights the estimate of global pollution generated by buildings.

Table 2.2 Estimate of global pollution that can be attributed to buildings (Brown and Bardi, 2001)

Pollution	**%**
Air quality (cities)	23
Climate change gases	50
Drinking water pollution	40
Landfill waste	50
Ozone depletion	50

Pollutants are usually released into the biodiversity causing severe land and water contamination, frequently due to negligence on construction project sites. Consequently, spillages are washed into underground aquatic systems and reservoirs (Huberman and Pearlmutter, 2008). The accumulated amount of adverse environmental impacts such as waste, noise, dust and hazardous emissions still occur during the construction process, which causes severe damage to humans and ecosystems (UNEP, 2003; Zolfagharian *et al*., 2012). With the rise in the number of constructions of new buildings, the ecosystems/biodiversity impact of construction has become an important issue.

Langford *et al*. (1999) argue that around one-third of the world's land is being degraded and pollutants are depleting environmental quality, interfering with the environment's capacity to provide a naturally balanced ecosystem. Thus, the need to identify the risks associated with pollution in the environment and the steps taken to minimise potential pollution has been suggested (Pitt *et al*., 2009). Having known the negative impacts of pollution, necessary steps should be taken by the industry to protect biodiversity (ecosystem, genetic, and cultural) through good design and landscaping (OGC, 2005). In addition, if the construction industry continues to overuse natural resources without mitigating measures, a limit on economic growth will eventually emerge. Hence, the destruction of the environment will undoubtedly have an adverse effect on the construction industry.

2.5.5 Planning, land-use and conservation

There is a wide range of environmental issues concerned with the interaction of the land use, planning system, and the construction industry. Almost all development undertaken by the construction industry requires planning permission (Dixon, 2010). Land use policies related to land's perceived value for construction frequently results in social inequities, particularly when it competes with energy biomass production, commercial food crops, and other uses (UNEP, 2003). The biodiversity on particular sites can be devastated by developments and through mineral extraction for the construction industry (Dixon, 2010).

UNEP-Earthscan (2002) warns that if the impacts of construction are not properly checked then consumption of natural resources through the expansion of the built environment global population will increase; economic activities and urbanisation will destroy or disturb natural habitats at about 70% of Earth's land surface by 2032. Construction-related activities have significant impacts on transport movements. Considerable pressure can be placed on the local road network and neighbouring uses through quarrying operations. This has often led to requests by governments to reduce transport energy use and the demand for land. Earth movements that usually take place during construction on rainy days typically lead to the deposition of mud if tyres are not cleaned when leaving construction sites. This earth movement has several consequences, such as the unpleasant aspect of the street, increased car accidents, and higher maintenance costs for public space and private properties. Some simple measures should be implemented on site to avoid these problems (Teixeira, 2005; Ametepey and Ansah, 2015). Other land uses can influence the propensity to travel and modal choice. In turn, these factors can impact the levels of energy used along with the pollution and emissions created.

The interaction between the built environment and the natural environment also has a significant impact on the hydrological system (Teixeira, 2005). The combined effect of urban expansion and agricultural intensification has exceeded the capacity of the land to absorb exceptional levels of rainfall (Dixon, 2010; Ametepey and Ansah, 2015). At the same time, rainfall has become more intensive, concentrated, and erratic due to climate change. Climate change prompted an increasing rate of severe flooding as witnessed in the UK, Italy, Germany, Cambodia, Vietnam and India since the year 2000 (Dixon, 2010).

The spatial planning system and design of buildings and landscapes will, therefore, contribute to absorbing the new rainfall peaks, and thereby reducing stress on our engineered drainage and river systems. It is estimated that construction-related energy consumption, including both direct and indirect activities, amount to around 50% of national energy use (Kumar and Kaushik, 2005). Hence, land use planning can contribute to energy consumption through the configuration and location of buildings as formal planning procedures largely control the location of developments initiated by the key stakeholders. Regarding density issues, higher density buildings are preferable to lower density. However, human living conditions can suffer unless density is compensated in the design. Where land is particularly scarce, the chosen option is becoming increasingly not to build, but to renovate. Renovation and maintenance account for one-third of construction activity in Europe (up to 50% in some countries) (UNEP, 2003).

Ametepey and Ansah (2015) study, soil alteration was ranked as the eighth most essential environmental impact of construction activities. They stated that land occupancy was the most crucial factor in this category. Building activities also irreversibly transform arable lands into physical assets such as buildings, roads, dams and other civil engineering projects (Spence and Mulligan, 1995; Langford *et al*., 1999; Uher, 1999). According to Langford *et al*. (1999), approximately 7% of the world's cropland was lost between 1980 and 1990. Arable land is also lost through quarrying and mining the raw materials during construction. Construction also contributes to the loss of forests through the timbers used in building and in providing energy for manufacturing building materials. Both deforestation and the burning of fossil fuel contribute directly to global warming and air pollution (UNEP, 2003; Ametepey and Ansah, 2015). A study by Teixeira (2005) affirmed that construction activities damage vegetation onsite and the environment because of land use. Special care needs to be established to ensure tree preservation, considering the relevance of trees as natural elements of the urban landscape.

UNEP (2003) reports that much of the deforestation in developing countries is due to clearing for local building and harvesting of timber for export. Compaction of land by buildings and infrastructure is often irreversible. However, a wide range of nature conservation initiatives and area designations has been developed to protect habitats. The preservation of trees is associated with respect for the environment and well-being of populations. Hence, diminishing or damaging existing trees may result in complaints and unfavourable public opinions. The specific preventive measure has to be put in place before falling trees. Multiple actions on land use usually lead to damage trees, and this sometimes leads to damages on the environment such as soil compaction, substantial increases in the soil level, opening ditches and trenches, removal of superficial soil layer, loss or damage to the roots and damaging of the trunk and leaves (Teixeira, 2005).

2.5.6 Health and wellbeing

Construction tools and resources regularly used by contract workers and construction firms, such as chemicals on site and even the diesel used by diggers and trucks, can significantly harm public health and the environment (EPA, 2016a; EPA, 2016b). Most construction projects are located in a densely populated area. Consequently, people who live close to construction sites are prone to harmful effects on their health because of dust, vibration and noise due to several construction activities such as excavation (Li *et al*., 2010). Burgan and Sansom (2006) observe that on average, human beings spend about 90% of their lives in buildings. Therefore, the internal environment of the buildings we live, work and play have proved to be the major contributor to our quality of life. For example, the fact that poor quality living space is responsible for health problems has been recognised by the WHO for some 15 years in what it terms ‘sick building syndrome’; the WHO also estimates that worldwide, 30% of offices, hotels, institutions and industrial premises have the syndrome. In the developed world, human beings spend approximately 90% of their lives within buildings (Clements, 2000). Hence, they are exposed to a range of chemicals arising from house furnishing and finishes. Other practices that take place within the building also affect their physiological and psychological reactions. Younger *et al*. (2008) observed a similar trend that inadequate heating or cooling, waste disposal, and ventilation systems result in adverse health effects including respiratory illnesses, asthma, infectious diseases, injuries, and mental health disorders. Carbon dioxide emissions from buildings are primarily caused by the use of electricity to provide heating, cooling, lighting, water, information management, and entertainment systems (Brown *et al.*, 2005; Younger *et al., 2008).*

Furthermore, the design and layout of buildings necessitates active measures to maintain conditions that ensure the health and general well-being of their occupants and these show that construction activities sometimes expose humanity to ill health. The study by Ametepey and Ansah (2015) affirms that accidents and incidents were ranked as the seventh most significant environmental impact of construction activities. The study reveals that architects and quantity surveyors agreed that fire outbreaks were the most severe environmental impact of construction activities. On the other hand, structural engineers' ranked breakage of service pipes as the most disturbing factor. However, some contractors and consultants raised the issue of building collapse in the course of construction as part of accidents and incidents experienced during construction.

Buildings have a very long life expectancy. Hence, it affects the environment and public health for a long time. In a similar study of accidents in the built environment conducted by Burgan and Sansom (2006) revealed that in England, for example, the construction industry accounted for 31% of all fatal injuries to workers in 2002/2003. The figure is significantly higher than other industrial sectors, and workers with the least time with their current employer (or at least time self-employed) had the highest rate of reportable injury. The breakdown of Europe industries involved in fatal and non-fatal accidents are highlighted in Figure 2.15.

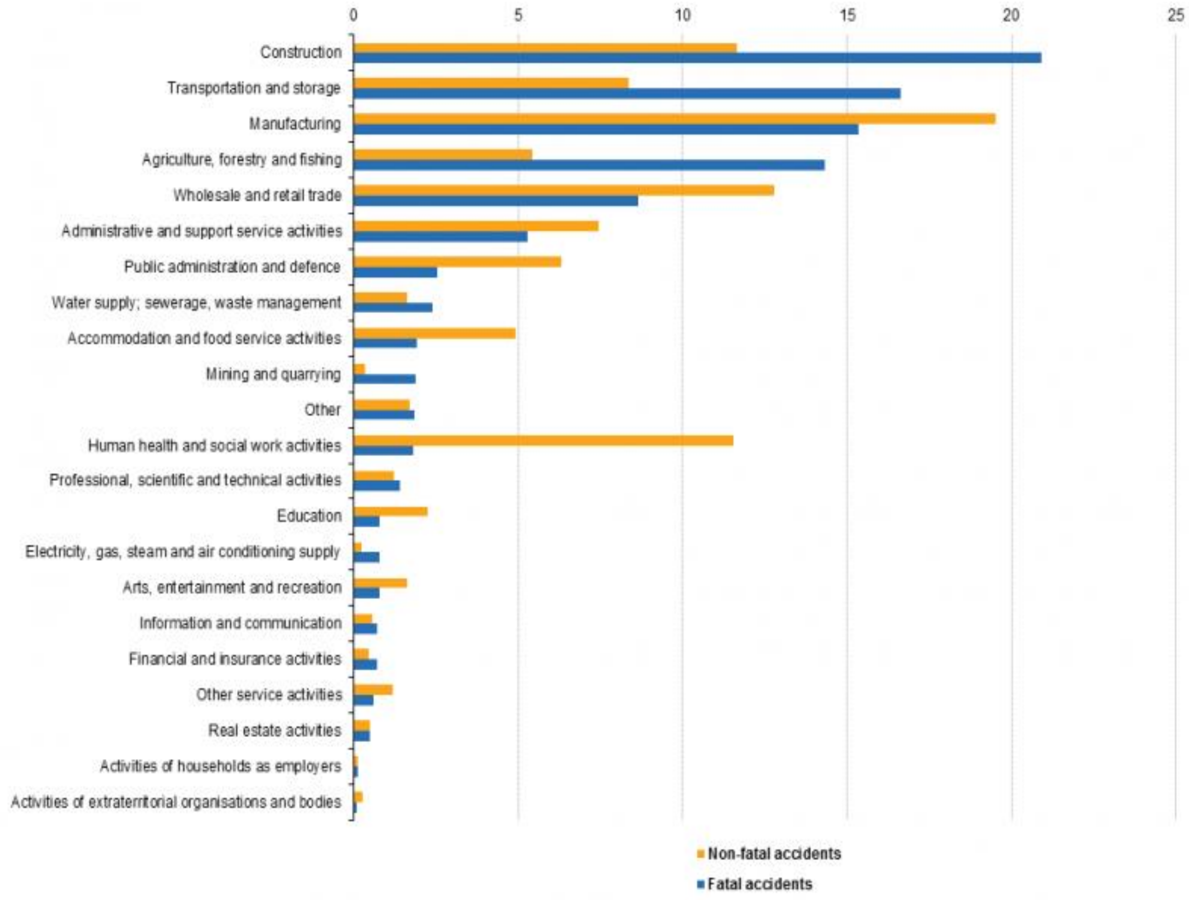


Figure 2.15 Fatal and non-fatal accidents at work by economic activity, EU-28, 2014 (% of fatal and non-fatal accidents (Eurostat, 2016).

The breakdown of Figure 2.15 shows that the rate of fatal accidents is very high in construction. The industry came first in fatal accidents and came third in non-fatal accidents after manufacturing. The need to tackle these impacts on the environment by the construction industry cannot be over-emphasised having reviewed the literature on the effects of construction on the environment. Therefore, the industry must inevitably change its historical methods of operating with little regard for environmental consequences and sustainability to a new mode that makes environmental concerns the centre of its efforts. Abidin (2010) agrees with this and states that the concern for the environment is previously a relatively small part of most of the construction organisations.

However, with the growing awareness of environmental protection and sustainability, this issue has gained broader attention. Applying sustainable principles and practices in construction projects have been suggested as a way towards fostering economic advancement in the construction industry, while reducing its impact on the environment (Hill and Bowen, 1997a; Myers, 2004; Ugwu and Haupt, 2007; Kuhtz, 2007; Ding, 2008). A paradigm shift is essential for the industry concerning environmental implications as a small part of construction process, instead of implementing the integration of all building projects within the broader context of the environmental agenda. Thus, the activities of the construction industry must work and comply with the needs to protect and sustain the environment.

2.6 Emergence of sustainable development and construction

2.6.1 Background

The beginning of industrialisation and economic development in most countries has been accompanied by growth in fossil fuel consumption with an increasing amount of coal, oil and natural gas being burned by electric power plants, factories, motor vehicles and households (Brundtland, 1987; AIA, 2013a). The resulting carbon-dioxide (CO_2) emissions from these developments have turned into the largest source of greenhouse gases, which are gases that trap the infrared radiation from the Earth within its atmosphere, causing global warming (Royal Society and UNAS, 2014). This is due to the Earth's ecological systems being so complex; the exact timing and extent to which human economic activities will change the planet's climate are still unclear, but many scientists believe that the changes are already observable. To mitigate the effects of global climate change, world leaders rose to the occasion, which characterised the need for sustainable development and generated a lot of interest in the last two decades (Brundtland, 1987; AIA, 2013a). However, more concerted efforts are needed from governments around the world with the political will to promote energy efficiency further and shift from today's heavy reliance on fossil fuels to eliminate the impacts of climate change.

The word 'sustainability' stems from forest management in the 12th to 16th centuries (Enhnert, 2009, 2012). However, over recent decades, the concept has been significantly widened. The term 'sustainable' was first used in the contemporary general sense by the Club of Rome in 1972 in its classic report on the limits of growth written by a group of scientists led by Dennis and Donella Meadows of the Massachusetts Institute of Technology US (Enhnert, 2009). Describing the desirable or needed state of global equilibrium, Grober (2007) and Finn (2009) used the word 'sustainable'. *Sustainable* without sudden and uncontrolled collapse and *sustainable* that is capable of satisfying the necessary material requirements of man. The formation of the concept *sustainable development* (SD) can be traced to 1980 when the International Union for the Conversation of Nature (IUCN), an association of nation states, environmental agencies, and non governmental organisations (NGOs) including the United Nations Environmental Program (UNEP), the World Wildlife Fund, a non-governmental organisation published the 'World Conservation Strategy' under the patronage of UN-General Secretary; this declaration was simultaneously presented in 34 capital cities around the world (Grober, 2007). The title was the Living Resource Conversation for Sustainable Development. The word *sustainable development* (SD) gained popularity with the Brundtland report in 1987 titled Our Common Future.

The report-allayed fears about the world's climate change and asserted the need for development to take care of the present generation without undermining the need for future generations to meet theirs. The report stated that SD at a societal level requires the simultaneous realisation of an economic, environmental and social dimension/concept of sustainability. Roger *et al*. (2008) reiterate that for a project to be termed as sustainable it has to incorporate the three concepts SD or a triple bottom line approach. Due to the report, 1992 Earth Summit in Rio de Janeiro was realised, which further made the word SD a global language (Hildebrand and Paul, 2007). In the summit, the United Nation presented the three concepts as strategic concepts for shaping and saving the future of the planet (Grober, 2007). However, Table 2.3 highlights the critical objectives of sustainability and its requirements for achieving sustainable development.

Table 2. 3 Critical objectives and necessary conditions for sustainable development (Adapted from (WCED, 1987b)

Critical Objectives	**The pursuit of sustainable development requirements**
Stimulating growth	An economic system that provides for solutions for tensions arising from disharmonious development
Changing the quality of growth	A political will needed to secure the citizen's participation in efficient decision-making

Meeting essential needs for jobs, food, energy, water and sanitation	A production system that respects the obligation to preserve the ecological base for development
Ensuring a sustainable level of population	An international system that fosters sustainable patterns of trade and finance
Conserving and enhancing the resource base	A flexible administrative system that has the capacity for self-correction
Re-orientating technology and managing risks	A technological system that fosters sustainable patterns of trade and finance
Integration of environment and economics in decision-making	

2.6.2 Sustainable development definitions

Sustainable development has become a commonly used term that goes beyond simple economic security to include issues of environmental impact and resource use, together with social effects. However, pressures are rapidly growing to embrace such an agenda and indeed to assess performance and improve the environment. Critical business decisions are being increasingly taken with environmental and social concerns alongside economic considerations and have been promoted globally as an essential part of the whole value system in all industries including governments. Sustainability is described as the ability to continue to support or maintain an action for a prolonged period approaching perpetuity (Vatalis *et al.*, 2011). In business terms, this is conventionally related to economic factors as businesses try to stabilise inputs and outputs to sustain a profitable enterprise.

Table 2.4 highlights definitions of sustainable development in the existing literature. However, considering these definitions this research adopts the definition of WCED

(1987), which refers to sustainable development as meeting the needs of today without compromising the ability to meet the needs of the future generation.

Table 2. 4 Definitions and interpretation of sustainable development

Authors	**Definitions of sustainable development (SD)**
Turner (1988)	Stated that in principles, such an optimal (sustainable growth) policy would seek to maintain an acceptable rate of growth in per-capita real incomes without depleting the national capital asset stock or the natural environment asset stock
Conway (1987)	The net productivity of biomass (positive mass balance per unit area per unit time) maintained over decades to centuries.
WCED, 1987	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Mitchell (1997)	A creatively ambitious phrase is an intuitively attractive, but slippery, concept.
Interpretation of sustainable development	
Redclift (1997)	Stated that SD is like motherhood, and God, it is difficult not to approve of it. At the same time, the idea of sustainable development is fraught with contradictions
Barbier (1987)	It is indistinguishable from the development of the society

O'Riordan (1995)	Its very ambiguity enables it to transcend the tensions inherent in its meaning
Mawhinney (2001)	SD tends to be an over-used and misunderstood phrase.

However, this growing awareness of sustainable development in all sectors has been remarkable, and the construction industry has taken centre stage in driving sustainable development through sustainable construction. Therefore, regarding the adopted definition of SD and the construction industry, it is essential that the industry's principles and practices reflect a sustainable growth in the built environment that will not endanger the future growth of the industry in achieving holistically sustainable construction, particularly sustainable retrofit. The construction industry, due to its activities, has had a significant positive and negative impact, especially on the social, environmental and economic aspects of sustainability in the UK and the entire globe (Pietrosemoli and Monroy, 2013). Some of the positive impacts as mentioned above, include a significant contribution to the UK Gross Domestic Product (GDP), job creation, and the production of different types of buildings and facilities to meet human needs (ICRIBC, 2002; Winch, 2010; Pietrosemoli and Monroy, 2013).

The negative impacts of construction, as discussed earlier, are well documented for its contribution to greenhouse gas emissions, which has contributed enormously to global warming/climate change (Stern, 2006; IPCC, 2007; Weight and Rawlinson, 2007; Levin, 2008; Stolarski *et al.*, 2010). For more discussion on the negative impacts see Section 2.5. However, sustainable development pillars, which are environmental, economic, and social as mentioned earlier, are inevitable in achieving sustainable construction. Hence, the next section discusses how it affects the industry and the need to integrate it in all construction activities.

2.6.3 The three concepts of sustainable development as it relates to sustainable construction

To achieve sustainable development through construction projects, the concepts or pillars of sustainable development must be taken into consideration, and these concepts are environmental protection, social progress, economic prosperity, and resources availability (i.e. environmental, social and economic aspects). Jonathan and Simon (2002) defined sustainable pillars as comprising of economic, social and environmental elements. Figure 2.16 highlights the three aspects of sustainable development and its elements in achieving sustainability.

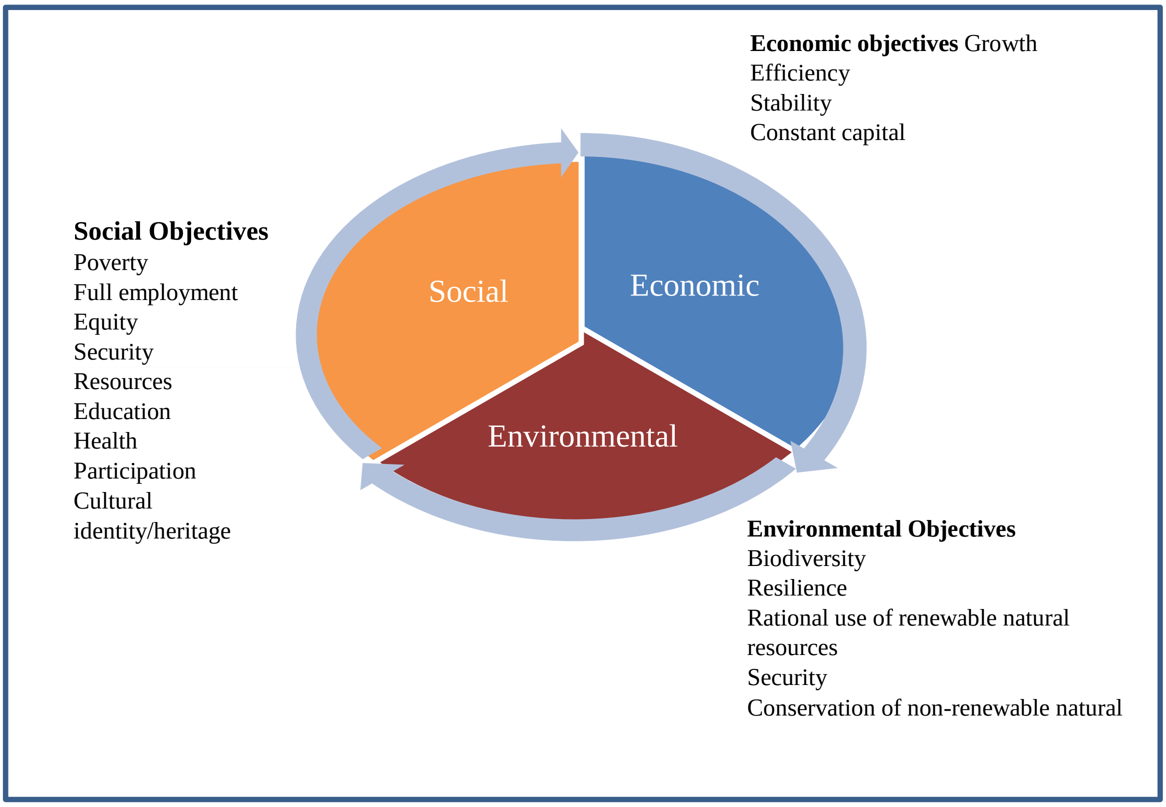


Figure 2.16 The three concepts of sustainable development

2.6.3.1 Environmental sustainability

An environmentally sustainable system must maintain a stable resource base and avoid over-exploitation of renewable resources to make investment adequate (Harris, 2003). Environmental sustainability also prevents harmful and irreversible effects on the environment by the efficient use of natural resources, encouraging renewable resources and also protecting the soil, water and air from contamination (Abidin and Paquire, 2007; Roufechaei *et al*., 2014). Even though the construction industry has little influence on the extraction of natural resources, they can help discourage this activity by demanding fewer non-renewable natural resources, more recycled materials, and efficient use of energy and mineral resources through sustainable construction (Addis and Talbot, 2001). However, some considerations are of relevance in the review of environmental sustainability, and these concerns are discussed below.

Environmental considerations of sustainability

The minimisation of waste**:** the HMG (2008), in its report, established that the construction and demolition industry produces the largest quantity of waste in the UK. The report states that the industry generates an estimated 120 million tonnes of waste, accounting for one-third of all waste produced each year in the UK. As previously noted, this is why the Government Green Construction Board (GCB) in its low carbon construction action included waste control and management as means of reducing environmental degradation and achieving sustainable construction (HMG, 2013b). In a relative view, RICS (2005a) states that it had been estimated that the construction industry produces 40% of all the waste in the UK including greenhouse gas emissions. These have necessitated the government to establish landfill capacity, which has been fully integrated into the sector (DTI, 2006b; Pitt et al., 2009; Menassa, 2011b). The introduction of the Landfill Tax and Aggregate Levy has helped in reducing waste and its minimisation due to the increased cost of waste disposal (OECD, 2006). This has compelled most major contractors in the construction industry to establish waste management procedures and practices (Group, 2004; Pitt *et al*., 2009).

Furthermore, the need for waste to be recycled has also been suggested, and this is in line with the objectives of achieving sustainable construction. GBC (2013) proposed a hierarchy to help in managing waste in the industry, and these include prevention, preparing for re-use, recycling, other recovery, and disposal. Some intellectual works by (Coventry *et al*., 2001; Greenwood, 2003; Poon *et al*., 2004; Baldwin *et al*., 2006; Ortiz *et al*., 2010; Wu *et al*., 2016) argue that building designers have an important role to play in construction waste minimisation and reduction. Suggestions have been made on three important roles design teams should play in the early stages of sustainable construction: giving advice to clients, initiating waste reduction at a project level, and generally improving design practices (Coventry *et al*., 2001; Greenwood *et al*., 2011).

Reducing and recovering construction waste is essential. McDonald and Smithers (1998), Teo and Loosemore (2001), and Esin and Cosgun (2007) suggest that the most efficient method of reducing the environmental impact of construction from waste is by principally preventing its generation and reducing it as far as possible. If waste generation could not be prevented or, at least, prevented to a certain degree, the next step should be to ensure that the construction waste is recycled and reused as much as possible (Esin and Cosgun, 2007). Analysis has shown that recovery reduces the amount of waste and Green House Gas (GHG) emissions, saves energy, and reduces the use of raw materials (Pimenteira *et al*., 2005). Recovery of useful energy and materials from waste has also been stressed as one of the key environmentally friendly practices for realising energy gains to lessen the pressing energy conditions (Marchettini *et al*., 2007).

Energy use reduction: Energy use is one of the most critical environmental issues and managing its use is inevitable in any functional society as discussed. The built environment is known to be the primary consumer of energy in the UK. According to Edwards (2002), 50% of total UK energy consumption is from the built environment, which is comprised of 45% heating, lighting, and ventilation of buildings then 5% is consumed through their construction. It is essential to state that the UK government has failed to live up to expectations in championing the course of energy review and reduction as it relates to sustainable development despite the fuel poverty bill (DTI, 2006b; Pitt *et al.*, 2009). This has necessitated the UK government to set a target to achieve a 60% reduction in energy use by 2050 (DTI, 2003a). A truly integrated approach to energy efficiency in building processes would need to be prompted by the project team right from the beginning of the projects to achieve the aimed energy consumption levels.

However, Thormark (2006) found out that the total energy needed for an energy efficient building may be even greater than in a building with a higher amount of energy required for operation. This is due to large amounts of energy being needed for production and maintenance of the technical equipment. Therefore, as the energy needed for operation decreases, more consideration must be given to the energy use for material production, which is the embodied energy. The embodied energy of a building is the total energy required for its construction, including the direct energy used in the construction and assembly process, and the indirect energy that is needed to produce the materials and mechanisms of the building (Huberman and Pearlmutter, 2008).

This indirect energy will include all required energy from the raw material extraction, through processing and production, and will consist of all energy used in transport during this process and the relevant portions of the energy embodied in the infrastructure of the factories and machinery of manufacturing, construction, and transportation. The primary goal of energy conservation is to reduce the consumption of fossil fuels, as well as increase the use of renewable energy in delivering sustainable buildings. Hence, attainable by selecting materials and components with low embodied energy, developing designs that will lead to energy-efficient building operation, energy self–sufficient building operation, designing for energy efficient deconstruction and recycling of materials, selecting means of transport for delivering materials and components to construction sites that are energy efficient, and developing energy efficient technological processes for the construction, fit-out, and maintenance of buildings (Akadiri, 2011a).

Efficiency in water use: it has been discovered that the UK water consumption rate in the last 30 years has increased to an estimated 70% (Brownhill and Yates, 2001). Consequently, with the need for approximately 4.1 million houses being built in the UK by 2016 (which was not achieved) combined with the increase in population and a higher standard of living, water use requirements will increase drastically, which might have a negative impact on society (Edwards, 2002, Pitt *et al*., 2009). It has been argued that the construction industry is in a position to implement water conservation techniques into refurbishment, retrofitting, and new build projects (Pitt *et al*., 2009). In a relative view, in its report, the DTI (2003b) states that incorporating water-efficient technology, such as low water flush toilets, domestic appliances, and reduced flow taps can achieve water use efficiency of about 20%. In similar views, some publications reveal strategies (Mendler and Odell, 2000; McCormack *et al*., 2007; Sev, 2009, Ilha *et al.*, 2009; Akadiri, 2011a), which can be employed to reduce the amount of water used through a building's life cycle. These approaches include system optimisation (i.e. efficient water systems design, leak detection, and repair), water conservation measures, and water reuse/recycling systems.

They suggest explicitly that a wide range of technologies and standards that can be employed within each of these strategies to save water consumption. These include:

- Water-efficient plumbing fixtures (ultra-low-flow toilets and urinals, waterless urinals, low-flow and censored sinks, low-flow showerheads, and water-efficient dishwashers and washing machines, design for dual plumbing to use recycled water for toilet flushing or a grey water system that recovers rainwater or other non-potable water for site irrigation;
- Minimising wastewater by using ultra-low-flush toilets, low-flow shower heads, and additional water conserving fixtures;
- Using re-circulating systems for centralised hot water distribution;
- Recycling water;
- Designing low-demand landscaping;
- Collecting rainwater using rainwater and greywater storage; and
- Using low-flow showerheads, dual flush toilets, and self-composting toilets.

Re-use and recycle: Zhang *et al*. (2000) argue that, through sustainable construction, the industry should ensure a systematic approach at an operational level that includes recycling construction materials and using renewable and recyclable materials. According to The Sustainable Construction Task Group (2004), 90% of existing building stocks will still be in use in the next 30 years; the group suggests that better management and retrofitting is needed and essential. BRE (2006b) study established that retrofitting and refurbishment are the more sustainable options if the industry’s positive impact is realised because it has a less environmental impact and is more cost-effective in comparison to redevelopment solutions (Anderson and Mills, 2002).

Efficient use of materials: there is a need for efficient use of materials in construction projects. Extraction and consumption of natural resources as building materials or as raw materials for the production of building materials and building materials production itself in delivering construction projects have a direct impact on natural biodiversity as earlier stated due to the fragmentation of natural areas and ecosystems caused by construction activities (Spence and Mulligan, 1995). In particular, a significant amount of mineral resources are consumed in the built environment, and most of these mineral resources are non-renewable. Therefore, it is imperative to reduce the utilisation of non-renewable materials.

Abeysundara *et al*. (2009) state that material use deliberations, particularly renewables, should be employed and discussed during different phases of the project, mainly in design during which the selection of materials is vital, and the choice should be based on sustainable materials' to reduce environmental impact. It is also imperative to mention that at the construction and deconstruction phases, several approaches can also be used for reducing the effects of materials consumption on the natural environment, for example, materials recycling and reuse, construction-for-disassembly by using modular, using materials and components available locally.

Pollution and biodiversity: the need to identify the risks associated with pollution in the environment and the steps taken to minimise potential pollution has been suggested (OGC, 2005, Pitt *et al*., 2009). It has been argued that pollution from construction industry affects bio-diversity, hence, necessary steps should be taken by the industry to protect the bio-diversity (ecosystem, genetic and cultural) through good design and landscaping (OGC, 2005).

2.6.3.2 Social sustainability

Brain (2010) argues that the social aspect of sustainability depends on an individual's economic status in relation to how rewarding their jobs are and how financially stable they are to suit their lifestyles. This is also applicable to the social aspect as it relates to the environmental factor. This is because the environment affects the social well-being of individuals, e.g. recreation involves the use of environmental resources and the physical environment we live in. A socially sustainable system must achieve fairness and equity in distribution and opportunity, adequate provision of social services including health, good education, gender equality and political accountability and participation, creating goodwill, improving community consultation and promoting interest in different fields (Harris, 2003). This area considers significant issues that influence the area such as poor health and crime; social expectations should be considered before any action is taken to make the area more sustainable (Boyko *et al*., 2006). Social sustanablity is concerned with human feelings, security, satisfaction, and the safety and comfort of society (Lombardi, 2001; Boyko *et al*., 2006; Roufechaei *et al*., 2014) and human contributions such as skills, health, knowledge, and motivation (Parkin, 2000a).

It also considers the quality of life, health, transport, accessibility, aesthetics, safety, and nuisance to neighbours (Roufechaei *et al*., 2014). The way the industry delivers the built environment has a significant impact on the social aspect of sustainability. If due consideration is not given to social aspect during the demolition, design and construction of buildings, it often results in the loss of opportunities and adverse social outcomes (Brain, 2010). It is essential that the industry considers the objectives of social sustainability in construction projects, policy development and programme implementation. This is because implementing social aspects of sustainability can also provide excellent living and working spaces resulting in increased employee productivity levels (Zhou and Lowe, 2003).

Social consideration of sustainability: the CIRIA (2011) argues that the quality, performance, and design of domestic and non-domestic buildings, and services and recreation, could directly affect the quality of life: the promotion of healthy living and cohesiveness of society. It stated that anyone that identifies or associates with a building could benefit from various sustainable practices. Walker (2000) asserts that stakeholders of the housing sector can provide crucial, valuable feedback about how they are affected and at the same time inter-relate in output delivery. It has been argued that sustainable buildings benefit from lower energy cost that is deemed to be vital, hence, the need for sustainable construction (Keeping and Shiers, 1996). However, Pit *et al.* (2009) argue that a good environment socially supports staff retention and employment and portrays the whole image of an organisation very positively. This, at the same time, keeps the organisation in an advantageous position. Shah (2007) argues that to achieve social sustainability in construction, stakeholders must be involved to have a positive impact on the local community/authority in the form of aspects such as the economy, skills, and working practice.

Therefore, the design of a building helps in developing the social aspect of sustainability or sustainable development in the built environment. The DTI (2003b) states, ‘Optimum design requires optimised performance on the construction site’. This implies that design plays a major role in delivering sustainable building projects. It is important that, while they are expected to work on the briefs or meet the needs of clients, they are expected to have the opportunity to inform the client about the necessary objectives that should be considered in the design to achieve a social aspect of sustainability. This can be achieved by creating awareness of the reduced operating costs, enhanced cooperate image, and consider the good well-being of end users (occupants). Additionally, Wyatt *et al*. (2000) argue that architects and other building design bodies have a great role to play. They affirm their suggestion quoting the code of conduct 1999 guarding architects who stated that while their fundamental responsibility is the client, it is essential that 'due regard to their wider responsibility to conserve and enhance the quality of the environment and its natural resources'.

2.6.3.3 Economic sustainability

Economic sustainability deals with a wide range of factors both at a local and global level (Gloet, 2006). It has been argued that an economically sustainable system must be able to produce goods and services continually to maintain manageable levels of government and external debt and to avoid extreme sectorial imbalances that damage agricultural produce or industrial production (Harris, 2003). The economic aspect of sustainability deals with the main economic concerns or drivers of adopting sustainable principles and the enhancement of property performance and durability as a result of maintenance and operational cost for the duration of the life cycle of the housing project (Kaats *et al*., 2007). Abidin and Paquire (2007) argue that economic sustainability increases profitability through the efficient use of human, material, and financial resources. On the other hand, regarding economic sustainability, the construction industry must consider affordable housing, the housing life cycle, and reduced expenditure on renovating and developing business enhancement, legislation compliance, profitability, and work management (Bennet and James, 1999).

Economic approaches to sustainability:

The global relevance of the construction industry, in relation to economic growth, particularly in the UK, has been widely stated. In the UK, the construction industry represents 8% of the GDP. It employs more than 2 million people in the UK with an estimated 20% of all employment linked to another sector in various ways (RICS, 2005a; Pitt *et al*., 2009; CIRIA, 2011). Abidin and Pasquire (2005) argue that the industry stakeholders had been considered the key drivers towards achieving sustainable development through sustainable construction. Abidin and Pasquire (2005) argue that the challenges of delivering this would be surmounted if the industry takes responsibility for achieving economic prosperity in the sector without undermining the societal gains.

The environmental impacts associated with construction, as discussed in Section 2.5, highlight the consequences of poorly managed construction projects and their impact on achieving sustainable construction. Abidin and Pasquire (2005) suggest that there is a necessity for an increase in client awareness of sustainability to avoid a predominantly financial decision-making process. Abidin and Pasquire (2005, 2007) argue that value management could help to reduce the environmental and social damage that will affect the industry economically. They suggest that this could be achieved if the industry can integrate solutions in the design process such as waste minimisation, energy efficiency, good indoor environment, low running costs, and user comfort. The industry can also help in achieving a good economic return, accountability, and excellence in social and environmental performance, such as value management and lean construction that will assist in realising or achieving sustainable development (Pitt *et al*., 2009).

2.7 Criticism of sustainability and sustainable development

Despite the commendable concepts of sustainability and sustainable development, it has been criticised since its emergence into prominence. The term sustainable development seems to connote scepticism expressed by many in the environmental community (Robinson, 2004). Much of the criticism is centred on the argument presented in the Brundtland report that global economic product would have to increase five- to 10-fold for the realisation of sustainable development. Some critics of sustainable development have described the concept of sustainability as ‘a fashionable concept’ (Beckerman, 1994) and ‘a central idea and goal’ for international bodies to accomplish effective integration between development and environmental challenges (Lafferty, 1999). Such an approach definition is more attractive to government and businesses than a more radical tackling of environmental issues. Zhenhua (2003) defines sustainability as a statement of aspirations: a voluntary agreement rather than a binding treaty. The term ‘sustainable development’ is perceived by some critics as fundamentally inconsistent in terms, between the opposing imperatives of growth and development, on the one hand, and environmental (and perhaps social and economic) sustainability on the other

(Robinson, 2004). These critics believe that trying to achieve sustainable development equals trying to square the circle, hence, trying to accomplish the impossible.

Considering these criticisms, it is not surprising that different conceptions of the meaning of sustainable development and sustainability tend to reflect the political and philosophical position of those proposing the definition more than any unambiguous scientific view (Mebratu, 1998). This is why Robinson (2004) argues the challenge relates to sustainable development being perceived as naturally reformist, mostly avoiding questions of power, exploitation, even redistribution. Hence, the necessity for more fundamental social and political change is disregarded. Instead, critics argue that champions of sustainable development suggest an incrementalism agenda that does not challenge any existing entrenched powers or privileges (Robinson, 2004). In this regard, the mantra of sustainability tends to distract society from the real social and political changes that are vital to improving human well-being in any substantial way, particularly for the poor. This argument can be related to the anti-globalisation campaign movement worldwide (Klein, 2000). Mitcham (1995) acknowledges that the sustainability concept incorporates a level of ‘studied or creative ambiguity’. For Robinson (2004) the ambiguity surrounding sustainability is a strength rather than a weakness. However, Dresner (2008) insists that sustainable development ambiguity, as mentioned earlier, does not diminish its meaningless concept, and, therefore, it is a welcome development. Considering this view, Jacobs (1999) states that the ambiguity surrounding sustainability is a ‘contestable concept’ rather than a meaningless one. This means that the interpretation of sustainability remains open to different conceptions.

From the criticism discussion, it is evident that some ‘schools of thought’ disagree with the sustainability concept, hence, lack coherence of understanding amongst scholars. However, the current global environmental challenges call for urgent attention from the comity of nations to promote further unwaveringly the importance of sustainability in society. However, the ensuing section discusses sustainability in construction.

2.8 Sustainable construction

Throughout the last decade, sustainable construction has emerged as a public discussion and has become a topic of policy, research and innovation. The term ‘sustainable construction’ was firstly purposed to define the responsibility of the construction industry for attaining sustainability/sustainable development. Several definitions have emerged. However, there has been a different definition of sustainable construction. Charles Kibert, during The First International Conference on Sustainable Construction in Tampa, 1994, defined sustainable construction as ‘*creating and operating a healthy built environment based on resources efficient and ecological principles*’ (cited in Du Plessis, 2007: p.69). Du Plessis (2007) defines it as ‘*a holistic process aiming to restore and maintain harmony between the natural and built environment and create settlements to affirm human dignity and encourage economic equity*’. Kibert (2003) defines sustainable construction as the creation and operation of a healthy built environment based on resource efficiency and ecological principles. The term ‘sustainable construction’ is described as the application of sustainable development in the construction industry (Al-Yami and Price, 2006).

However, Khalfan *et al.* (2002) describe sustainable construction as a subset of sustainable development, which encapsulates matters such as design, tendering, site planning and organisation, material selection, recycling, and waste minimisation. Du Plessis *et al.* (2002) define sustainable construction as *‘a holistic process aiming to restore and maintain harmony between the natural and the built environments, and create settlements and affirm human dignity and encourage economic equity*’ (p.8). These definitions take sustainable construction beyond reducing adverse impacts, but include the restoration of the environment and identifying the socio-economic aspects of sustainable development as well as defining goals towards sustainable development through sustainable construction. These definitions are not wholly satisfactory, but they identity with the three aspects of sustainable development.

Nevertheless, sustainable construction can be classified into demolishing, and new build, and sustainable retrofit of existing housing stock. Of course, as the name suggests, ‘demolition and new build’ means building a new structure from demolition to groundwork and the entire construction process, including finishing and handover with sustainable or low carbon materials, considering three sustainable development factors. However, sustainable retrofitting means the refurbishment of an existing building with low carbon materials to improve energy efficiency. Further discussion on sustainable retrofitting can be seen in Section 2.10.

2.8.1 Sustainable construction in the UK

In the UK, there is commitment and effort towards achieving sustainable development set out in five sustainable development strategies (SDS) to secure the future of the country in relation to environmental degradation. Those five strategies are referred to as the 'guiding principles' of sustainable development, and they include living within the planet's environmental limits, ensuring a strong, healthy and just society, achieving a sustainable economy, promoting good governance, and using sound science responsibly (DEFRA, 2011). Such commitment to sustainable construction is referred to as *building a better quality of life – a strategy for more sustainable construction* (DETR, 2000a). Since the agenda has been made public, the sustainable construction agenda has been taken forward through a dynamic partnership between the government and the industry. As a result of that, there have been several developments, which are summarised below.

- There has been an increase in the number of voluntary policies, legislation, regulations, economic measures, and fiscal incentives, such as Landfill Tax, Climate Change Levy, Aggregates Levy, Renewable Grant Schemes, Land Use Incentives, and changes to Building Regulations.
- The Building Regulations, the Planning White Paper, the Communities Plan and the Energy White Paper have been amended to reflect the sustainable construction agenda. There are several joint initiatives to promote awareness, capacity building, and reporting mechanisms, such as Global Reporting Initiatives, CIRIA's industry sustainability indicators, the sustainable construction task force, and the sustainable building task force.
- Sectors within the industry (e.g. steel, concrete, brick, and civil engineering) have developed their sustainability strategies and action plans and have started reporting on progress.
- A host of sustainable construction project initiatives have emerged providing tangible evidence of positive outcomes such as Rethinking Construction, the Waste and Resources Action Programme (WRAP), and the Sustainable Construction Road Show (SCRS).

- The government nationwide has funded research centres in relation to sustainable construction. The centres have organised numerous conferences and have published books and journals. These publications are available in universities and are used in offering various courses and degrees in different fields.
- There exists a plethora of research on sustainable construction concepts, including tools, frameworks, technologies, materials, energy systems, water conservation systems, waste minimisation, recycling techniques, alternative materials, and environmental management. The results are available as publications (e.g. CIRIA reports), digests (e.g. BRE), guidance notes (e.g. Environment Agency Pollution Prevention Guidance (EAPPG), videos, and training packs.

However, the UK government has introduced a wide range of measures to promote competitiveness, such as the Enterprise Strategy, Enterprise: unlocking the UK's talent (DBIS, 2008a) and the Innovation White Paper, Innovation Nation (DBIS, 2008b). For the UK to achieve its environmental targets, the government has to first collaborate with the construction industry to demonstrate that a change was needed and second, implement a strategic reform in the manner in which the industry operated to improve both environmental standards and national sustainability. Thus, the introduction of a strategy for achieving sustainable construction. This strategy is developed by the government and the industry to focus on sustainability in construction (HMG, 2008). The strategy is a joint industry and government initiative and is intended to promote leadership and behavioural change, as well as to deliver substantial benefits to both the industry and the broader economy (HMG, 2008). However, this strategy complements the Action Plan for Civil Engineering published in July 2007 (DTTP, 2007), but it does not encompass some of the broader issues facing developers such as planning (DCLG, 2012b), the management of the existing built environment (NPBEC, 2016), and transport policy (HCEAC, 2016). The HMG (2008) outlines important targets agreed in the strategy that is believed would radically change the sustainability practice in the construction industry including:

- Increasing profitability through the efficient use of resources;
- Encouraging firms to secure the opportunities offered by sustainable products or ways of working; and
- Enhancing the company's image and profile in the marketplace by addressing issues relating to corporate and social responsibility.

The HMG (2008) states that the purpose of the strategy is aimed at providing clarity around the existing policy framework and signalling the future direction of government policy. It seeks to realise the shared vision of sustainable construction by:

- Providing transparency to businesses on the government's position by bringing together diverse regulations and initiatives relating to sustainability;
- Setting and committing to higher standards to help achieve sustainability in specific areas; and
- Industry and government are making specific commitments to take the sustainable construction agenda forward.

To achieve the key targets of the strategy, the UK government and industry have developed a set of all-encompassing objectives related to the 'ends' and 'means' of sustainable construction. The 'ends' relate directly to sustainability issues, such as climate change and biodiversity; the 'means' define processes needed to assist in achieving the 'ends' (see Table 2.5). Table 2.5 also highlights the 'overarching targets' of the strategy with a brief discussion. The 'chapter headings' in Table 2.5 outline a vital delivery plan and specific actions the government and the industry should employ in delivering the targets.

Table 2. 5 UK strategy for sustainable construction (Adapted, HMG, 2008)

	Chapter Headings	Overarching targets
The 'Means'	Material	That the materials used in construction should have the least environmental and social impact as is feasible both socially and economically.
	Procurement	This is to achieve improved whole life value through the promotion of best practices in construction and supply side integration, by encouraging the adoption of the construction commitments in both the public and private sectors and throughout the supply chain.
	Design	The overall objective of good design is to ensure that buildings; infrastructure; public spaces and places are buildable: fit for purpose; resource efficient; sustainable; resilient; adaptable and attractive. The aim is to achieve greater use of design quality assessment told relevant to buildings; infrastructure; public spaces and places.
	Innovation	To enhance the industry's capacity to innovate and increase the sustainability of both the construction process and its resultant assets.
	People	An increase in organisation committing to a planned approach to training (e.g. skills pledges; investors in people or other business tools; continuous professional development (CPD); lifelong learning). Reduce the incidence rate of fatal and major injury accidents by 10% year on year from 2000 levels.
	Better Regulation	A 25% reduction in the administrative burdens affecting the private and third sectors, a 30% reduction in those affecting the public sector by 2010.
The 'Ends	Climate Change Regulation	Reducing total UK carbon-dioxide (CO_2) emission to about 60% on 1990 levels by 2050 and by at least 26% by 2020. Within this at least government has already set out its policy that new homes will be zero carbon by 2016, and an ambition that new schools, public sector non- domestic building and other non-domestic buildings will be zero carbon by 2018 and 2019 respectively.
	Water	To assist with the future water vision to reduce per capita consumption of water in the home through cost effective measures, to an average of 130 litres per person per day by 2030, or possible even 120 litres per person per day depending on new technological developments and innovation.
	Biodiversity	That the conservation and enhancement of biodiversity within and around construction sites is considered throughout all stages of a development.
	Waste	By 2012, a 50% reduction of construction, demolition and excavation waste to landfill compared to 2008.
	Material	That the materials used in construction should have the least environmental and social impact as is feasible both socially and economically.

On the surface, it would appear that these efforts by the government are a significant success story and the industry movement toward more sustainable construction has gained considerable momentum. However, the actual situation may not be as expected because the industry is still confronted with major challenges (Kibert, 2005; CIRIA, 2011). It is significant to note that in these government's strategies and efforts to achieve sustainable construction, it is unfortunate that retrofit projects receive the least attention. The essence of embarking on retrofitted building projects to contribute to GHG reduction is inevitable and cannot be over-emphasised. In addition, lack of knowledge management in making an informed decision in the uptake and delivery of sustainable construction remains a big challenge for the industry (Egbu *et al.*, 2004; Shelbourn *et al*., 2006; Maduka *et al*., 2016b).

2.9 Sustainable construction practices

With a clear sustainability strategy, stakeholders should identify and select their specific sustainable construction practices to assume their commitments. Perera *et al*. (2007) argue that sustainable practices should consider the environmental, social, and economic consequences of design, manufacture and production methods, non-renewable material use, logistics, recycling options, use, operation, maintenance, reuse, suppliers' capabilities, and service delivery and disposal. Stubbs (2008) states that the construction industry has traditionally been driven by financial concerns that have often prevented proper consideration of environmentally friendly solutions.

Furthermore, construction techniques have evolved over long timeframes, and some areas of the industry are reluctant to abandon or change their tried and tested methods particularly when they maximise profits. Within this context, progress towards environmental management procedures has been slower compared to other sectors, particularly those that are more controlled by technological developments. Against this backdrop, it is no surprise that changes in construction practices are now seen as increasingly important in addressing the issues of environmental damage and overall sustainability. Environmental awareness is gradually improving, but the industry needs to shake off its reputation for being reluctant to adopt environmental necessities (Maduka *et al*., 2016b).

DTI (2006c) and HoC (2006) outlined key sustainable construction practices, namely: (a) establishing effective construction programmes; (b) developing and supporting well focused and capable public sector clients; (c) designing and decision- making based on 'whole-life value'; (d) using the appropriate procurement and contracting strategies; (e) working collaboratively with fully integrated teams; and (f) evaluating performance, and embedding project learning. HoC (2006) states that sustainable construction practices include five major areas: 1. Compliance with sustainability legislation; 2. Design and procurement technology and innovation; 3. organisational structure and process; 4. Education and training; and 5. Measurement and reporting. Different organisations' characteristics lead to different choices in sustainable construction practices (HoC, 2006). It is pertinent to state that sustainable construction practices should be consistent in all construction projects.

First, better regulation will provide the right balance between regulation and environmental protection without hugely increasing costs or preventing compliance (HMG, 2008). Second, sustainable design has a significant impact (both positive and negative) on project delivery before construction begins. Sustainable procurement provides a green supply chain system where all the materials and equipment are supplied in a sustainable manner (Vanegas, 2003). Third, technology research and development (R&D) plays a vital role in the sustainable construction, and efficient R&D will result in considerable improvement in sustainability performance (Miyatake, 1996). Fourth, appropriate organisational structure and process are also necessary to determine responsibilities, authority, lines of communication, processes, and resources needed to implement sustainable management arrangements (Hill and Bowen, 1997a).

Ruparathna and Hewage (2015) argue that an appropriate process is demonstrated when organisations meet their needs for goods, services, works, and utilities in a way that achieves value for money on a whole life basis in terms of generating benefits not only to the organisation, but also to society and the economy, whilst minimising damage to the environment. Fifth, the importance of education and training for sustainable development has been pointed out by many governments and non-governmental organisations (NGOs) because it changes the way stakeholders think about nature (Huckle and Sterling, 1996). Finally, measurement and reporting provide proof of business care for sustainable construction and encourage construction organisations to promote their sustainability performance (Michael *et al.*, 2009).

2.9.1 Achieving sustainable construction

Kibert (1994b) states that the sustainable construction concept focuses on creating a sustainable built environment under six principles, which include: 1. Minimise resource consumption; (2) Maximise reuse; (3) Use renewable or recyclable resources; (4) Protect national environment; (5) Create a healthy, non-toxic environment; and (6) Pursue quality in creating the built environment. Hill and Bowen (1997b) summarisethe concepts of sustainable construction and divide them into four pillars including social, economic, biophysical and technical principles with a set of the process-oriented principles. Procurement design, innovation, people and better regulation are considered as a means for achieving sustainable construction (HM Government, 2008). DTI (2006a) and HoC (2006) outline key sustainable construction practices namely: establishing effective construction programmes, developing and supporting well focused and capable public sector clients, designing and decision making based on ‘whole-life value’, using the appropriate procurement and contracting strategies, working collaboratively with fully integrated teams, evaluating performance, and embedding project learning/knowledge. These sustainable practices are reiterated in some existing studies, for example CIB, (1999b), Christini *et al*. (2004), Trufil and Hunter (2006), Nelms *et al*. (2007), Kibert (2008), and Pitt *et al*., 2009). Additionally, the efforts of the UK government to support sustainable construction are revealed as stated in CEEQUAL (2019); through CEEQUAL, the UK government encourages and promotes the realisation of high economic, environmental, and social performance in all forms of civil and sustainable construction projects and delivers best practices. CEEQUAL supports UK Government strategies and other governments by providing the infrastructure professions and global industry with an incentive and procedure for evaluating, benchmarking, and rating the sustainability performance of projects and contracts as a measure of the industry’s contribution to sustainable development.

According to Stubbs (2008), sustainable construction aims to apply the principles of sustainable development to the construction industry. Stubbs (2008) further states that it involves the delivery of buildings, structures, supporting infrastructure, and their immediate surroundings, which: (a) maximise the efficient use of resources by using fewer raw materials and less energy, as well as causing less pollution and waste;

(b) improve quality of life and offer customer satisfaction; (c) offer flexibility, with the perspective to accommodate for future changes in use; (d) provide and support pleasing natural and social environments; and (e) still deliver profits. All these factors have to be considered at the earliest possible stage of a project's development to maximise its sustainability during the construction phase and over its operational lifetime. It is easy to forget that a building's impact lasts long after the construction phase. However, the efficiency of a building regarding operation and maintenance is mostly decided in the early planning, specification, and designing stages (Sodagar and Fieldson, 2008; Greenwood *et al*., 2011). In achieving sustainable construction, Greenwood *et al*. (2011) and Stubbs (2017) suggest that sustainable project proposals should therefore carefully consider design construction, operation, and ultimately demolition phases. As well as having direct impacts on sustainability, the location and structure of buildings also has indirect impacts by influencing the level of sustainable behaviour of occupants (Stubbs, 2008). For example, offices away from transport routes encourage car use and windows that cannot be opened, hence, promote the use of air conditioning, and poorly planned working environments lead to reductions in well-being, health, and productivity.

Sodgar and Fieldson's (2008) publication is themed 'Towards a sustainable construction practice'. Adopting the 'key stakeholder's roles', this study investigates the key stakeholders' roles and responsibilities in achieving sustainable building and supports it with other existing literature, as presented below. The key stakeholders' roles include sustainable client-ship, sustainable design, sustainable services design, sustainable cost management, sustainable construction, sustainable operation, and sustainable deconstruction.

Sustainable client-ship: Sodgar and Fieldson (2008) state the need for key stakeholders to show leadership in selecting the design and procurement team and managing the project to promote proper use of human resource and knowledge. They emphasised the respect of the client for the values of the organisations it involves in building procurement alongside the precise definition of its benefits. The USGBC (2011) agree to this and emphasise the need for key stakeholder integration. They state that to achieve sustainable development through sustainable construction, it is essential that economic, social and environmental gains should be sought jointly and simultaneously by key stakeholders through the planning system.

Sustainable design: Good design is a crucial aspect of sustainable development that is inseparable from proper planning, and should contribute positively to making places better for people. Sodgar and Fieldson (2008) state that the identification of the most appropriate design strategies is essential in sustainable construction so that, if applied to all aspects of design from inspection to completion, it should maximise quality and minimise impact. They emphasise the need to monitor the entire life circle of the construction (planning to disposal) and application of low energy in the building process. McGraw-Hill-Construction (2006) and DCLG (2012a) corroborate this by indicating that a design philosophy that seeks to maximise the quality of the built environment, while minimising or eliminating negative impacts to the natural environment, is essential to managing risk through adaptation.

Kibert (2005) argues that sustainable design by the involvement of all key internal and external stakeholders is vital. Diverse representation from the project team functions (design, architecture, building contractor, environmental engineer, real estate consultant, etc.) is ideal (McGraw-Hill-Construction, 2006). Establishing design criteria will help communicate the project's goals and priorities to the project team in a measurable technical form (Robichaud and Anantatmula, 2008). The DCLG (2012) argues that policies on sustainable design and construction should be set out in a development plan document to ensure full consultation with the local community and other stakeholders and examination by the Planning Inspectorate. Such policies should focus on local opportunities and constraints, while avoiding the repetition of nationally available information.

Sustainable services: Sodagar and Fieldson's (2008) design of renewable services systems should be carried out as part of the building form design and site layout, not as an afterthought, otherwise maximum generation capacity will not be achieved. The building should also be targeted at maximising efficiency before low carbon technologies that need to be included in carrying out the design. The DCLG (2012) states that proper application or implementation of sustainable design should achieve minimum reductions in greenhouse gas emission (regulated and unregulated energy use) from renewable energy generation on site or in the locality of the development as long as a direct physical connection is used. Unless it can be demonstrated, that such provision is not technically or economically viable (DCLG, 2012).

Sustainable cost management: Sodagar and Fieldson (2008) argue that calculation of capital or initial cost with running cost/maintenance should be made, and these costs must balance and be justified. Knowledge management alongside corporate responsibility evaluation to provide better decisions in cost evaluation for sustainability should be applied. Lack of confidence, lack of education and fear of failure should be avoided. Robichaud and Anantatmula (2011) argue that complete preconstruction estimates with input from the builder, project manager, architect and real estate consultant are vital. They stated that estimating costs associated with specialised areas such as sustainable building products requires experience. The budget may also include an emphasis on life-cycle costing, shifting the focus from short-term to long-term gains from operational savings (Robichaud and Anantatmula, 2008, DCLG, 2012a).

Sustainable construction: This is the management of the construction process in a safe, efficient and effective way to save money and time, and much of this cost is related to fuel use and logistics (Sodagar and Fieldson, 2008). Kibert (2005) argues that the goal of sustainable construction is to create and operate a healthy built environment based on resource efficiency and ecological design with an emphasis on seven core principles across the building's life cycle: reducing resource consumption, reusing resources, using recyclable resources, protecting nature, eliminating toxins, applying life-cycle costs, and focusing on quality. Employing modularisation and off-site construction methods to reduce performance uncertainties and risk of accidents on site is suggested (Sodagar and Fieldson, 2008). This will help to achieve environmental benefits regarding reducing waste from materials and transportation and can improve building performance concerning air tightness and finish quality. Robichaud and Anantatmula (2008) suggest launching construction with a kick-off meeting, which includes a sustainable education component for on-site construction personnel; monthly on-site meetings are required by entire site workforce and include periodic education and training sessions on sustainable building construction projects.

Sustainable operation: Good and well-informed facilities management is critical to excellent building performance, post-occupancy evaluation carried out regularly is vital, and the monitoring of services is necessary to ensure the building is operating as it was designed to and occupant surveying will help to establish comfort levels.

The need for additional investment from time to time is stated (Sodagar and Fieldson, 2008). Maintenance and cleaning are vital to ensure a building continues to perform well. Robichaud and Anantatmula (2008) suggest that, in sustainable operation, key stakeholders such as government regulators should work as partners in the project, as opposed to being an outside influence. Hence, less rework and field adjustments reduce the chances of having to request re-inspections.

Sustainable deconstruction: Implementing deconstruction is not an easy task. Hence, Sodgar and Fieldson (2008) suggest that good, well-informed facilities management is critical to excellent building performance, post-occupancy evaluation carried out regularly is vital, monitoring of services is necessary to ensure the building is operating as it was designed to, and occupant surveying will help to establish comfort levels. Kibert (2001) argues that successful implementation could not occur without a support structure of government, regulations, and businesses working together toward a joint goal. Deconstruction can result in environmentally sound community economic development through the formation of partnerships between non-profit social service and environmental organisations, government agencies, and the private sector (Catalli and Goode, 1997). It is necessary first to educate and train those who are potential de-constructors or rather stakeholders working in the field of demolition are primary targets (Kibert, 2001). In addition to education and training, outlets for the recouped materials has to be created.

Deconstruction can supply useful materials for building materials yards, recycling centres, and remanufacturing enterprises, which, in turn, can create additional jobs and community revenues (Kibert 2001). Kibert (2001) states that deconstruction has advantages over conventional demolition and that the advantages are an: (a) increased diversion rate of demolition waste from landfill; (b) potential reuse of building components; (c) increased ease of recycling of materials; and (d) enhanced environmental protection locally and globally. Kothari (2009) corroborate this by stating that deconstruction assists in waste management, maximises reuse and recycling, reduces environmental impact, minimises negative social impacts, and reduces unrenewable fuel usage. Sodgar and Fieldson (2008) suggest the need for additional investment from time to time for a sustainable outcome.

2. 9.2 Regulatory legislation, policies and guidance into achieving sustainable construction

Appropriate organisational structures and processes are essential to determine responsibilities, authority, lines of communication, processes, and resources to implement sustainable construction (Hill and Bowen, 1997). However, better regulations and policies will provide the right balance between environmental regulations and protection without unduly increasing costs or deterring compliance (HMG, 2011). The following explains the importance of sustainability legislation and policies in achieving sustainable construction.

2.9.2.1 Who are bound by these policies and guidance?

- Building owners/clients and occupiers who are considering what action they need to take to improve energy performance, and to meet or surpass a range of statutory requirements.
- Architects, surveyors and related professionals who are preparing proposals for work on traditional or historic buildings, and who need to make an appropriate professional response to requirements, which can often conflict.
- Building contractors, materials and component suppliers who need to understand the implications of decisions they make in carrying out their work, or of the technical advice they give to their customers.
- Officials, such as conservation and planning officers, building-control surveyors, approved inspectors, environmental health officers and housing officers, who will be experts in one area (for example building conservation, general legislation or energy performance). Hence, it may be less familiar with the balances that need to be struck in reaching reasonable solutions that suit all parties. Table 2.6 highlights government policies and responsibilities.

Table 2. 6 Regulatory legislation, policies and guidance into achieving sustainable construction

Government Policies and Legislations	**Roles and Responsibilities**
Code for Sustainable Homes (CSH) (DCLG, 2006a; DECC, 2011b)	Has a target to achieve the UK government's objective of 80% carbon reduction in both new and existing buildings by 2050 (Kapsalaki *et al.*, 2012). It has different levels of energy improvement, e.g. Level 3 to achieve 25% energy improvement, level 4 to achieve 44%, level 5 to deliver 100% and Level 6 to deliver 0%. To ensure that from 2016 all new builds must comply with the code levels.
Building Research Establishment Environmental Assessment Method (BREEAM)	To ensure the environmental impacts of buildings and energy rating performance on a simple scale of Pass to Excellent. The housing standard is known as Eco-Homes. The rating is a comprehensive environmental assessment process that covers all the following aspects: Management; operational energy; transport; water; materials; land use; the ecological value and pollution. It promotes and adapts best practices for sustainable design and post-occupancy management within the sector. To reduce the whole life costs for new and refurbishment projects.

	To develop stakeholders by providing training and information for sustainable design, construction and post-occupancy management.
Climate Change Act 2008 (HMG, 2008, 2011).	Has a five-year carbon budget reduction that defines emissions pathway to achieve 2050 CO_2 reduction target. A clear strategy to CO_2 reduction in the UK Established an independent expert body Committee for Climate Change (CCC) to advise the government properly and report to the parliament on the progress made. Domestic and non-domestic sectors included in this Act.
Energy Performance Certificates (EPC) (DCLG, 2012).	To ensure that buildings in the UK meet the required EU standards in Energy Performance Building Directives. Certificates provided to Clients or accredited energy assessors using standard methods and assumptions about energy usage produce the industry. Ensure that stakeholders in the industry (buyers, owners, occupiers etc.) should see the needed information on the energy efficiency and carbon emissions from their buildings so they can consider energy

	efficiency and fuel costs as part of their investment. The accreditation scheme covers existing buildings, new buildings, commercial buildings, energy display certificates and air-conditioning inspection reports. Types of accredited energy assessors include; Building Research Establishment, ECMK Ltd, Quidos, Sterling accreditation, Stroma etc.
Building Regulations (DCLG, 2012).	It sets a standard on the minimum energy reduction level in a building for acceptable performance. Mainly applied to new buildings hence no general required standard for existing buildings. It is supported by the Approved Document (Part L), which serves as guidance for complying with various forms of construction. This document is in four sections that include: (a) new dwelling buildings (L1A); (b) existing dwelling buildings (L1B); (c) new non-dwelling buildings (L2A); and (d) existing non-dwelling buildings (L2B).
Fuel Poverty Policy (National Statistics, 2011)	Policy created largely to reduce CO_2 and high cost of energy. Reduce the increase in fuel bills
Building Performance and Evaluation Certificate (BPEC) (Commission, 2002,	To ensure robust measurement and certification procedure is in place (Kelly *et al*., 2012).

Green.Fiscal.Commission, 2009, DECC, 2011a).	Helps to aggregate data in various ways to ascertain the performance of buildings in different categories (Kelly *et al.*, 2012). Exposes hidden information about the performance of a building Addresses the issue of imperfect information and encourages much-needed investments in building energy efficient homes (Commission, 2002).
Display Energy Certificates (DEC) (DCLG, 2012).	It champions the improvement of energy performance of buildings, and it covers England and Wales. Ensure that public knowledge was created on the energy use of buildings to enlighten the visitors of energy use to a particular building. Display the certificate in a prominent and visible part of a building for visitors to that building to be aware. Ensure that the certificate displayed has an energy rating of the building from A-G with A indicates Very Efficient and G indicates the Least Efficient and these are based on the actual quantity of metered energy used in the building for the last 12 years. Provides the building with a valid advisory report, which contains recommendations for improving the energy performance of the building.

	The report also includes short-term payback of up to 3 years (to build energy management measures), medium payback which is 3 to 7 years (upgrading building services) and long-term payback, which is more than 7 years (low carbon or zero technologies).

2.9.3 Sustainable construction principles

As the sustainable construction initiative continues to develop and gain popularity, critics and supporters alike are continually evaluating the progress (Adrien and Laura, 2010). By employing sustainability principles, the evaluation has to include more than the immediate investors/clients/tenants of the buildings, but also consider suppliers, the local community in which the structure resides, and other key stakeholders. Sustainable principles have to be embraced, promoted, and implemented in construction projects. In respect to sustainable principles for sustainable construction, various efforts have been made to examine several definitions of sustainability in an attempt to articulate principles to be maintained in achieving sustainable construction. Kibert (1994a) states that sustainable construction principle focuses on creating a sustainable built environment under six principles:

1) minimise resource consumption ;

2) maximise resource reuse ;

3) use renewable or recyclable resources ;

4) protect the natural environment;

5) create a healthy, non-toxic environment; and

6) pursue quality in managing the built environment.

Amongst the published works relating to the principles of sustainable construction are Kibert (1994a), Liddle (1994), Miyatake (1996), Hill and Bowen (1997a), DETR

(2000b), Ding (2008), SECBE (2009), Abidin (2010), and Maduka *et al*. (2016b). In general, there is a consensus that the extent of the principles of sustainable construction reflects those of sustainable development, which is about synergistic relationships between economic, social and environmental aspects of sustainability. Each of these three pillars/aspects (and their related principles) are over-arched by a set of process-orientated tenets. The principles of sustainable construction govern three main pillars: environmental protection, social well-being, and economic prosperity (Addis and Talbot, 2001; Brownhill and Yates, 2001). The benefits of these principles in the built environment and society in general (Hill and Bowen, 1997a) are essential for the present and future generations including environmental protection, as it concerns the built and natural environments.

The built environment refers to the activities within the construction project itself, which may, if not handled efficiently, have a severe adverse impact on the environment. Environmental sustainability involves the extraction of natural resources (Addis and Talbot, 2001). Social well-being relates to the human feelings: security, satisfaction, safety and comfort (Lombardi, 2001) and human contributions: skills, health, knowledge and motivation (Parkin, 2000b), the involvement of stakeholders, equality and diversity in the workplace, and creating employment opportunities (Sourani and Sohail, 2013). Finally, economic sustainability involves the monetary gains from the project for the benefits of the clients, construction players, public and the government (Abidin and Paquire, 2007). Hence, it focuses on issues such as whole-life costing, support of local economies and financial affordability for intended beneficiaries. Construction activities need to reduce environmental impact and enhance social and economic contribution (Hill and Bowen, 1997a) if the key stakeholders fully recognise sustainable principles in delivering construction projects. It is essential that when stakeholders set up a sustainability strategy in projects, the principles of sustainable construction should be implemented in the approach and appreciated by all stakeholders.

Hill and Bowen (1997a) summarise the principles of sustainable construction and divide them into four ‘pillars’, including social, economic, environmental, and technical principles. However, this research highlights three main principles of sustainability in Tables 2.7, 2.8, and 2.9. It is relevant to state that some of these principles were used when asking questions during the collection of empirical data. This was achieved through a survey questionnaire; respondents were asked to ascertain the principles of sustainable construction. Chapter 6 of this thesis has details of the empirical evidence of sustainable principles and practices in sustainable construction.

Table 2. 7 Economic principles of sustainable construction

Economic sustainable principles	**Sources**
Ensure financial affordability for intended beneficiaries	(Hill and Bowen, 1997a; Zhou and Lowe, 2003; Plank, 2008, Tan *et al*., 2011; Kibert, 2016)
Promote employment creation and, in some situations, labour intensive construction	(Hill and Bowen, 1997a; Zhou and Lowe, 2003; Plank, 2008; Tan *et al*., 2011; Kibert, 2016)
Use full-cost accounting and real-cost pricing to set prices and tariffs	(Hill and Bowen, 1997)
Enhance competitiveness in the market place by adopting policies and practices that advance sustainability	(Hill and Bowen, 1997)
Choose environmentally responsible suppliers and contractors and Stakeholder partnership	(Hill and Bowen, 1997a; Zhou and Lowe, 2003; Plank, 2008; Tan *et al*., 2011; Kibert, 2016)
Invest some of the proceeds from the use of non-renewable resources in social and human-made capital, to maintain the capacity	(Hill and Bowen, 1997a, Zhou and Lowe, 2003; Plank, 2008; Tan *et al*., 2011; Kibert, 2016)

Table 2. 8 Environmental principles of sustainable construction

Environmental principles of sustainable construction	**Sources**
Extract fossil fuels and minerals, and produce persistent substances foreign to nature, at rates that are not faster than their slow redeposit into the earth's crust.	(Hill and Bowen, 1997; Kibert, 1994a)
Reduce the use of four generic resources used in construction, namely, energy, water, materials and land.	(Hill and Bowen, 1997; Kibert, 1994)
• Maximise resources reuse, and /or recycling • Use renewable resources in preference to non-renewable resources	(Kibert, 1994a; Hill and Bowen, 1997a)
Maintain and restore the earth's vitality and ecological diversity	(Kibert, 1994a; Hill and Bowen, 1997a)
Create a healthy and non-toxic environment	(Kibert, 1994a; Hill and Bowen, 1997a)
Minimise air, land and water pollution at global and local levels	(Hill and Bowen, 1997)

Table 2. 9 Social principles of sustainable construction

Social principles of sustainable construction	**Sources**
Seeking intergenerational equity	(Hill and Bowen, 1997a; Zuo *et al*., 2012a; Yin *et al*., 2018)
Stakeholders participation	(CIB, 1999^{a}; GCCP, 2000; Adetunji *et al*., 2003; Ashley *et al*., 2003)
Improve the quality of human life, including poverty alleviation	(Hill and Bowen, 1997a; CIB, 1999a; Sourani and Sohail, 2005; Zuo *et al*., 2012a; Yin *et al*., 2018)

Protect and promote human health through healthy and safe working environment	(Hill and Bowen, 1997a; GCCP, 2000; Adetunji *et al*., 2003; Ashley *et al*., 2003; Zuo *et al*., 2012a; Yin *et al*., 2018)
Social inclusion	(Ashley *et al*., 2003; Berardi, 2013; Kibert, 2016)
Improving the image of construction	(DETR, 2000[a]; CIB, 2010; Yin *et al*., 2018)
Employment and equal opportunities in employment	(DETR, 2000a; Adetunji *et al*., 2003; Sourani and Sohail, 2005; Plank, 2008; Tan *et al*., 2011; Kibert, 2016)
Protect and promote human health through healthy and safe working environment	(Hill and Bowen, 1997a; GCCP, 2000; Adetunji *et al*., 2003; Ashley *et al*., 2003; Plank, 2008; CIB, 2010)
Equality	(GCCP, 2000; Rethinking-Construction, 2002; Adetunji *et al*., 2003; Tan *et al*., 2011)
Seek for fair and equitable distribution of social costs of construction	(Hill and Bowen, 1997a; Plank, 2008; Tan *et al*., 2011; Kibert, 2016)
Make provision for social self-determination and cultural diversity in development planning	(Hill and Bowen, 1997a; CIB, 1999a; Sourani and Sohail, 2005; CIB, 2010; Kibert, 2016)
Compensation and benefits	(Adetunji *et al*., 2003; Berardi, 2013; Kibert, 2016)
Implement skills training and capacity enhancement of disadvantaged people	(Hill and Bowen, 1997a; DETR, 2000a; Rethinking-Construction, 2002; Sourani and Sohail, 2005; Plank, 2008, Kibert, 2016)

2.9.3.1. The need to promote and implement sustainable principles in construction projects

It is vital that construction stakeholders, globally, should start to appreciate sustainability, acknowledge the benefits of sustainable construction, and admonish those sustainable principles to be supported, promoted, and implemented in all construction projects, which will, in turn, achieve sustainable development. For example, Kibert (1994a), Hill and Bowen (1997a), Bartlett and Howard (2000), Hydes and Creech (2000), and Maduka *et al.* (2016b), add that if sustainable principles are implemented in sustainable construction it will contribute positively to a better quality of life, work efficiency and a healthy work environment. Yates (2003) explores the business benefits of sustainability principles and concludes that the benefits are diverse and potentially very significant. Ochieng *et al*. (2014) developed a sustainability framework for small and medium contractors to improve their performance against the three dimensions of sustainability.

According to Curwell (1998) the construction industry as a whole must rapidly come to terms with reality regarding the broader environmental, social challenges, and agenda that are presented by the concept of sustainable development, because the built environment affects all human activities. Hence, there is a need to holistically promote sustainable principles in the built environment. The Environment Agency suggests that the industry has to change the way buildings are delivered, produce energy, and make technology more efficient, and these must go hand in hand with changes in behaviour and the lifestyle needed if we are to survive climate change and thrive (Harman, 2007). Therefore, any method that can overcome climate change is worth trying and should be considered as part of the growing sustainability agenda (George *et al*., 2012). Moreover, the promotion of sustainable practice is achieving the right balance between these sustainable principles in implementing construction projects (Ochieng *et al*., 2014). Therefore, the need to apply sustainable principles in construction projects is significant because what is built today will provide the future sustainable built environment and will influence the ability of future generations to meet their needs (Pitt *et al*., 2009).

2.9.4 Environmental assessment methods

Throughout the world, many industrial sectors are beginning to recognise the impacts of their activities on the environment and make significant changes to mitigate their environmental impact. The construction and property sector are beginning to acknowledge their responsibilities for the environment, thereby causing a shift on how buildings are designed, built, and operated (Greenwood *et al*., 2011). This change in attitude comes from conscious public policy decisions imposing requirements on industrial and economic activities and from a growing market demand for environmentally sound products and services (Abidin, 2010).

The interest in assessing buildings seems to be continually increasing. A central issue in striving towards reduced environmental impact is the need for a practical and meaningful yardstick for measuring environmental performance, regarding both identifying starting points and monitoring progress.

From the construction and property sector's perspective, this can be divided into two slightly different points of view: measuring the environmental impact of design, construction and property management activities (as services or industrial production processes) and the environmental impact of buildings (as products) (Adrien and Laura, 2010). Therefore, the need for environmental assessment methods is vital to reduce environmental impacts in construction projects. With the rising interest and demand from policymakers to achieve a sustainable society, the need for environmentally related information is growing. There has been an increasing interest in environmental assessments of the built environment (Greenwood *et al*., 2011).

A building assessment method (also sometimes referred to as building assessment tool, building performance assessment, sustainable building assessment, etc.) is a tool that rates how well a building is performing or is expected to deliver to a specified set of criteria after construction (Cole, 2005). They aim to provide a collective set of standards for assessing the environmental impact of buildings. Hence, gathering detailed information about the building architecture and its operation to identify priorities for sustainable building design and structure environmental information, and create a body of information about the impacts of buildings on the environment (Cole, 1998, 1999; MacDonald *et al*., 2016). These tools serve as a method for improving performance systematically and logically, by measuring and comparing your performance against others, and then using lessons learned from the best to make targeted improvements (SECBE, 2009).

These tools can be used to assess the construction/fit out and refurbishment of a residential or commercial property by judging some factors including health and wellbeing, energy, and waste. Building assessment methods is an indicator that targets to measure key features of vital subsystems and elements of concern in a building (Gardner, 1989; Nguyen and Altan, 2011). Most building assessment methods rank buildings relative to standard practices, building necessities, or ultimate goals. Any planning or policy system designed to promote sustainable buildings needs to be involved in a building assessment method designed to evaluate the sustainability of buildings and to reduce the possibility of uninformed decision-making in delivering sustainable buildings. The use of most building assessment method is best approached from the start of a development project, such as in the design phase to ensure that all of the criteria are included in the building plans (Say and Wood, 2008). It is challenging to use a building assessment method after crucial decisions about building architecture, engineering, and siting issues have been made (Cole, 2005).

Before discussing the mentioned environmental assessment tools, it is important to state why these tools are essential. What these methods assess is the environmental capacity, which includes the ecological integrity and equity of urban development plans, programmes and projects captured regarding the built stock, transport, safety, security, health and well-being needed for cities to institute a quality of life (Deakin and Reid, 2014). Cole (1999, 2005), Dixon (2015) and Say and Wood (2008) note the need to conduct an environmental assessment before construction, including:

- Meeting the client’s contractual requirement;
- Enhancing the market value for possible higher rental incomes and increased marketability, increased energy efficiency and lowered lifetime maintenance costs
- Demonstrating compliance with environmental requirements from occupiers, planners, governments, and development agencies;
- Environmental improvements in support of a more comprehensive corporate strategy or as a standalone contribution;

- Marketing as a selling point to potential customers or tenants;
- Staff and end-user benefits – to create a better place for people to live and work;
- Best practice: ensuring best up to date practice, providing a checklist for comparing buildings and guiding their improvement

Numerous environmental assessments methods and tools exist globally in the built environment. These assessment methods focus on energy use in buildings, the sick building syndrome and indoor climate, building materials containing hazardous substances, and many other aspects in fragmented or integrated manners. Some of them assess building components and some whole buildings, while others also consider the surrounding environment (Todd *et al*., 2001; Forsberg and Malmborg, 2004; Malmqvist, 2008; Trinius and Nibel, 2008). Greenwood *et al*. (2011) in their study acknowledged that regarding sustainable building, some codes and methods of measuring compliance have been designed; typically, they have been developed locally (starting in the UK and USA and now proliferating) and some have been adapted for international use.

Two of the earliest and most familiar examples of these rating tools were the Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED). However, this study will discuss, in detail, the environmental methods used mainly in sustainable construction in the UK. In the UK there are three conventional sustainability benchmark tools, which are BREEAM, LEED, and the Ska Rating systems (Dixon, 2015). However, this research will also discuss Passivhaus, which is popular in the UK and ENVEST used in the UK. It is important to note that BREEAM and Ska use UK policies (Dixon, 2015) nevertheless LEED and Passivhaus can sit alongside as part of a global corporate environmental strategy.

Furthermore, this research employed the three most popular environmental assessment method revealed in the empirical data (BREEAM, LEEDS and Passivhaus) to develop sustainable retrofitted building process, which also contributed to the development of sustainable retrofitted building decision-support framework (SRBDSF).

2.9.4.1 Building Research Establishment Environmental Assessment Method

BREEAM, launched in 1990, was the first to offer an environmental label for buildings (Fowler and Rauch, 2006), developed by the British Research Establishment (BRE). BREEAM has been further developed and now there are several BREEAM tools for different kinds of buildings: offices, residential houses, blocks of flats, industries, healthcare, retail, education, communities, and domestic refurbishments (Wallhagen, 2010). BREEAM is comprised of nine variations of assessment tools to fit the building occupancy, including Courts, EcoHomes (single and family residential), industrial, multi-residential, prisons, offices, retail, schools, and bespoke (which includes all buildings that fall outside the standard BREEAM category ratings) (Say and Wood, 2008). For projects in the UK, there are six standard schemes including new construction, communities, in-use, Eco Homes, refurbishment and Code for Sustainable Homes (soon to be replaced by the Home Quality Mark) (Dixon, 2015). However, the Eco Homes tool has been developed into a ‘Code for Sustainable Homes’ (CSH) and was also transformed into code for residential buildings in England and Wales in 2009 (DCLG, 2009).

Crawley and Aho (1999), Malmqvist (2008), and Haapio and Viitaniemi (2008) state that versions of BREEAM could have many other purposes, for example, internal management for existing buildings and market communication (e.g. advertising, direct marketing, branding, packaging, your online presence, printed materials, public relations activities, sales presentations, sponsorships, trade show appearances, and more). There are now different schemes around the world, most of which have been based on or inspired by BREEAM, but each has been adapted to suit the region in which they are to be used. Even though it originated in the UK, projects outside the UK can use BREEAM International. Hence, the BREEAM version is available to Austria, Australia, Germany, Hong Kong, The Netherlands, Norway, Spain, and Sweden (Wallhagen, 2010). BREEAM is a voluntary, consensus-based, market-focused assessment method, which uses three scales for environmental implications: global, local, and indoor issues (Say and Wood, 2008). It is targeted at developers, builders, designers and owner-occupiers, and environmental labels and allows users to differentiate their buildings from those of their competitors and take affirmative steps to minimise their environmental impact.

When a structure has been evaluated using BREEAM, the result is a single score. The assessment/category rating works by giving a building a score based on its performance against eight sections. Those sections include energy and water use, the health and well-being of inhabitants, pollution, transportation challenges, materials, waste and ecology and management facility, and compares them to established benchmarks (Reijnders and van Roekel, 1999; Say and Wood, 2008; Wallhagen, 2010). There are minimum standards, which are credits that have to be achieved to secure a specific rating. To support innovation, BREEAM offers additional 'innovation credits' for the recognition of sustainability-related benefits or performance levels that are currently not recognised by standard BREEAM assessment issues and criteria (Adrien and Laura, 2010, Dixon, 2015). The buildings' score for these eight sections (and innovation credits if applicable) will establish its BREEAM rating. BREEAM rating system include Outstanding (above 85% and the highest rating), followed by Excellent (Above 70%), Very Good (55% to 70%), Good (45% to 55%), Pass (30% to 45%), and Unclassified (below 30%) (BRE, 2008). Although it is a voluntary scheme, some authorities require a BREEAM assessment, e.g. the Welsh Government National Planning Policy requires new builds over 1000m2 to achieve Very Good and Excellent for the credit 'ENE01 Reduction of Carbon Emissions'.

In terms of BREEAM limitations, Awadh (2017) states that BREEAM International 2016 for New Construction rating system is deemed to address the environmental, social, and economic pillars with the least unbalanced weighting. However, BREEAM rating systems give the environmental pillar the most importance and the economic pillar the least. Based on this, the environmental assessment method assesses the environmental impact of developments rather than their sustainability. Cole (2005) argues that, although BREEAM is an environmental assessment method, it could certainly provide a useful framework for guiding project decisions towards a sustainable design outcome (Cole, 2005). In terms of the social pillar, it is at risk of not being adequately covered in projects' decision processes and is not given important weighting in the method. According to Berardi (2011), addressing the social aspect of sustainable development requires contextual design and relating the building to its neighbourhood. BREEAM is a United Kingdom Accreditation Service

(UKAS) accredited third-party certification scheme and entails a vigorous auditing process (UKGBC, 2013).

2.9.4.2 Leadership in Energy and Environmental Design (LEED)

LEED is a green building certification system developed through consensus of the US Green Building Council (USGBC) launched in 1998 (USGBC, 2008). LEED is a building assessment system that has been instrumental in determining the environmental impact of buildings. As construction industry pursues sustainable aggressive environmental goals, specific targets for certification through the US Green Building Council's LEED rating system are common (Kats, 2003). LEED is aimed at improving a building's environmental performance in areas such as energy savings, water efficiency and CO_2 emissions reduction. Similar to BREEAM, LEED certification is available for five project types; Building Design and Construction, Interior Design and Construction, Buildings Operations and Maintenance, Neighbourhood Development and Homes (Fowler and Rauch, 2006; Zimmerman and Kibert, 2007; Dixon, 2015). However, LEED is a point-based system in which building projects earn LEED points for satisfying specific green or sustainable building criteria certification.

The certification process offers four categories based on the number of points accrued, and the highest rating is Platinum (80 points or more), followed by Gold (60–79 points), Silver (50–59), and Certified (40–49 points) (USGBC, 2008). There is a flat registration fee that is paid up front at the time of registration (Dixon, 2015). The certification fee is based on the size of the project and the rating system that the project was registered under, hence, it is subject to change. Furthermore, the LEED certification indicates that a building has been designed with triple-bottom-line sustainability (environmental, social and economic) in mind. Hence, the building will provide a healthier work environment, which will lead to improved employee health and increased productivity because the adverse impacts on the environment have been reduced or eliminated, and the long-term financial impacts have also been assessed (Ny *et al*., 2006). In the construction industry, companies have a choice to determine which level they would like their building to achieve (Retzlaff, 2009).

However, LEED's total score is 110 points, contributed by 100 base points (see Table, 2.10), there is an opportunity to gain an additional six points for 'innovation in design' and four points for ‘regional priority’ (Wallhagen, 2010; Wu *et al*., 2016) Fundamentals are required, and the building does not receive any points. According to Wallhagen (2010) many of the points are relatively easy to earn, such as allocating parking for low emission cars and bicycles and including changing rooms. Others, such as teaching construction workers to place waste in three different bins are also entirely feasible to reach based on training and enforcement. Sustainable construction also makes business sense as buildings environmentally built will often see a premium in rent prices of 1%–2% for a silver LEED certification (Kats, 2003). Some studies propose LEED as a strategic sustainable development framework, and these include Ny *et al.* (2006) incorporating the natural step (TNS) based on backcasting from basic principles for sustainability. Zimmerman and Kibert (2007) propose LEED as a potential application of the TNS to overcome the significant shortcomings of building assessment systems.

Table 2. 10 LEED categories and points (over 100 total score points) (Adrien and Laura, 2010)

Categories	**Points**
Sustainable site	26
Water efficiency	10
Energy and atmosphere	35
Matls and resources	14
Indoor and environment quality	14
Innovation and design	6
Regional priority	4

In terms of LEED limitations, Awadh (2017) argues that LEED has not attributed any weighting for the economic aspect of sustainability; which is one element that gets the most resistance by key stakeholders. As the design is driven by cost, the economic viability of a building is systematically covered automatically in project decisions. However, and in most cases, operational and maintenance costs are not considered. In the developing countries, where construction is continuously increasing, sustainability practices are more or less driven by the ‘green certification’ with less attention given to the operation stage. In terms of the social pillar, it is at risk of not being adequately covered in projects' decision processes and not given significant weighting in the method (Awadh, 2017; Mattoni *et al.*, 2018). LEED is argued to be lenient in energy performance credits (Awadh, 2017). There are also differences in the way LEED calculates credits. They are linked to the US Dollar (especially the energy credits), which means that if the exchange rate is unfavourable, and then the building's rating could suffer. A downside is that these credits are not available for non-US projects (Doan *et al.*, 2017).

2.9.4.3 Ska Rating

The SKA rating system is a voluntary assessment tool that commenced as a research project commissioned in 2005 by Skansen Ltd, in conjunction with Royal Institute of Chartered Surveyors (RICS) and Architecture, Engineering, Consulting, Operations, and Maintenance (AECOM). It was developed to ascertain if it was possible to measure the environmental impact of an office fit out (Dixon, 2015). It was formally launched in November 2009, and since then the SKA retail, fit out assessment has been created (Dixon, 2015). Ska Rating assists organisations in making informed decisions regarding fit-out in the perspective of the developing significance of sustainability in society in relation to construction.

It is designed to be of specific use for occupiers, but has benefits for other property stakeholders, including property owners, developers, consultants, fit-out contractors, and the supply chain. No matter what your starting point, a Ska Rating will assist in measuring up to 100% of the environmental performance of an office fit-out (Design-Building, 2015). The 100% performance rating covers energy and CO_2; waste; water; pollution; transport; materials and wellbeing (RICS, 2017). Ska's good practice measure explains the criteria that needs to be achieved, including the reasons behind the rule and guidance on how to attain it (Design-Building, 2015). RICS (2017) reveals that Ska Rating does not consider the base build. Instead, it measures only what the user intends to do to add value to the building. Key aspects of the rating system are:

- Flexible scoping: match the rating to the scope of the fit-out;
- Easy to use and free online tool;
- A clear label and easy to understand: Bronze, Silver Gold plus % scores; and
- Formal quality assurance scheme for those who require a certificate.

Design-Building (2015) and RICS (2017), in summarising the Ska rating assessment, state that the process involves three stages. The stages include:

1. Design: this step is about client identifying measures and problems required in the scope, hence, avails the client the opportunity to prioritise measures for decision-making regarding design, cost, programme, and benefit and add them to the project scope. This stage will also set the environmental performance standards of project delivery as it relates to waste and energy in use;

2. Handover: this ensures that the criteria specified has been delivered, thus performance and waste benchmarks are delivered;

3. Occupancy: this involves an optional review of the performance of the fit-out against its original brief after a year the project has been delivered. To have the project certified, you need a licensed Ska assessor to undertake the Ska assessment. Hence, RICS is in charge of Ska assessment because they operate an accreditation scheme to enable qualified professionals to conduct quality assured Ska Rating assessments on behalf of organisations. Dixon (2015) states that, as of July 2015, there are 191 accredited assessors, assessments in progress (formal and informal): 2070, completed assessments (informal): 981. Formally certified assessments: 369, these assessments comprise the following ratings in Table 2.11.

Table 2. 11 Ska scheme rating (Dixon, 2015)

Ska scheme	Gold	Silver	Bronze
Offices	84	91	34
Retail	13	114	28
Pilot	1	1	3

The pilot is projects such as higher education, for which an appropriate scheme may be developed in the future.

Ska limitations was designed as a self-assessment rating tool and is focused on rating the scope of works added to the base building. Hence, Ska does not currently have a full 'in-use' assessment as project delivery teams are often different from their operational teams and 'in-use' assessment is based on a different set of decisions, made by a different set of people to those in the design stage (UKGBC, 2013). However, UKGBC (2013) revealed that there is an 'occupancy stage' assessment that measures energy and water consumption in the 12 months following the completion of a project. Take up of the occupancy stage assessment, which is non-mandatory, has been limited.

Ska is reliant on the assessor’s knowledge to make a real impact and the evidence required is not as robust as BREEAM (UKGBC, 2013). Design-Building (2015) states that the responsibility is on the assessor to determine whether credits can be awarded. There is also a reliance on the Energy Technology List (ETL) to determine whether certain credits can be awarded for various types of technology (Dixon, 2015). This can be detailed work and can take an assessor beyond their level of expertise and increase the time it takes to produce an assessment, adding to the cost. Conversely, it makes the process less of a ‘tick box exercise’, making it more attractive to project teams and allowing for integrating more appropriate solutions (UKGBC, 2013).

Regarding Ska Costs, UKGBC (2013) state that there is no, or limited, uplift in associated project costs in achieving a Ska rating, but this is dependent on the project team and whether Ska expertise was involved from the design phase. If requirements are incorporated pre-tender, the project team is committed to integrating Ska and can apply the necessary pressure on the contractor to do the same, and then experiences show that no extra costs are incurred (UKGBC, 2013).

In terms of Ska future development, UKGBC (2013) revealed that Ska does not currently cover residential retrofitting, but there may be interest, especially for large property owners, Registered Social Landlords (RSLs), or hotel chains for which an assessment could be applied to a portfolio or a large stock of properties. RICS is piloting the Ska Volume Certification scheme to enable the evaluation of a single design applied to multiple sites using a sampling approach (UKGBC, 2013).

2.9.4.4 ENVEST

Clarity-Environment (2016) describes ENVEST as a life cycle environmental impact assessment-based design tool for use through the earliest phases of commercial/mixed use building design. It is a UK-based environmental rating method. The ENVEST tool is unique thus developed in three versions: for new commercial mixed-use and multi-residential buildings, for existing commercial mixed-use, and multi-residential buildings and houses. It simultaneously reveals both the operational impacts and the materials impacts of a building as the design evolves. In doing so, it shows the critical design trade-offs to minimise greenhouse gas emissions and other impacts over the life of the building (Howard, 2017). ENVEST simultaneously estimates construction cost and the whole of life cost of a project (Howard, 2017). Clarity-Environment (2016) and Howard (2017) reveal that ENVEST are used for the following: (a) Developers use it to set a better brief with practical targets for cost and environmental impact that match client's aspirations; (b) Designers (Architects, Engineers, Cost Consultants, Environmental Consultants) use it from inception to get onto a design trajectory immediately to significantly lower cost and lower environmental impacts of building. The design team can choose to optimise based on any of 16 different environmental impact categories (including climate change and a composite weighted Eco-point). They are also used to ascertain profound insights into the trade-offs, design synergies or perverse outcomes from every decision; (c) Educators use it in teaching assignments to reorganise the intuition of design students; and (d) Material/product suppliers use it to reveal the environmental and cost merits of your specific products in ENVEST at the point where design and specification decisions are made.

However, when using ENVEST, the initial design is locked-in as the reference, and the design team can experiment with different shapes, glazing areas, shading options, roof lights and atria, orientations, specifications (and hence material choices), structural systems, and building services systems (including solar PV's and water heating) (Howard, 2017). ENVEST works with the limited information available at inception; requiring just location (postcode); building size; a mix of uses and budget to start working. As ENVEST default parameters are replaced with design decisions, its reference design transforms into the actual design. Hence, every decision is based on a sweet spot diagram, (vector plot of the cost vs environmental effect) of choice compared to the reference informs every decision.

ENVEST potently reveals the often perverse consequences of design decisions as they are being made and before they are locked in. Clarity-Environment (2016) and Howard (2017) states that ENVEST includes a low resolution and rapid estimating energy model. It has been affirmed that assessment method is highly dynamic, modelling and reconciling 16 layers of interaction between climate, uses, daylighting, building services, controls, element specifications (materials), structure, interior finishes, colour, life, cleaning and maintenance, and their associated costs to reveal perverse outcomes. The method can always significantly reduce both the initial and life-cycle costs and environmental impacts for a building design simultaneously. Savings in cost and environmental effects are usually in the 10–20% range, but can be much more significant (Howard, 2017).

Regarding the limitation of ENVEST Clarity-Environment (2016), it revealed that it was developed for commercial use in buildings and has partially developed versions for sustainable retrofitting and new build. There is also a partially developed web-based version of ENVEST that allows buildings to be situated and manipulated on a site map, providing BIM interconnectivity. This will be completed subject to funding (Clarity-Environment, 2016).

2.9.4.5 Passivhaus

In response to the UK government's overarching climate change mitigation strategy (DEFRA, 2007, HMG, 2011) and recast (EU, 2010), targets have been set for the implementation of a revised zero carbon dwelling standard in the UK by 2016 (DCLG, 2011, ZCH, 2011, McLeod *et al*., 2012). As a result of these legislative drivers and voluntary adoption of advanced performance standards, such as the Passivhaus standard, there have been significant changes in the way dwellings are being designed and constructed both in the UK and across Europe (MacDonald *et al*., 2016). Passivhaus is a German originated environment assessment method. A Passive House is a building in which thermal comfort can be achieved solely by heating or cooling of the supply air, which is requisite for sufficient indoor air quality without using additional recirculated air (Feist, 2007). Passivhaus is a specific energy performance standard that delivers very high levels of energy efficiency, while the Code for Sustainable Home and BREEAM are all-encompassing sustainability assessment ratings, which address a large number of environmental issues.

The fundamental aim of the Passivhaus standard is to dramatically reduce the requirement for space heating and cooling and also creating excellent indoor, air quality and comfort level (McLeod *et al*., 2012). The Passivhaus standard is considered a low energy building performance standard; characterised by insulations, airtight envelopes, the use of mechanical ventilation with heat comfort criteria recovery (MVHR), and optional use of passive solar gains. This is why Larsen and Jensen (2011) reveal that the Passivhaus standard is sometimes confused with more generic approaches to passive solar architecture, with which it shares some universal principles. They further argued that where the Passivhaus standard differs from more generic concepts is in its ability to reduce the permitted space heating demand and primary energy consumption. Hence, it is considered as both a robust energy performance specification and a holistic low energy design concept. These standards are, by no means, mutually exclusive; subsections within these sustainability standards account for energy and carbon dioxide emissions that are the most heavily weighted and most challenging to achieve (MacDonald *et al*., 2016).

The Passivhaus standard is a comprehensive low energy standard intended primarily for new buildings. However, the standard achieved when delivering retrofit buildings projects can prove costly (Paasivhaus, 2017). According to McLeod *et al.* (2012), Passivhaus thermal comfort is provided to the most considerable practical extent through the use of passive measures listed below, which can be applied not only to the residential sector, but also to commercial, industrial, and public buildings:

- Good levels of insulation with minimal thermal bridges;
- Passive solar gains and internal heat sources;
- Excellent standard of airtightness;
- Good indoor air quality, provided by a whole-house mechanical ventilation system with highly efficient heat recovery.

However, there are no strict requirements concerning domestic hot water, lighting, and appliance consumption; instead, the standard imposes an overall limit on primary energy consumption, which promotes energy efficiency in all of these areas (Mcleaod *et al*., 2017).

Nevertheless, the overheating risks experiences by Passivhaus dwellers or occupiers has revealed to be one of the major challenges. However, overheating is highly dependent on context, and is strongly influenced by both user behaviour, including ventilation patterns, shading strategies and internal gains (Wagner and Mauthner, 2008, Larsen and Jensen, 2011) and the building's thermal specification (Schnieders, 2005, 2009). Notably, in almost every case, external shading was necessary to maintain summer thermal comfort.

In the designing of a Passivhaus, Schnieders (2009) cautioned '*it is important to note that the differences in climates and the effects of individual building parameters are so large that a dedicated energy balance must be set up for every Passive House*' (p.279). Hence, the use of standard values for different buildings is not appropriate (Schnieders, 2009). These findings highlight the parametric sensitivity of Passivhaus and ultra-low energy buildings, reinforcing the need to study these issues further in the context to deliver solutions.

Questions regarding the performance of Passivhaus in the summer and the risk of overheating for some Passivhaus buildings located in different cities in the UK and other European climatic zones have been discovered in a number of studies (Fletcher *et al*., 2017; McLeod *et al*., 2012; Tabatabaei Sameni *et al*., 2015; Hwang and Chen, 2010; Almeida-Silva *et al*., 2014). In the UK, research studies focussing on summer temperatures and thermal comfort during the winter season are fewer and more limited compared to those concerned with performance in the heating season (Hwang and Chen, 2010; Almeida-Silva *et al*., 2014). Overheating of Passivhaus affects the health of the occupant adversely. Hwang and Chen (2010) revealed that overheating in dwellings with vulnerable occupants presents additional challenges. This was corroborated by Almeida-Silva *et al*. (2014) and Fletcher *et al*. (2017) who revealed that older adults are affected more by overheating of Passivhaus because they are physiologically less able to regulate their bodies to respond to both hot and cold temperatures.

These findings appear to be in contrast with the Passivhaus claim of superior levels of comfort to traditional buildings. The issue of overheating will be worse when adopting the Passivhaus design for existing dwellings that need to be sustainably retrofitted. However, Mcleaod *et al*. (2017) argue that there is a current lack of empirical evidence to establish that an existing building will be worse off if Passivhaus is applied. Tabatabaei Sameni *et al*. (2015) suggest that the relevant provisions that can assist in the reduction of overheating are a proper layout can minimise additional solar gain, an adequate thermal mass, a good level of ventilation, and reduced internal benefits.

2.10 Sustainable retrofit

To retrofit means providing something with elements or features not included or fitted when it was first produced or adding new features to a building that it did not have when it was initially constructed (Eames *et al.*, 2014). Sustainable retrofit is the refurbishment of an existing building with low carbon materials in consideration of the three concepts of sustainability or sustainable development. Nevertheless, BBP (2010) and Eames *et al*. (2014) define sustainable retrofit as incremental improvements to the building's fabric and systems with the primary target of improving energy, water, and waste efficiencies to reduce carbon emissions. This definition excludes disruptive refurbishment that would require the building to be vacated for an extended time, for behavioural training programmes, and space rationalisation or utilisation. In a similar definition, Gatlin *et al.* (2009) describe a retrofit as an upgrade performed to an existing building that is wholly or partially occupied to improve energy or environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise. These are achieved in a way that is economically beneficial to the owner. Currently, energy efficiency in existing buildings is often addressed by upgrading outdated engineering systems, such as lighting and heating, ventilation, and air conditioning (HVAC) systems, with better-performing technologies.

2.10.1 Types of retrofits

Two types of retrofits are standard and deep retrofits (BSC, 2013). Table 2.12 highlights the types of retrofit building projects with their definitions.

Table 2.12 Standard and Deep Sustainable Retrofits

Standard Retrofit	**Deep/Active Retrofit**
1. This measure provides a cost-effective and low-risk efficiency upgrade options for building owners who are limited to making incremental capital upgrades to their building. Standard retrofit measures include equipment, system and	1. A deep retrofit involves the whole or holistic building construction process that involves integrated building design in achieving great percentage energy saving cost and improvement in a building (AIA, 2013b; BSC, 2013; Eames *et al.*, 2014)

assembly retrofits (Fuerst and MaAlister, 2009; Scanla, 2010).	
2. It involves isolated building or system upgrades. It is a very simple and fast retrofit measure albeit saving little energy at the end of the process (Scanla, 2010).	2. Laitner *et al*. (2012) opine that the integrated design process enables a deep retrofit project to achieve more than a simple standard retrofit part. Laitner *et al.* (2012) further explained that Integrated design *approaches* simply means a design process that explores the *interdependency* of different building systems for example; envelope and perimeter-zone mechanical and lighting to optimise energy reduction. This process is also typically iterative, meaning that the design team is open to considering various ideas to find the optimal solution.
3. Standard retrofits are often staged with one measure conducted after another. The sequencing of standard retrofit measures is important as the impact of a retrofit to one system (e.g. lighting) will affect other systems (reduced HVAC load) (Fuerst and MaAlister, 2009; Scanla, 2010).	3. It can yield the discovery of useful synergies between systems that afford energy savings more than what was intended to be achieved with the optimisation of each system (Mass.Save, 2013).
4. This process is applicable in both residential and non-residential buildings (Fuerst and MaAlister, 2009).	4. This process is suitable in both residential and non-residential buildings (Fuerst and MaAlister, 2009).

	5. Eames *et al.* (2014) state that it is the most economical and convenient type of retrofit due to its long-term benefit and can save up to 50% or more energy in a building.
	6. This retrofit affects multiple building systems and assemblies (e.g. envelope, lighting, and HVAC, insulation and solar control) to achieve dramatic energy savings alongside optimal performance (Scanla, 2010).
	7. It has been stated that deep retrofits can reduce a building’s energy use by over 50%; they require a more significant upfront investment and may have more extended payback periods (AIA, 2013a).

Figure 2.17 highlights deep retrofitted building and necessities. The ensuing sections discuss some technology activities that take place in delivering sustainable retrofitted building projects.

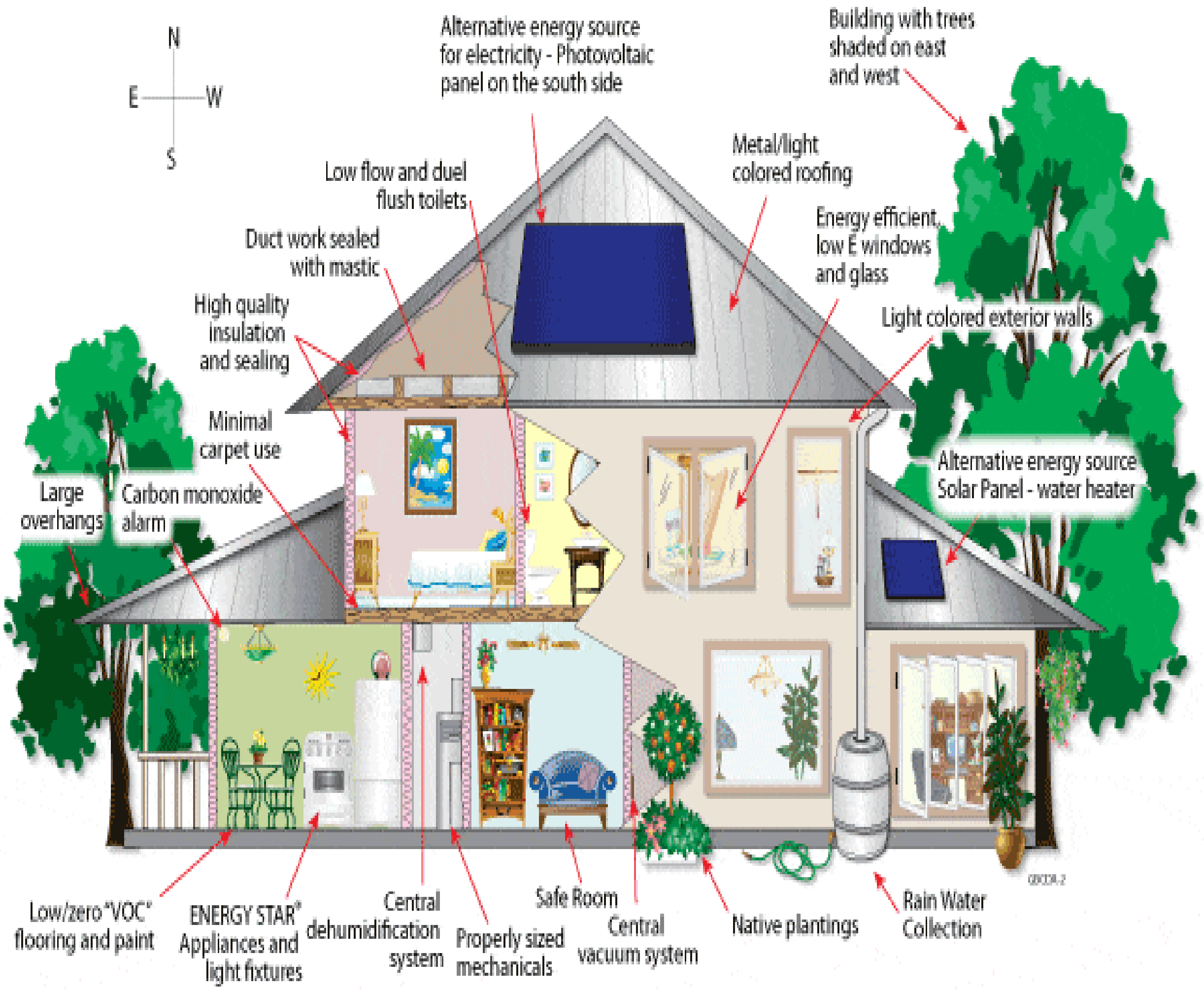


Figure 2. 17 Deep sustainable retrofitted building features (The-Constructor, 2018)

2.10.2 The essence for sustainable retrofitted building projects in the United Kingdom

As previously stated, sustainable construction is classified into the demolishing, new build, and sustainable retrofit of existing housing stock. The need to give top priority to sustainable building retrofit has been emphasised (IFG, 2008). Furthermore, Bell (2004) argues that, although improving the energy performance standards of a new building is important, it would require a dramatic change in replacement rates for it to make a significant contribution to CO_2 reductions in the next 50 to 100 years. The benefits of choosing sustainable retrofits over new builds have also been brought into focus as existing buildings comprises the majority of greenhouse gas emissions from the sector (Smith, 2004).

Consequently, to deliver this reduction, the country must focus on sustainable retrofitted building projects since the majority of the existing housing stock needed in the UK has been built (Sustainable.Development.Commission, 2011, Lowery, 2012). CIOB (2011) revealed that there are approximately 30 million buildings (domestic and non-domestic) in the UK. Around 28 million of these (including 25 million homes) are required to be retrofitted by the end of 2050 if the carbon targets are to be met (CIOB, 2011). The energy used to heat, light and run domestic buildings alone accounts for 27% of all UK CO_2 emissions and around 22% of public commercial buildings (UKGBC, 2015). Britain has one of the oldest domestic stocks in the developed world, for example, an estimated 4 million or 20% of the building stock was constructed before 1919, about 20% constructed between 1920 and 1939, and an estimated 8.5 million properties are over 60 years old (Pre-1944: 38%, 1945–1984: 46%, 1985 onwards: 16%) (CIOB, 2011). The UKGBC (2015) has revealed that approximately 1.8 million non-domestic buildings exist in the UK. These are currently responsible for roughly 18% of the country's total CO_2 emissions, while residential homes account for around 27%. Consequently, three-quarters of the non-domestic building stocks are more than 25 years old, while nearly one-third are over 70 years old (pre-1940: 31%,1940–1985: 46%, 1985 onwards: 23%) (BRE, 2011).

Delivering sustainable retrofitted building projects remains a challenge to the industry. There is a potential for substantial carbon emission reduction through appropriate approaches to sustainable retrofit; however, achieving it presents a multifaceted and challenging problem to the industry (Lowery, 2012, Stafford *et al*., 2012; McManus *et al.,* 2013). The need to tackle the challenges in delivery sustainable retrofit project is essential despite being an additional burden to the industry since the industry is heavily laden with other problems that includes lack of knowledge management in project construction activities (Egan, 1998; Dainty and Ison, 2005; Maduka *et al*., 2015e), reduced construction time, poor costing and quality performance (Lathan, 1994; Egan, 1998) and the fragmented nature of the industry (Egan, 1998; Shelbourn *et al*., 2006; Petri, 2014). However, amongst all the existing challenges in the delivery of sustainable retrofitted building projects, lack of knowledge management remains one of the biggest problem facing the industry particularly in making an informed and appropriate decision (Shelbourn *et al.*, 2006; Maduka *et al*., 2015e; Maduka *et al*., 2015a).

2.10.3 Retrofit technology installations

In construction project delivery, decision-makers are concerned with the substantial upfront capital needed for retrofit installations rather than exploring the long-term benefits of energy efficient technologies. One of the most significant barriers that impedes the adoption of energy efficient retrofits is the building owners' false view that energy retrofits for example technologies involved are too expensive (Adam *et al.*, 2011). Contrary to this opinion, empirical evidence shows that sustainable retrofits are often profitable (AIA, 2013b; BSC, 2013; Kukreja, 2016).

The most common tools used for energy efficiency include energy efficient technologies for heating and air conditioning systems, improved insulation, and the use of more natural lighting. These retrofit options are often considered due to the simple installation and proven monetary returns (Bonda and Katie, 2007). Nevertheless, the benefits of retrofit technologies are ambiguous to its key stakeholders (Adams *et al.*, 2012). Retrofit technology depends on a multitude of variables including the current state of the building, the specific technology implemented and the available financial incentives (AIA, 2013a). The ensuing sections discuss the type of retrofit technologies that exists amongst others.

2.10.3.1 Lighting

Adam *et al.* (2011) state that buildings that use excessive or inefficient lighting systems might implement lighting system upgrades ranging from simple changes to a complete replacement. Occupancy sensors and time clocks are examples of simple energy saving controls that can automatically reduce hours of lighting. Light Emitting Diode (LED) technology is another lighting retrofit that provides significant energy savings up to 70% over time, making the replacement useful (UDE-NREL, 2013). Figures 2.18 and 2.19 showcase types of energy-efficient lights (LED) and solar panel LED lighting for buildings.

Figure 2. 18 The light emitting diode (LED)

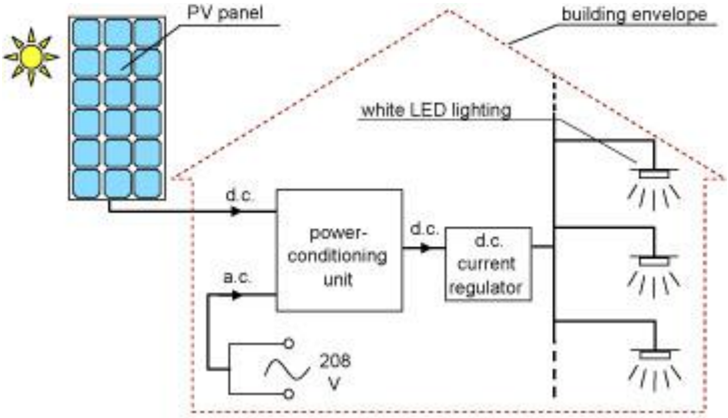


Figure 2. 19 Solar panel LED lighting for building (WDG, 2018)

2.10.3.2 Heating, Ventilation, and Air Conditioning (HVAC)

McGraw-Hill (2009, 2011) state that an HVAC system provides buildings with adequate air flow, heating, and cooling. Teke (2014) states that HVAC systems control temperature, humidity and air quality inside buildings and locations. The heating function is generally used in cold climates, and the cooling function is generally used in warm and hot climates. Air conditioning refers to the removal of indoor air humidity. Adam *et al.* (2011) state that it is a relatively new technology and suggest that building energy management systems (EMS) can be installed to monitor energy use and automatically adjust temperature settings, accordingly. Within each HVAC system, there is a set of components that could also be improved while delivering retrofit building projects (Teke, 2014). For example, in one system, an old boiler, furnace, and heat pump can be upgraded to increase energy efficiency. Figure 2.20 showcases HVAC systems and renewable energy installations.

Best Practice in Sustainable HVAC

Traditional HVAC systems can, if not used appropriately, damage the environment with energy and fossil fuels, thereby polluting the surrounding atmosphere and depleting resources. Mckee (2015) states that the best solution is to use and build HVAC systems that use less energy, and some key HVAC installation best practices include:

1. Incorporate HVAC systems early in the design phase;
2. Size HVAC system to meet actual loads;
3. Specify high-efficiency furnaces and air conditioning units;
4. Seal around electrical outlets and all wall penetrations;
5. Insulate all ducts in the attic or crawl space;
6. Design adequate returns to keep the house pressure balanced; and
7. Install a heat recovery ventilation system.

Figure 2. 20 illustrates the HVAC system of a building

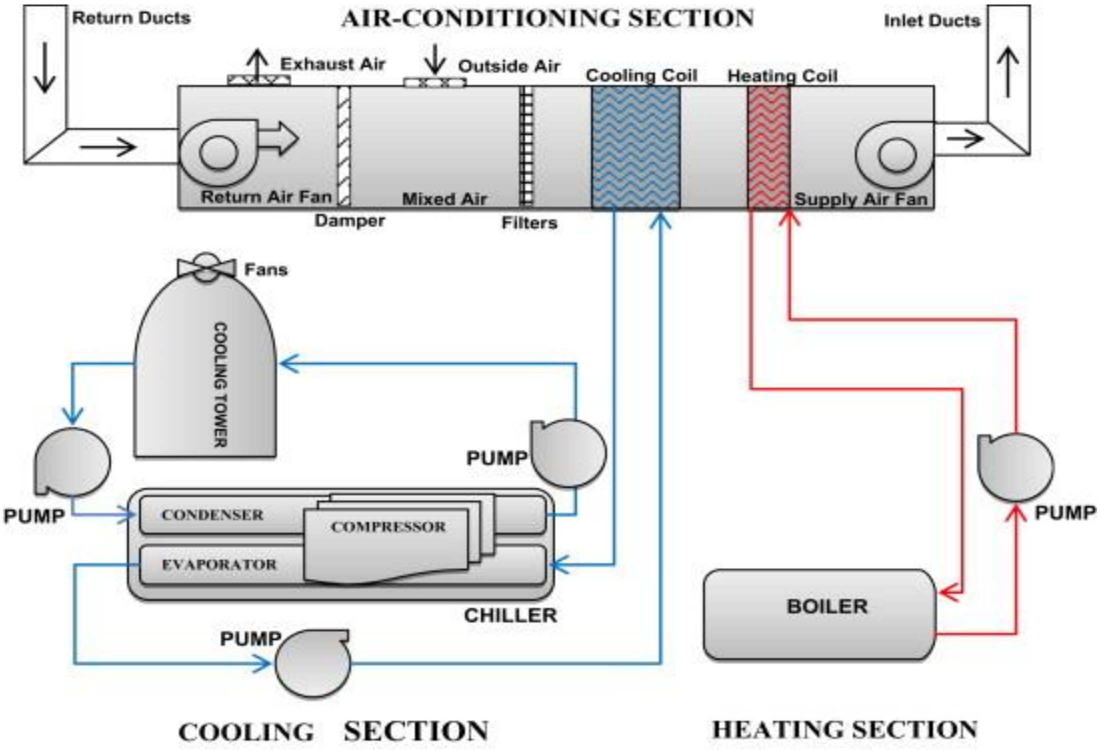


Figure 2. 20 HVAC system of a building (Teke and Timur, 2014)

2.10.3.3 Insulation and window upgrade

Insulation upgrades, including weather stripping, weather sealing, and the replacement of old doors and windows with high-performance versions, provide improvements with a quick payback period. The energy efficiency of a dwelling can be increased dramatically by upgrading the insulation standard, thus reducing energy loss to the environment. Possible measures are many, and best results are achieved by combining several methods of insulation, such as substantially increasing the insulation layer in the outer walls, toward the cold loft and the basement, as well as installing windows with a higher energy standard and timber flat roof insulation (Klöckner and Nayum, 2016). However, Greenspec (2017) recommend that the correct choice of insulation is essential when adhering waterproofing, particularly when solvent-based adhesives are used.

Figure 2.21 Internal solid wall insulation process (GREENAGE, 20016)

Figures 2.21, 2.22 and 2.23 highlight the activities involved in wall insulation. Figure 2.21 highlights the internal wall insulation process and how it is achieved while Figure 2.22 highlights back solid wall insulation process in retrofitted building projects.

Figure 2.22 Back solid wall insulation process (GREENAGE, 2016)

Figure 2.23 highlights are existing external wall without insulation and after insulation in a retrofitted building project.

Figure 2.23 Before and after external solid wall insulation (Heat-Insulation, 2018)

Upgrading windows in retrofit projects increase personal comfort and productivity by reducing draughts and noise, attracting more occupants for residential buildings in large cities and providing employees with a work-conducive environment (Katz, 2008, Adam *et al.*, 2011). Windows are one of the most exposed parts of a house. They are very vulnerable to weather and wind. Currently, there are double and triple glazed windows used in the industry in upgrading conventional windows. The aim of double and triple glazing is to provide better thermal and sound insulation than conventional windows.

Double and triple glazed windows reduce greenhouse gas emissions, energy bills, maintenance costs, and ambient noise, enhancing a building's value (Ecostar, 2016 and IWS, 2018). Double glazed windows are manufactured using a second or double pane of glass. However, triple glazing is unequalled in terms of energy and sound performance when compared to double glazing. Some homeowners are determined to make their homes as energy efficient as possible, reducing their carbon footprint and saving money on their home energy bills because triple glazing is becoming an increasingly popular option in the UK (IWS, 2016). Triple glazed windows are constructed using a third or 'triple' pane of glass, this additional pane of glass results in the window featuring an additional cavity (these are filled with argon gas) compared to modern double-glazing and it is this additional cavity that produces the thermal and acoustic benefits that make triple glazing more popular and desirable.

Figure 2.24 Double glazed windows (Ecostar, 2016)

Figures 2.24 highlights double windows and its thickness while Figure 2.25 highlights triple glazed window thickness. These are used for the sustainable retrofitting of buildings.

Figure 2. 25 Triple glazed windows (IWS, 2018)

2.10.3.4 Rooftop solar (photovoltaics)

Rooftop solar panels directly convert the sun’s radiation to electricity. Solar panels produce few emissions and require minimal maintenance beyond the initial installation (UDE-NREL, 2013). Solar power is also the only type of retrofit material that adds to a building’s energy supply rather than reduce energy consumption. The main drawback of rooftop photovoltaic power is that it is widely recognised as the most expensive type of renewable energy (UDE-NREL, 2013).

Figure 2.26 An installed photovoltaics rooftop in a retrofitted building (Chelsfieldsolar, 2018)

Figures 2.26 and 2.27 highlights rooftop solar panels while Figure 2.28 highlights a solar panel and its contact with the sun to generate alternative current (AC) and the thermostat.

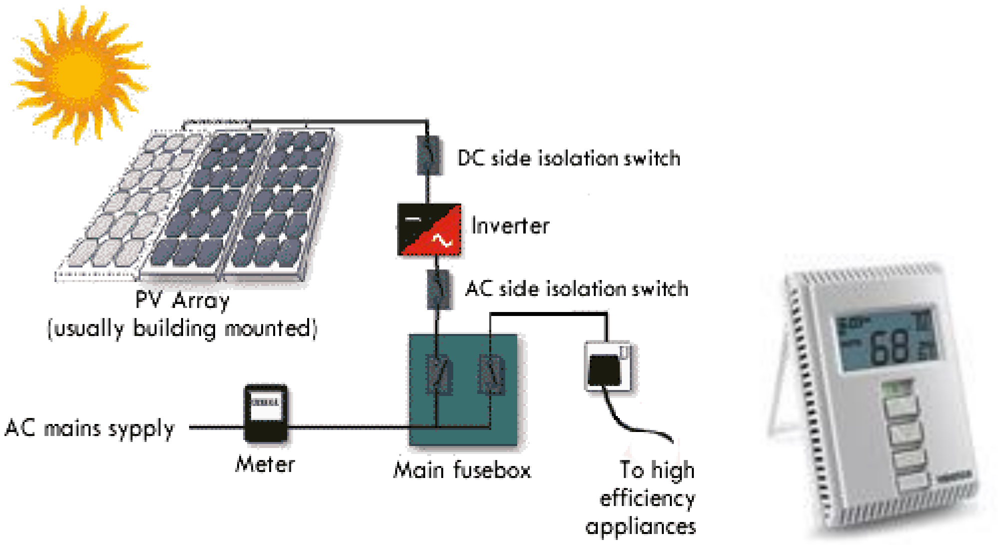


Figure 2.27 The solar panel and its contacts with sun to generate AC and the thermostat (ASE, 2018)

2.11 Benefits of sustainable retrofitted building

Benefits of sustainable retrofitted buildings are essential and cannot be overstressed in promoting the embarking and delivery of sustainable retrofitted building projects. The benefits of a sustainable retrofitted building can range from environmental to economic and social. By adopting sustainable practices, the industry can take maximum advantage of environmental and economic performance (Heerwagen, 2000). Sustainable construction principles and practices, when applied in construction projects, provides significant benefits. To achieve economic, social and environmental benefits of sustainable construction, it is essential that benefits are sought jointly and simultaneously (Kukreja, 2016) for greater awareness. Benefits of a sustainable retrofitted building include environmental, economic, and social.

2.11.1 Environmental benefits of sustainable retrofitted building

In a truly sustainable environment, an ecosystem would maintain populations, biodiversity, and overall functionality over an extended period. Ideally, construction decisions made by the key stakeholders should promote equilibrium within our natural systems and seek to encourage growth (Heerwagen, 2000; Design-Build, 2011; Kukreja, 2016). Unnecessary disturbances to the environment need to be avoided whenever possible. If there is a disturbance, it should be mitigated to the maximum practicable extent (Heerwagen, 2000). When construction discussions and decisions are made during project delivery, it is necessary always to consider environmental impacts of the proposed outcome or result (C Wanamaker, 2016) to have sustainable benefits in the society.

Several determinants are directly related to environmental benefits of sustainable retrofitted building; hence, they should be acknowledged during construction project delivery. One of the essential determinants is the proper management of natural resources (RICS, 2005a). In addition, the industry can even promote habitat restoration and preservation as a means to negotiate a satisfactory solution to a problem (DETR 2009). Contributing to protecting and enhancing our natural, built and historic environment, and, as part of this, helping to improve biodiversity, use natural resources prudently, minimise waste and pollution, and mitigate and adapt to climate change including moving to a low carbon economy (Kukreja, 2016). Delivering sustainable retrofitted buildings reduces the use of water, raw materials, energy and land (Heerwagen, 2000; Zhou and Lowe, 2003; RICS, 2005a). It also reduces greenhouse gas emissions and waste and pollution in the environment (Design-Build, 2011; WBDG, 2017). Table 2.13 highlights some specific environmental benefits in a sustainable retrofitted building.

Table 2.13 Environmental benefits of sustainable retrofitted building

Environmental Benefits	**References**
Reduced waste of water and water efficiency savings	Heerwagen (2000); Heerwagen *et al.* (1999); Zhou and Lowe (2003); Kukreja (2016) and WBDG (2017)
Conserve and restore natural resources or decreased use of natural resources and protect the eco-system and lower impacts of ecosystem	Heerwagen (2000); DETR (2000a); Stubbs (2008); Vatalis *et al.* (2011); Kukreja (2016) and WBDG (2017).
Improved air and water quality	Fisk and Rosenfeld (1997); Seppanen *et al.* (1999); Heerwagen (2000); RICS (2005a); Design-Build (2011) and Kukreja (2016) .
Waste Reduction	Heerwagen (2000); RICS (2005a); Design-Build (2011); Kukreja (2016); and WBDG (2017).

Temperature Control	RICS (2005a) and Design-Build (2011)
Reduced greenhouse gas emission	Miyatake (1996); Zhou and Lowe (2003); and RICS (2005a)
Replacing poor design with better construction project design	WBDG (2017)
Reduce land disturbance for new roads	Heerwagen (2000) and Zhou and Lowe (2003)
Reduce air pollution	Miyatake (1996); Heerwagen (2000); Zhou and Lowe (2003); Design-Build (2011); and Kukreja (2016).
Reduced volume of solid waste	Zhou and Lowe (2003) and Design-Build (2011)
Aversion of extreme weather condition impacts	Heerwagen (2000) and Zhou and Lowe (2003).
Efficient use of resources	Miyatake (1996); Heerwagen (2000); Zhou and Lowe (2003); RICS (2005b); and Stubbs (2008)
Prevent soil loss	Heerwagen (2000)
Improve forest management	Heerwagen (2000)
Reduce greenhouse gas emissions	Heerwagen (2000);Zhou and Lowe (2003); RICS (2005a); Stubbs (2008); Design-Build (2011); and WBDG (2017).

2.11.2 Economic benefits of sustainable retrofitted building

Similar to environmental sustainability, economic sustainability involves creating economic value from a construction project or decision being undertaken. Economic sustainability means that decisions are made in the most equitable and fiscally sound way possible while considering the other aspects of sustainability. In most cases, projects and decisions must be made in view of long-term benefits rather than just short-term benefits (C Wanamaker, 2016). It is important to point out that considering only the economic aspect of sustainability may not necessarily promote true sustainability or sustainable development. For many other sectors, including construction, economic sustainability or growth are their main focal point. On a large scale (globally or locally), this conservative approach to construction can ultimately lead to unsatisfactory results. However, when construction practitioners and key stakeholders apply economic sustainability in construction combined with the social and environmental aspects of sustainability, a positive outcome is assured, hence, it is good for humanity (Zhou and Lowe, 2003; RICS, 2005a; Kukreja, 2016).

The objectives of sustainable construction are to reduce energy usage and the protection of natural and social environments, providing healthy and comfortable living environments and economic benefits for key stakeholders (Zhou and Lowe, 2003). The economic benefits of sustainable construction are vital, and stimulus but is rarely understood by key stakeholders (Zhou and Lowe, 2003). Traditionally, the primary objective of construction was to obtain the best quality at the lowest construction cost within a limit period. Occasionally was the post constructing expenses, and the occupier's liability in the building considered (Heerwagen, 2000). Citex (1999) and Castillano *et al.* (2000) found that the initial cost of construction accounts for only 2% of a building, while another 6% is expended on operations and maintenance, the remaining 92% is spent on the people who work in the building based on an asset life of 30 years. Sustainable retrofit project expands the consideration of financial capital costs to include environmental and human capital costs.

Johnson (2000) found that high-performance buildings produce more economic benefits for key stakeholders than buildings based on more traditional designs. Johnson (200) divides potential economic benefits into four types: total cost savings, productivity, image, and reputation, including economic and environmental benefits. Sustainable retrofitted buildings are relevant to business interests across the full spectrum of concerns, from portfolio issues to enhanced quality of individual workspace. Sustainable construction expands the consideration of financial capital costs to include environmental and human capital costs (Zhou and Lowe, 2003). Not only does sustainable building improve the quality of our environment but it also has many economic benefits. Using sustainable materials, reducing energy consumption, and improving water efficiency assists in achieving economic benefits in sustainable retrofitted buildings. Table 2.14 highlights some of the specific economic benefits of sustainable retrofitted building.

Table 2. 14 Economic benefits of sustainable retrofitted building

Economic Benefits	**References**
Helps aid in the expansion of the green or sustainable market	Heerwagen (2000); Yates (2001); RICS (2005a); RICS (2005a); RICS (2005b); Stubbs (2008); Design-Build (2011) and Kukreja (2016)
Optimizes the life cycle of the building	Design-Build (2011)
Reduced operating/maintenance cost including dealing with occupants' complaints	Citex (1999)**;** Heerwagen (2000); Castillano *et al.* (2000); Hydes and Creech (2000); Yates (2003); Zhou and Lowe (2003); RICS (2005a); Stubbs (2008); Design-Build (2011) and Kukreja (2016)
Increases property value and resale value	Heerwagen (2000); Yates (2003); RICS (2005a) and Design-Build (2011)
Reduced absenteeism or improve employees' attendance and productivity	Holcomb and Pedelty (1994); Fisk and Rosenfeld (1997); Heerwagen and Wise (1998); Sensharma *et al*. (1998); Heerwagen (2000); Harris (2003); Zhou and Lowe (2003); Miller and Buys (2008); Design-Build (2011) and Kukreja (2016)
Improves worker satisfaction and productivity	Holcomb and Pedelty (1994); Fisk and Rosenfeld (1997); Heerwagen and Wise (1998); Sensharma *et al*. (1998); Heerwagen (2000); Harris (2003); Zhou and Lowe (2003); Miller and Buys (2008); Design-Build (2011) and Kukreja (2016)

Reduced legal and insurance costs associated with reduced risks to current and future generations	Heerwagen (2000): Yates (2001) and Kibert (2016)
Reduced regulatory inspection load	Heerwagen (2000) and (Kibert, 2016)
Enhanced relationships with stakeholders	Heerwagen (2000) and Zhou and Lowe (2003);
Builds a strong, responsive and competitive economy	Hart (1995); Zhou and Lowe (2003); and CIB (2010)
Increased overall organisational productivity	Heerwagen (2000); Yates (2001); Zhou and Lowe (2003); and Stubbs (2008)
Reduced risks/avoided costs and liability	Heerwagen (2000); CIB (2010)
Reduced pollution damage impacts	Miyatake (1996); Heerwagen (2000) Design-Build (2011); and Kukreja (2016)
Minimise energy use and lower cost of energy	Hydes and Creech (2000);Yates (2001); Zhou and Lowe (2003); RICS (2005a); and Vatalis *et al*. (2011)
Improving the building envelope	Johnson (2000); Harris (2003) and Zhou and Lowe (2003)
Major image/ marketing spin-offs	Makower (1994); Heerwagen (2000) and Yates (2003); Stubbs (2008)
Capital cost savings	Yates (2003) and Stubbs (2008)
Increased investment returns	DETR (2000a) and Yates (2003)
Increased productivity, staff recruitment and retention	Turban and Greening (1996); Langford *et al.* (1999); Leiber (1998);Yates (2003); Stubbs (2008); and Kukreja (2016)
More efficient use of resources	Yates (2003) and Zhou and Lowe (2003)

Reduced energy use and cost saving	DETR (2000a); Hydes and Creech (2000); Yates (2001); Zhou and Lowe (2003); RICS (2005a) and Vatalis *et al*. (2011).
Enhancement of company image and reputation	Zhou and Lowe (2003)

2.11.3 Social benefits of sustainable retrofitted building

Social sustainability is based on the concept that a decision or project promotes the improvement of society. In general, future generations should have the same or higher quality of life benefits as the current generation does. This benefit encompasses many things such as human rights, environmental law, and public involvement and participation (Heerwagen *et al*., 1997, Heerwagen, 2000). Failing to emphasise the social part of decision or action in a construction project can result in the slow collapse of the spheres of sustainability and society (CWanamaker, 2016). Social benefits support strong vibrant and healthy communities, by providing the supply of housing required to meet the needs of present and future generations and by creating a high quality built environment, with accessible local services that reflects the community's needs and supports its health, social and cultural well-being (Heerwagen, 2000; Harris, 2003; Design-Build, 2011).

The environmental and economic benefits of green buildings are widespread. However, social benefits of green buildings are often ignored (CWanamaker, 2016; Kukreja, 2016). The social benefits of sustainable construction through design are related to improvements in quality of life, health, and well-being (Kukreja, 2016). These benefits can be accomplished at different levels including buildings, the community, and society in general. At a building level, research on the human benefits of sustainable design has centred on three primary topics: health, comfort, and satisfaction. At a community or societal level, the social benefits of sustainable design include knowledge transfer, improved environmental quality, neighbourhood restoration, and reduced health risks from pollutants associated with building energy use (Heerwagen *et al*., 1997). Better health of building occupants' studies of the health benefits of sustainable design focuses primarily on indoor environmental quality, especially air quality. Table 2.15 highlights more specific social benefits of sustainable construction particularly sustainable retrofitted building projects.

Table 2. 15 Social benefits of sustainable retrofitted building

Social Benefits	References
Improve quality of life, comfort, satisfaction, and well-being of building occupants	Fisk and Rosenfeld (1997); Heerwagen (2000); DETR (2000a); Zhou and Lowe (2003); RICS (2005a); Vatalis et al. (2011) and Kukreja (2016).
Minimise the strain on local infrastructure	Heerwagen (2000); Design-Build (2011); and Kukreja (2016)
Widening the choice of high-quality homes	Heerwagen (2000) and Zhou and Lowe (2003)
Create an aesthetically pleasing environment	Heerwagen (2000) and Design-Build (2011)
Increases occupants' overall morale	Heerwagen (2000) and Design-Build (2011)
Reduced health risks from pollutants associated with building energy use.	Fisk and Rosenfeld (1997); Harris (2003) and Stubbs (2008)
Occupant safety and security	Harris (2003) and Kibert (2016)
Use of locally produced and manufactured products	Harris (2003) and Zhou and Lowe (2003)
Improved public image	Heerwagen (2000); Zhou and Lowe (2003); and Makower (1994)
Easier job creation in cities, towns and villages	Zhou and Lowe (2003) and Yates (2003)
Community outreach and education	Heerwagen (2000) and Stubbs (2008)
Improved ability to work with community stakeholders	Heerwagen (2000) and Zhou and Lowe (2003); Berardi (2013); and Yin (2018)
Creating more usable floor space	Zhou and Lowe (2003)
Increased daylighting	Kaplan (1992); Heerwagen et al. (1995) Sims *et al*. (1998); Heerwagen and Wise (1998) 1998 and Leather *et al*. (1998)
Enhance community liveability	Heerwagen (2000)

Increased use of recyclable materials	Heerwagen (2000); Plank (2008); Tan (2011) and Kibert (2016)
Improved security	Harris (2003); Stubbs (2008) and WBDG (2017)

2.12 Barriers and enablers to sustainable retrofitted building projects

The discussion of barriers to sustainable construction is necessary. It is pertinent to note that this study is focusing on barriers and enablers related to embarking on sustainable retrofitted building projects. Hakkinen and Belloni (2011) argue that some barriers might become drivers if they are used in another or opposite way. The rationale behind this has been aforementioned in the introduction because the majority of the greenhouse gas emission comes from the built environment. This discussion will discuss some barriers, and this is essential to have a better understanding of the reason there has been a slow pace in embarking, uptake and delivery of sustainable retrofit projects. However, there exists a reasonable number of barriers and enablers in the literature, but this research will discuss the following barriers in detail: cost perception, lack of understanding by clients, inappropriate timing, collaboration, and lack of managing knowledge since barriers are the opposite of drivers.

2.12.1 Cost perception

There has been a widespread misconception about the costs of sustainable building (SB) compared with the traditional or conventional building, and this unforeseen cost has been addressed as one of the major barriers to the delivery of sustainable retrofit building projects (Hakkinen and Belloni, 2011). Retrofit projects have been hindered due to the stakeholders' misgivings or uncertainties about higher risks due to perceived high cost (Hydes and Creech, 2000; Larsson and Clark, 2000; Nelms *et al.*, 2005). Hakkinen and Belloni (2011) argue that many studies show that sustainable buildings have no significant increase in the cost of investment and further explained that there is no explicit answer for the cost effects of sustainable retrofit projects. Bon and Hutchinson (2000) and Zhou and Lowe (2003) state that it is widespread that energy efficient buildings, during operation, save a lot of costs which is not appropriately conveyed to the stakeholders. They revealed that real cost data for a broad range of technologies and design solutions in energy efficient buildings contradicts the perceptions of stakeholders about the high (perceived) cost of energy-efficient buildings. Additionally, they demonstrate that significant improvement in retrofitting of existing buildings can be achieved with minimal extra cost. In the same vein, Hydes and Creech (2000) discovered that the significant barrier to the uptake of sustainable retrofitted building projects is the misconception and misrepresentation of incurring higher capital cost and low market value. They argue that cost consultants have often caused this misconception. In line with this, Bartlett and Howard (2000) reveal that cost consultants have primarily over-estimated the capital cost of energy efficient building projects, hence underestimating or undervaluing potential cost savings. Additionally, the higher cost may also come from consultants' fees and indirectly from the unfamiliarity of the design team and contractors with SB building methods (Hydes and Creech, 2000; Hakkinen and Belloni, 2011). In their studies, Sodgar and Fieldson (2008), Sayce *et al*. (2007), and Lam *et al*. (2009) have documented that one of the challenges to embarking on retrofit projects is the fear of additional cost. To overcome these barriers, they suggest the availability of financial incentives and innovative measures by the government and local authorities through financial institutions.

2.12.2 Lack of understanding by clients

To achieve sustainable or retrofitted building projects, it is expected that clients must express interest and willingness to understand the development of SB processes (Hakkinen and Belloni, 2011). Interest in aspects such as material supplies, knowledge, methods, and cost value are essential for clients to understand. Accordingly, few key stakeholders may express interest to own an SB (Bon and Hutchinson, 2000). It is important to note that different kind of client can exert different relevance. Government and local authorities have more influence on the issue of SB because they own and develop most public buildings hence, may affect significantly if they promote and champion the embarking, uptake and delivery of retrofit projects. Bossink (2004) suggests it is crucial for local organisations to get very much involved in sustainable building projects, especially when market pull is absent. The author states that the involvement of the government and local authorities in the issue of SB would help break the barrier to embarking on and delivery of sustainable retrofitted buildings.

Waddel (2008) identifies the importance of co-operating policies and market-related issues in sustainable building projects and argues that SB may become more important for organisations when they recognise, understand, and declare an interest in corporate social responsibility and related reporting as it regards to sustainable retrofitted building projects. For example, sustainable building product retailers view environmental issues as a competitive issue. The behaviour to lack of understanding by clients has been demonstrated in their consideration of the environmental problems lifestyle performance as it relates to sustainable retrofit projects (Hakkinen and Belloni, 2011).

2.12.3 Inappropriate timing

Hakkinen and Belloni (2011) state that correct timing to get some major actors (e.g. models of cooperation, models of communication, roles of different stakeholders, decision makers, management process and scheduling) involved SB projects has been identified as one of the major key issues for project success in delivering sustainable retrofitted building project. They also stated that timing issues had been identified as possible process-related barriers. The importance of the availability of key stakeholders and required expertise in SB projects during the early planning stage is crucial. A large part of SB potential or possibilities is lost if the right actors, including the design options, are not considered at the beginning planning stage (Hakkinen and Belloni, 2011). In a relative view, Rydin (2006) states that this concern is not only at the building project stage, but also in the preceding planning process. Access to basic services and supply of sustainable energy services are examples of planning issues that have an impact on SB.

Horman *et al*. (2005) stress that the need for timely adoption of project objectives, timely selection of an experienced design and construction team, and the avoidance of haste are vital to ensure that the goals of the project are being shared at an early stage with team members. Accordingly, Williams and Dair (2007) emphasise the relevance of the schedule in SB projects. They state that delivering SB is hindered when designers are involved in later stages of the project. Riley *et al.* (2003) and Greenwood *et al*. (2011) argue that construction organisations are essential and should be included during the design stage of any sustainable building project because they play a vital role from the beginning to the end of the build due to the essential services they provide, including cost estimation. Furthermore, it is of necessity that there is an accurate cost estimation at an early stage of SB projects because this will assist the client in fitting the necessary variables in the project's budget (Hakkinen and Belloni, 2011).

The need to involve the project manager at an early stage of the project is suggested. In line with this, Ang *et al*. (2005) emphasise that involving the project manager at the planning stage of sustainable retrofit projects is essential. They state that this is important because the project manager represents the client and organises the evaluation processes. Martar *et al*. (2008) also emphasise the need for a standard framework that integrates tasks and aspects of SB with construction practices at the planning stage. They state that the absence of a standard structure at an early stage, or at an appropriate time during the project, is one of the significant technical barriers to delivering retrofit projects.

2.12.4 Lack of collaboration

The retrofitted building project is an all-inclusive solution that requires good collaboration and effective communication within team members of the project for optimal performance. Hakkinen and Belloni (2011) argue that the lack of collaboration between team members in a retrofitted building project has shown to slow down the uptake of SB projects. They state that SB projects need the collaboration and close interaction of key stakeholders (suppliers, professionals, clients, and users) due to the fact that the project requires the high collaboration of all key stakeholders. The models of cooperation can be enhanced with the help of integrated methods and information technology solutions. In a related view, Rydin (2006) state that one of the significant barriers to embarking on and delivery of the retrofit projects is a lack of collaboration. Rydin (2006) argues that SB requires innovation, new knowledge, and learning within stakeholders and organisations. Hence, the need for collaboration in delivering projects is essential.

In addition, Mills and Glass (2009) state that necessary skills are needed in the sustainable retrofitted building project delivery and such skills include awareness, communication, experience, comprehension, lateral thinking, leadership, technical knowledge, passion, and negotiation. Therefore, the need for collaboration among the stakeholders cannot be overemphasised. Reed *et al*. (2000) suggest that the collaborative process encourages all actors in a building project to interact and communicate with each other. In stressing the need for collaboration in retrofitted building projects, Horman *et al*. (2006) suggest a delivery method that integrates the designers, contractors, operations, and the maintenance managers under one contract to the client. Emphasising a similar suggestion, Deane (2008) affirms that the preferred design model for delivering SB projects is an integrated design process, which includes all key stakeholders (owner, designers, developers, builder, tenant and facility operators) from the beginning. Retrofitted building project necessitates a strong interdisciplinary collaboration within the designers, builders, clients and other stakeholders right from the planning process of the project (Hakkinen and Belloni, 2011).

Ballard and Kim (2007) pointed out that the power to implement project roadmap successfully lies within the stakeholders if there is collaboration. They argue that the lack of collaboration with the supply chain has often hindered the successful delivery of SB projects and sustainable requirements. This is because the present construction industry is characterised by a complex supply chain in which various players may have a competing interest; therefore, there is a need for collaboration. Given this argument, Anon (2007) suggests that the public sector could play a significant role in initiating the transformation of supply chain towards joint goals and collaboration. The industry should collaborate regarding sharing information about good practices to benefit from each other’s experience in delivering retrofitted building projects (Hakkinen and Belloni, 2011).

2.12.5 Lack of managing knowledge

There is a lot of scholarly documentation that lack of knowledge management has been considered to be a hindrance to embarking, uptake and delivery of sustainable retrofit building projects (Ala-Juusela *et al*., 2006; Shelbourn *et al*., 2006; Hakkinen and Belloni, 2011; Shari and Soebarto, 2012). Hakkinen and Belloni (2011) state that knowledge management in retrofitted building projects enables the consideration of wide spectrum of aspects including building performance, environmental issues, life-cycle costs, and service life, and rapid adapting of the design to the specific requirement case. Robinson *et al*. (2001 2005) argue that the lack of managing knowledge in the industry poses a threat to achieving sustainable building principles and best practices. They further state that knowledge management is an essential enabler for all innovations in construction organisations. Shelbourn *et al*. (2006)

suggest that to achieve sustainable construction, it is necessary that the industry intensifies its efforts to move towards a knowledge-intensive mode Dewick and Miozzo (2002) and Pitt *et al.* (2009) argue that institutional challenges and limitations (such as corporate governance structure and the extent of stakeholder ownership) and lack of knowledge are also reasons why there has been reluctant to change. Sayce *et al*. (2007) affirm that the non-existence of knowledge management (KM) practices between construction stakeholders impedes the dissemination of knowledge and information, which contributes to the reluctance to embarking on, uptake, and delivery of sustainable retrofitted building projects.

Lack of technical information to manage these pose a challenge to the industry in the uptake of sustainable construction. These point to the fact that KM is a necessity in delivering sustainable building projects (Shari and Soebarto, 2012). In attaining the goals of sustainable construction towards sustainable development, it is essential to realise the need for KM to be adopted in the industry. The need for KM is vital to have an improved understanding of sustainability issues in the built environment and how key stakeholders grasp various technologies as a solution in delivering retrofit projects. Eliufoo (2008) and Khalfan *et al.* (2002) affirm that sustainable retrofit building projects could be delivered if new resources of knowledge and expertise inform construction activities. Khalfan *et al*. (2002) and Shelbourn *et al.* (2006) argue that, due to the fragmentation of the industry, knowledge is lost and not managed adequately within movements of people from one project to the other. They explain that knowledge gained in a project is often poorly organised and buried in details and there is no mechanism or technology in place to properly manage the captured knowledge; this still exists, even in sustainable building projects.

Given this, Shelbourn *et al*. (2006) suggest the need to properly manage knowledge by capturing, storing, sharing, and reusing mechanisms. There will be an integrated solution if the industry adopts and inculcate this into retrofitted building projects. Due to the difficulty in the uptake and delivery of retrofit projects, it is essential that knowledge is managed adequately with appropriate technology. The intent behind good decision-making is embedded in employing knowledge management across projects (Shelbourn *et al*., 2006). Knowledge has been argued to be explicit and tacit (Gorman, 2002 and Shelbourne, 2006); therefore, the full uptake and delivery of retrofitted building projects will largely be achieved if the industry fully adopts and integrate knowledge management into its activities.

2.12.6 Lack of appropriate decision making in choosing different sustainable technologies

Lack of appropriate decision-making in choosing the right technologies has been identified as one of the setbacks in achieving sustainable construction in building projects. It has been argued to be one the major barriers to embarking, uptake, and delivery of sustainable construction (Dangana and Pan, 2013) particularly. Reddy and Painully (2004), Wang *et al.* (2009), Pan and Dainty (2012), and Maduka *et al.* (2015) argue that one of the main problems of achieving sustainable development through construction is due to the nature of the multifaceted decision-making tasks of choosing sustainable technologies from different range of options with stakeholder needs. Factors such as lack of skills, uncertainties, higher costs, risks, multi-disciplinary profession with conflicting interests, and huge numbers of different technological options have complicated the decision-making process for stakeholders (Reddy and Painully, 2004; Dainty and Ison, 2005; Wang *et al*., 2009; Buchholz *et al*., 2012).

These factors have influenced stakeholders to over-rely on tried and tested sustainable technologies instead of assisting in making informed choices. Decision-making can have detrimental effects if not appropriately made due to its possible impacts on building performance and stakeholders' satisfaction (British Retail Consortium, 2012; IEA, 2012). Additionally, Rees (2006) argues that progress had been relatively achieved after 20 years of implementing information and technology into sustainable building construction. However, real energy efficiency improvement is yet to be achieved if industry stakeholders do not make an appropriate decision in sustainable options (Antonio and Van Harmelen, 2004; Fensel *et al.*, 2005). The need for a knowledge-based decision tool is necessary to overcome inappropriate decision making in choosing the right technologies in sustainable construction (Pan and Dainty, 2012). Table 2.16 further enumerates the barriers and enablers that exist in embarking on, uptake, and delivery of sustainable construction projects, particularly sustainable retrofitted building projects.

Table 2. 16 Enablers and Barriers to sustainable building projects

Authors	Country	Enablers	Barriers
ACE (2003); Pitt *et al*. (2009) Williams and Dair (2007); and NEFUS (2015)	United Kingdom	• Client awareness • Financial Incentives • Building regulations • Client demands • Taxes and levies • Planning policy • Labelling and measurement • Investment • Legislation and standards	• Affordability • Lack of client awareness • Building regulation • Lack of understanding business case • Lack of client demand • Lack of proven alternative technologies • Planning policy • Lack of one labelling • Stakeholders lack interest • Landlord-tenant issues • The role of insurance companies • Lack of proper stakeholder communication real and perceived cost • Inadequate expertise and power • Poor consideration of sustainability measures
Azizi *et al*. (2011)	New Zealand	• The increase in the level of awareness due to many types of research on the performance of the sustainable building. • Higher profit in return and more economic cooperation • The implementation of new policies.	• Regulator risk • Finance • Standard of care/legal risk inexperience consultant and contractors • Unsatisfactory performance of the sustainable building.
Hakkinen and Belloni (2011)	Finland	• The development and adoption of methods for sustainable building requirement management • The mobilisation of sustainable building tools • The development of designers • Development of awareness of clients' benefit in a sustainable building project • The development of designers' competence and the team is working. • The new concepts and services development.	• Steering mechanism • Economics • Lack of understanding that exists amongst stakeholders • Procedure (procurement and tendering, timing, cooperation and networking) • Underpinning knowledge (knowledge and common knowledge, the availability of methods, tools and innovation)
Winston (2010)	Dublin Ireland		• Lack of a shared vision of sustainable building projects • Poor quality designs instructions/emphasis on demolition • Negative attitude toward social mix demolition • Limited knowledge and expertise in sustainable building methods • The negative perception of higher density housing • Limited resources • A failure to realise the need for social integration

			- Inadequate building regulations and non-existing ones.
Zhang *et al*. (2010)	China	- Sustainable brand reputation improvement - Lower construction and operation cost - Gain favourable land prices - More channels available for financing	- Higher cost as it relates customer demand - Unsatisfactory policy implementation efforts - Higher costs for sustainable appliance and design saving material
Landman (1999) TCC (2008) Ambec and Lanoie (2008) Duah *et al*. (2014).	United States	- Increased building value - Increased worker productivity - Occupancy rates - Asking for rent with ease - Return on investment - Better access to certain markets - Differentiating products - Easy Management and relations with external stakeholders - Young and educated worker attraction - Lower cost of finance (available) - Easy management of risk and services to the external stakeholders. - Lower cost of financial capital - Raw materials and energy reduction	- Long-term payback time - Lack of information about the benefits of sustainable building - Short-term budget horizon - Cost and documentation for LEED certification - Lack of knowledge education and training particularly among building - The risk and fear associated with using new technology or processes - The misconception that is associated with both perceived and real costs and benefits. - The deficiencies associated with policy and incentives structure - The lack of consistency within the assortment of definitions and approaches to sustainable building. - Lack of interest in demand from clients (developers and owners) - The failure of service fee structures to account for the recovery of long-term savings
Richardson and Lynes (2007)	Canada		- Lack of quantifiable sustainable targets - Inadequate flow of information between professional designers, facilities management and faculty - Lack of internal leadership within the key stakeholders that are involved in decision-making power. - A lack of quantifiable sustainability targets - An operational structure that does not reward building design with lower energy cost

Wilson and Tagaza (2004)	Australia	• Improving staff health and staff satisfaction and productivity levels through superior indoor environmental quality. • Reinforcing green band of an organisation • Satisfying government ESD (Ecological Sustainable Design) standards for the building leased and occupied by the government. • Avoiding obsolescence by embodying ESD standards in building design.	• Different contact form of project delivery • A higher initial capital cost • Short term payback financial modelling • Longer design time using integrated design teams • Perceived lack of demand from tenants • The longer approval process for new technologies and recycled materials • Protracted planning process • Introduction of more sustainable and recycled materials
Klöckner and Nayum (2016)	Norway	• Awareness • Demand • Financial incentives • Legislation and standards • Labelling	• Stakeholders lack interest • Landlord-tenant issues • The role of insurance companies • Lack of proper stakeholder communication
Daniel *et al.* (2018)	Nigeria		• Lack of demand for the sustainable product and lack of inclusion in contract clauses • Lack of policy, standard and strategy to promote sustainability • Lack of demand for sustainable product and lack of inclusion in contract clauses • Lack of consideration for sustainability in design and short-term benefit culture
Ametepey and Ansah (2015)	Ghana		• Resistance to change • Lack of government commitment • Perceived high cost
Chan *et al*. (2009)	Hong Kong	• Increased building value • Lower lifetime cost • Higher lifetime • Lower operation cost • Governments' regulation/building code	• Assumed the higher upfront cost • Lack of awareness • Inadequate education • Lack of financial incentives from the government
Galvin (2014)	Germany	• Economically viable, i.e. it always pays back • Fuel savings over the technical lifetime of the upgrade measures.	• The high cost of retrofitting • Hard to treat building stock • Bad government policy frameworks and regulations • Lack of active inspection building system

This study has reviewed the barriers and enablers to delivering sustainable retrofitted building projects, thus, will further broadly examine, in ensuing chapters, the lack of knowledge management between key stakeholders and decision-making issues in delivering sustainable retrofitted building projects. This review broadened the researcher's knowledge on barriers and enablers to the delivery sustainable retrofit project, hence, has contributed to quantitative (survey) and qualitative (interviews) data collection.

2.13 Chapter conclusion

There is no doubt that the construction industry and sustainability are connected due to the impacts of construction. Sustainable construction particularly retrofit remains essential if the environment is sustainable for the current and the future generation. Promoting sustainable retrofitted building projects by key stakeholders is crucial and cannot be over-emphasised. However, the barriers and enablers to delivering sustainable retrofitted building projects discussed in this chapter are numerous, notably the lack of managing project knowledge on the embarking on and delivery of retrofit projects. Furthermore, discussions in Sections 2.5, 2.6, 2.8, 2.9, 2.10, 2.11, and 2.12 summarised the main concerns of key stakeholders in delivering sustainable retrofit projects, generalised the areas required for further empirical investigation, and formed some research questions for the present research. The thought flow and debate involved in the entire chapter presents a solid theoretical underpinning for the research design and research methodological considerations. Using a largely scoped literature review, this chapter has identified some of the issues in delivering retrofit projects.

As established in this chapter, delivering sustainable retrofitted building projects remains a challenge due to lack of knowledge management in making informed and appropriate decisions, the fragmentation of the industry, and diverse stakeholders' different subjective perceptions. Hence, the ensuing chapter discusses knowledge management and its approaches, and how relevant it is when employed in making informed and appropriate decisions in delivering sustainable retrofitted building projects.

CHAPTER 3: REVIEW OF KNOWLEDGE MANAGEMENT IN THE CONSTRUCTION INDUSTRY

3.1 Introduction

Knowledge management (KM) has received a great deal of attention in recent years. The role and essence of KM as a key source of potential advantage for construction organisation have been addressed by numerous authors see for example: web prototype for live capture and reuse of project knowledge (Udeaja *et al*., 2008b), integrated knowledge management model and system for construction (Kanapeckiene *et al*., 2010b), knowledge mapping in sustainability (Gilmour *et al*., 2013), and exploring KM principles to develop a decision-making framework for key stakeholders (Maduka *et al*., 2015a). Success from KM depends on the effective and efficient deployment of different KM strategies and tools within the context of a specific organisation (Udeaja *et al*., 2008b). It has been revealed that KM procedures have a significant influence on organisations achieving optimal performance, particularly in construction projects (Maduka *et al*., 2015d). Delivering sustainable retrofitted building projects remains a challenge (fragmented nature of the industry, diversity of stakeholders and the complexities of retrofitting and tight schedules) due to lack of managing project knowledge by key stakeholders in making informed decisions in the embarking on and delivery of sustainable retrofitted building projects (Maduka *et al.*, 2015a). In a similar publication, Miller *et al*. (2008b) affirm that, whilst there is a genuine need for stakeholders to drive the uptake of sustainable retrofit, the level of managing knowledge in delivering low-energy retrofit projects and specific sustainability features remain disappointingly low. This is because key stakeholders in the construction industry find it difficult to access core knowledge for highly knowledge-intensive activities, such as problem-solving and decision-making (Egbu *et al*., 2004; Anumba *et al.*, 2005b).

Construction organisations have been managing knowledge informally for years, but the challenges facing today's industry particularly in sustainable retrofit building projects means that most organisations need a more structured, coherent approach/process to KM to deliver projects (Khalfan *et al*., 2002; Shelbourn *et al*., 2006; Maduka *et al*., 2015d). It has been argued that success in KM depends on the effective and efficient deployment of different KM strategies and tools within the context of a particular organisation (Udeaja *et al*., 2008a). It has been revealed that

KM procedures have a significant influence on organisations achieving optimal performance in construction projects (Zack *et al*., 2009). Different studies have used different terms for KM procedures, for example knowledge sharing (Robinson *et al*., 2002; Egbu and Robinson, 2005), knowledge utilisation (Asoh *et al*., 2007), knowledge capture and reuse (Udeaja *et al*., 2008a), knowledge creation (Yang *et al*., 2010), knowledge organisation (Ramachandran, 2010), and knowledge storage (Allameh *et al*., 2011). However, what differentiates each of these is the difference in viewpoint, application, and level of detail. This chapter will examine the definition of knowledge and discuss explicit and tacit knowledge, and knowledge management procedures, which include knowledge acquisition and creation, knowledge capture, knowledge storage and retrieval, knowledge sharing and transfer, knowledge application, and knowledge reuse. Additionally, the essence of KM and the construction industry in delivering sustainable retrofitted building projects are discussed in this chapter.

3.2 What is knowledge?

It is vital to comprehend what constitutes knowledge and what falls under the category of information or data. This is because the word 'knowledge' often takes on a variety of meanings (Davenport and Prusak, 2000b; Frost and Ueda, 2010) and it is necessary to differentiate data and information from knowledge and what it constitutes. Davenport and Prusak (2000) when describing knowledge state that '*knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organisations, it often becomes embedded not only in documents or repositories but also in organisational routines, processes, practices, and norms*' (p.5).

According to Thierauf (1999) and Bali *et al.* (2009) data are facts and figures that communicate a specific idea, but are not structured in any appropriate way, and provides no further information regarding patterns and context. It is argued that for data to become *information*, it must be contextualised, categorised, calculated, and condensed (Davenport and Prusak, 2000b). Information, therefore, paints a bigger picture; it is data with relevance and purpose (Bali *et al*., 2009). In essence, information is found in answers to questions that begin with such words as *who,* *what, where, when, and how many* (Ackoff, 1999). However, since a clear definition has been set between knowledge, information, and data, it is pertinent to go one step further to state the two forms in which knowledge exists. Knowledge has been recognised to exist both in explicit and tacit forms (Smith, 2004, Shelbourn *et al*., 2006, Duah *et al*., 2014).

3.3 Explicit and tacit knowledge

There are two types of knowledge: tacit and explicit knowledge. The ensuing sections will discuss the two knowledge types that exist.

3.3.1 Tacit knowledge

Tacit knowledge is knowledge that is not expressed. Thus, it is difficult to articulate, which often resembles intuition and that is a cumulative store based on practice, experience, mental maps, insights, expertise, know-how, trade secrets, learning, and skills sets embedded in the past and present of people's experiences, processes, and values (Smith, 2004; Hussain *et al*., 2004). Tacit knowledge has been referred to as personal knowledge about specific context. Such knowledge or experience is difficult to formulate, record, or express explicitly since it is stored in human brains and minds (Kanapeckiene *et al*., 2010a). It is part of the personal experience and is shared or transferred directly and exchanged efficiently (Spender, 1996). Such knowledge is unstructured and intangible; it is difficult to codify (Zhang *et al*., 2009). It is argued that much new knowledge is created through the synergistic link and interplay between tacit and explicit knowledge (Nonaka and Takeuchi, 1995b).

Ryle (1949) and Polanyi (1962) recommend that the peculiarity between tacit and explicit knowledge is critical to understanding how people deal with the world in a purposive way. Anumba *et al*. (2005a) argue that an appropriate balance of explicit *versus* tacit approaches is dependent on each organisation's strategy and the specific circumstance that is being addressed. An organisation is bound to require elements of both approaches and must integrate the two efficiently to achieve maximum positive impact (Hari *et al*., 2005).

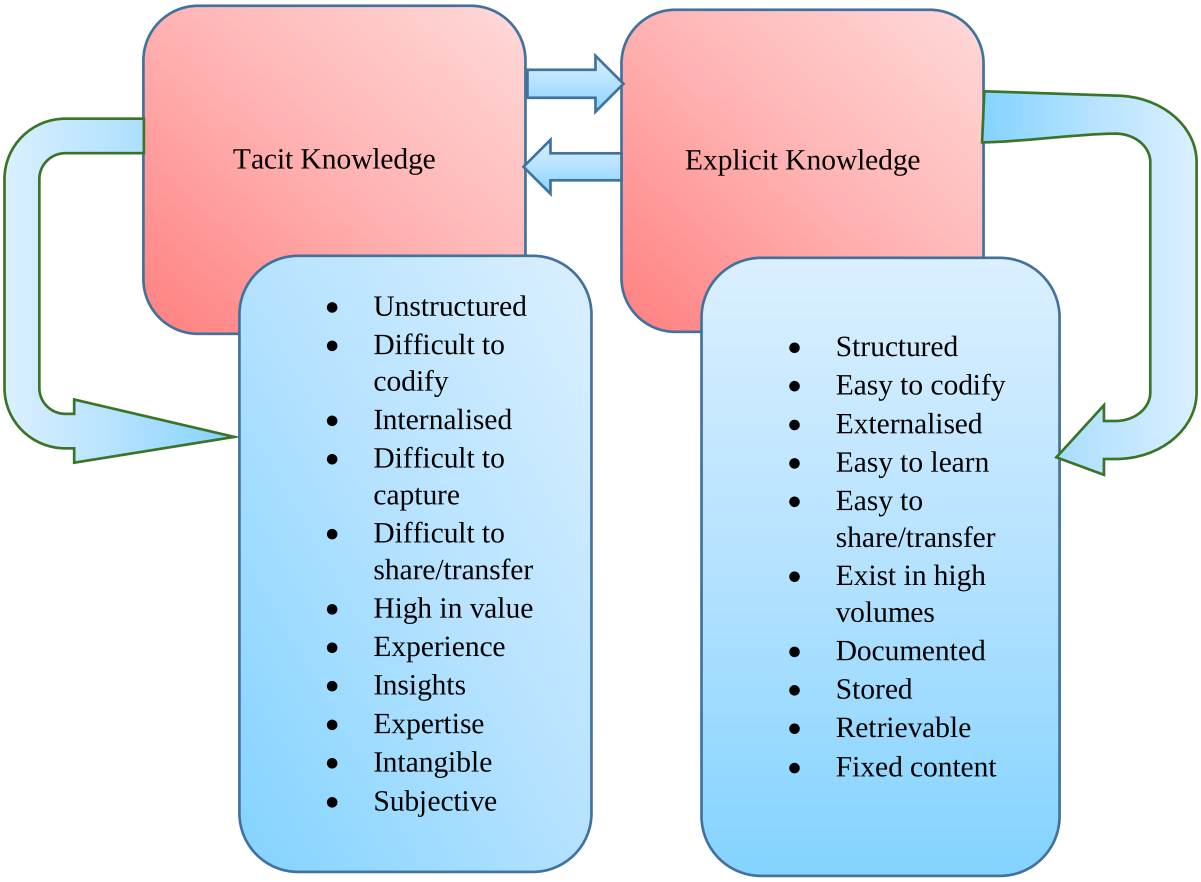


Figure 3.1 Tacit and Explicit knowledge

Figure 3.1 reveals the categories of both tacit and explicit knowledge. It widens the knowledge of the research as it relates to knowledge management and assists in designing both the survey and case study investigations.

3.3.2 Explicit knowledge

Explicit knowledge is referred to as the knowledge that can be codified and documented. This would include such things as project information, design drawing and specifications, cost reports, and other information archived in paper or electronic format (Smith, 2001; Zhang *et al*., 2009). Explicit knowledge is learned and acquired and can be shared and transferred through a medium of precise or formal language (Kanapeckiene *et al*., 2010a). Explicit knowledge is easily collected, documented, stored, and retrieved very independently of any single individual through technological means and systems (Hari *et al*., 2005).

For KM to succeed in the industry, key stakeholders need to understand what constitutes knowledge and this leads to the definition and discussion of KM in the ensuing paragraph.

3.4 Knowledge management

Knowledge cannot achieve competitive advantage unless it is managed. Knowledge management was introduced more than two decades ago to assist organisations in creating, sharing, and using knowledge more systematically (Yusof and Abu Bakar, 2012). Different definitions of knowledge management exist in academic literature, and these descriptions are coined to each author's perspective. KM deals with the identification, optimisation, and active management of intellectual assets to create value, increase productivity and gain, and sustain competitive advantage (Webb, 1998). KM has been described as information that has been used and integrated within a person's knowledge-based experience and behavioural patterns (DeTienne and Jensen, 2001). In other words, KM is the organisational optimisation of knowledge to achieve enhanced performance, increased value, competitive advantage, and the return on investment through the use of various tools, processes, methods, and techniques (Skyrme and Amidon, 1997). Yang and Ho (2007) describe KM as the process of identifying/creating, assimilating, and applying organisational knowledge to exploit new opportunities and enhance corporate performance.

Expanding upon this definition, Frost (2010) affirmsthat KM encompasses the understanding of: '*where and in what forms knowledge exists; what the industry needs to know; how to promote a culture conducive to learning, sharing, and knowledge creation; how to make the right people at the appropriate time; how to best generate or acquire new relevant knowledge; how to manage all of these factors so as to enhance performance in line with the industry's strategic goals and short-term opportunities and threats*'(p.1). In construction, Egbu *et al*. (2004) define KM as an important resource for construction organisations due to its capability to provide market leverage and contributions to organisational innovations and project success. Furthermore, Ogunlana *et al*. (2002) argue' that individuals have different knowledge-based capabilities and experiences, which lead to different problem-solving approaches and decision-making and can be achieved through KM. Yusuf and Abu Bakar (2012), in their study, reveal that the world's most successful organisations are experts at managing knowledge.

Achieving success from KM depends on the effective and efficient deployment of different KM procedures within the context of a specific organisation (Chin-Loy *et al.*, 2007; Udeaja *et al.*, 2008a; Omerzel, 2010). Nonaka and Takeuchi (1995b) state that since knowledge mainly exists in the mind, a transition process should be performed, hence, intellectual property has to be transited to achieve organisational knowledge needs. They suggest that knowledge could be created through continuous interaction between tacit and explicit knowledge to form four modes: socialisation externalisation, internalisation, and combination (SECI). They describe this transition process as a continuous spiral (see Figure 3.2). SECI is briefly explained below.

1. Socialisation (tacit-tacit): tacit knowledge is shared among individuals allowing the creation of new knowledge.
2. Externalisation (tacit-explicit): tacit knowledge is formed into explicit knowledge by the creation of concepts.
3. Combination (explicit-explicit): the created concept is justified through a combination of existing knowledge, e.g. against the criteria cost and profit margin.
4. Internalisation (explicit-implicit): the new external knowledge is shared within the company. Individuals create tacit knowledge from the explicit knowledge by internalisation, thus adding this knowledge to their knowledge pool, which can start a continuous spiral. Figure 3.2 illustrates the continuous interaction of tacit and explicit knowledge.

Figure 3.2 was essential for informing the research on the need for tacit and explicit knowledge management to be applied in the retrofit project. It also contributed to the collection of data through a questionnaire survey and a semi-structured interview.

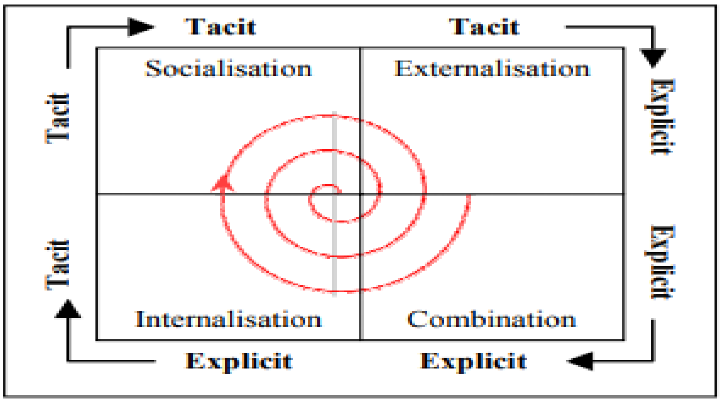


Figure 3.2 SECI model (Nonaka and Takeuchi, 1995)

Nevertheless, achieving success from KM depends on the effective and efficient deployment of different KM procedures within the context of a specific organisation (Chin-Loy *et al.*, 2007; Udeaja *et al.*, 2008a; Omerzel, 2010). The ensuing section discusses knowledge management approaches/processes that exist in the literature.

3.4.1 Knowledge management procedures/processes

Success from KM depends on the effective and efficient deployment of different KM processes/procedures within the context of a specific organisation (Udeaja *et al.*, 2008a). It has been revealed that KM procedures have considerable influence on organisations achieving optimal performance in construction projects (Zaim *et al.*, 200; Goll *et al.*, 2007). Different studies have used different terms for KM procedures, for example, Davenport and Prusak (2000a), Rollet (2003), Chin-Loy *et al*. (2007), Chen and Mohamed (2008), Fong and Choi (2009), Zack *et al*. (2009) and Omerzel (2010). What differentiates each of these is the difference in viewpoints, application, and level of detail. However, considering the literature on existing different knowledge management procedures, this research will discuss six KM procedures, which include knowledge acquisition and creation, knowledge capture, knowledge storage and retrieval, knowledge sharing/transfer, knowledge application, and knowledge reuse. Figure 3.3 highlights the KM procedure cycle.

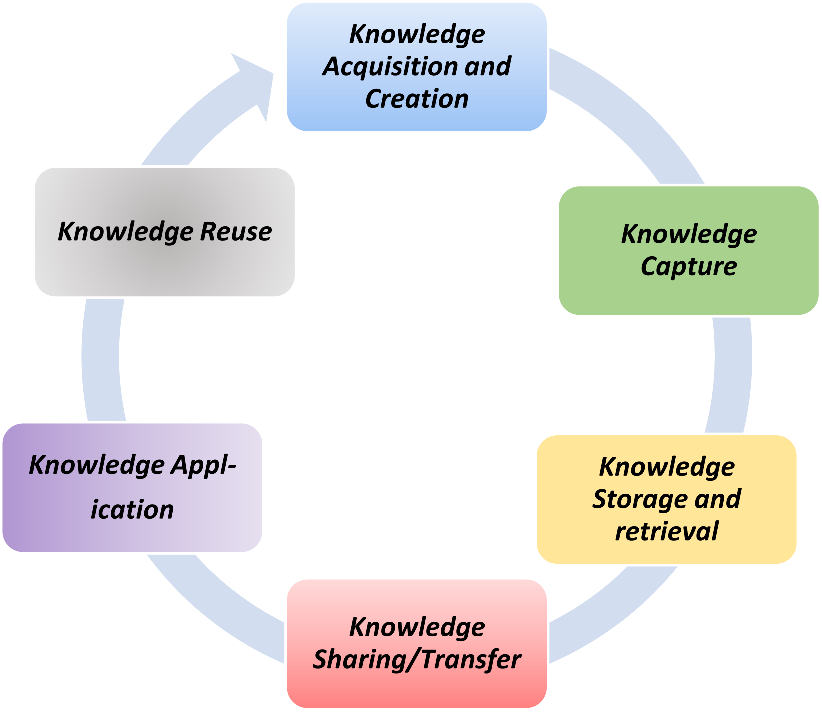


Figure 3.3 Knowledge management processes/procedures cycle

3.4.2 Knowledge acquisition and creation

Organisations acquire knowledge from both external and internal sources. The ways to acquire information from external include: 1) benchmarking best practices from other organizations; 2) attending conferences; 3) hiring consultants; 4) monitoring economic, social and technological trends; 5) collecting data from customers, competitors, and resources; 6) recruiting new staff; 7) collaborating with other organizations; 8) building alliances; 9) forming joint ventures; and 10) establishing knowledge links with business partners (Morse, 2000). Organisations acquire knowledge internally by tapping into the knowledge of its staff, learning from experience, and implementing continuous process improvement. Two critical points regarding knowledge acquisition are, first, to ascertain if the information is acquired from an external or an internal source is subject to perceptual filters (norms, values, and procedures) that guide what information the organisation considers and eventually accepts; and second, to ascertain that a company's core competency strategy systemically guides knowledge acquisition. Individuals search for information, internally and externally, which enhances performance and adds to existing knowledge bases. For organisations to meet their strategic objectives, knowledge acquired from multiple sources must be organised around the company's key business processes and knowledge domains modelled in the organisation's value chain (Morse, 2000). However, the knowledge acquired can be created for the benefit of the organisation and to be accessible to the general employee for competitive advantage.

Knowledge creation is referred to as an emergent process in which motivation, inspiration and experimentation play an essential role (Lynn *et al.*, 1996). Organisational knowledge creation is the ability of an institute to develop new and useful ideas and solutions and circulate it in the organisation, products, services, and systems for optimal productivity (Nonaka and Takeuchi, 1995b; Marakas, 1999). Nonaka *et al*. (2001) describe knowledge creation as a spiral that goes through pairs of seemingly antithetical concepts, such as order and chaos, micro and macro, part and whole, mind and body, tacit and explicit, self and order, deduction and induction, and creativity and control. Successful organisations are ones that consistently create and circulate new knowledge in the organisation, applying it to new product technology. Knowledge creation is essential and has to be the centrepiece for organisational growth and success (Atefeh *et al*., 1999).

One of the main critical success factors in each organisation is how much knowledge organisations have through its staff, for which the knowledge is enhanced for more significant and future benefits of the organisation, is essential. There are two different paradigms of knowledge creation. First, is the scientific view of knowledge or 'knowledge is truth' view (Alvesson and Willmott, 1996), in which knowledge is considered as a statutory body of facts and rational laws. Second, what is referred to as the social paradigm of knowledge construction (Burgoyne and Reynolds, 1997), in which knowledge can be socially constructed through employee interchange. The KM literature distinguishes between individual and organisational knowledge creation. These differences are important, since knowledge creation process features are different depending on whether the knowledge is individual or organisational. It is argued that social knowledge is the total amount of things people know (Goucher, 2007). Ang and Massingham (2007) present a list of factors that affect knowledge creation. They classify these elements into four groups: cultural, organisational, knowledge sources, and knowledge processes.

Morse's (2000) study states that organisations create new knowledge through numerous activities, which include: 1) *action learning*, involving working on problems, focusing on the learning acquired, and actually implementing solutions; 2) *systematic problem solving*, which requires a mindset, disciplined in both reductionism and holistic thinking, attention to detail, and a willingness to push beyond the obvious to assess underlying causes; and 3) *learning from experience,* which involves reviewing a company's successes and failures, assessing them systematically, and transferring and recording the 'lessons learned' in a way that will be of maximum benefit to the organisation.

3.4.3 Knowledge capture

Knowledge capture deals with the process of retrieving either explicit or tacit knowledge that is embedded in people, artefacts, or organisational entities (Hsieh *et al.*, 2009). Knowledge capture prevents the loss of critical knowledge due to staff retirement, job downsizing, and subcontracting. Egbu and Robinson (2005) reveal that many organisations are concerned more with telephones, faxes, emails, he internet, and intranet. This is because they disregard the recording of valuable experience in electronic form in the area of documentation, databases, web pages and, knowledge-based structures that can assist in preventing the repetition of mistakes in organisational activities. Examples of this knowledge-based system are neural networks, fuzzy logic, genetic algorithm case-based reasoning, and agent and knowledge discovery database (KDD). Knowledge capture can also be useful to training staff and to preserve the company's expertise, particularly before an employee leaves the company (Hari *et al*., 2005; Tan *et al.*, 2006). Some tools, such as an expert system, can be useful in capturing and codifying knowledge within the organisation environment.

Tan *et al*. (2010b) stated that knowledge capture involves three processes that include knowledge identification and location, knowledge representation, and storage and knowledge validation. Identifying knowledge and locating it requires identification of the types of knowledge to be managed and the location of the learning situation (Kamara *et al*., 2003; Udeaja *et al*., 2006). Hence, creating new knowledge and individuals with relevant knowledge (Tan *et al*., 2007; Carrillo *et al*., 2000). Knowledge representation and storing comprises indexing, organising, and structuring knowledge (Robinson *et al.*, 2002; Rollet, 2003) into theme-specific knowledge areas and authoring knowledge (Markus, 2001) in the standard or format specified. Knowledge validation involves giving credibility to the captured knowledge by ensuring that the knowledge captured and stored is fit for purpose.

3.4.4 Knowledge storage and retrieval

Knowledge storage and retrieval is an essential aspect of knowledge management. It is important that organisations manage their memories (which contain several forms of knowledge, such as documents or data that are stored in experiential systems) rather than leaving the re-utilisation of memory to the chance that organisational staff member happens to know. Empirical studies have shown that while organisations create knowledge and learn, they also forget (i.e. do not remember or lose track of the created knowledge) (Argote *et al.*, 1990; Darr *et al.*, 1996). However, the storage and retrieval of organisational knowledge, also referred to as organisational memory by Walsh and Ungson (1991) and Stein and Zwass (1995), constitute an important aspect of effective organisational knowledge management. Storing knowledge or organisational memory includes knowledge residing in several component forms which include written documentation, structured information stored in electronic databases, codified human knowledge stored in expert systems, documented organisational procedures and processes, and tacit knowledge acquired by individuals and networks of the individual (Tan *et al.*, 1999).

It is widespread knowledge that much of an organisation's explicit knowledge resides in unstructured documents in the form of memos, design blueprints, notes and meeting minutes, hence, the need to capture, store, and retrieve knowledge (Dworan, 1997). To store and retrieve knowledge, it is essential that an organisation ascertain what is important to retain/store and how best to store it. Dworan (1997) reveals that knowledge should be structured and stored so that organisations can find and deliver it quickly and correctly. When storing knowledge, it is vital to consider how different groups can retrieve the information. Functional and effective knowledge storage systems allow categorisation around learning needs, work objectives, user expertise, use of the knowledge, and location (where the information is stored).

3.4.5 Knowledge sharing/transfer

Knowledge transfer and sharing refer to making knowledge very active and relevant for the organisation in creating values. Knowledge sharing is described as the provision of the right knowledge to the right person at the needed time (Mertins *et al.*, 2001; Robinson *et al.*, 2002). In general, KM needs to be employed in a company's products, processes, and services. If an organisation does not find it easy to locate the right kind of knowledge in the correct form, the company may find it challenging to sustain its competitive advantage. When innovation and creativity are the hallmarks of competitiveness, an organisation should be swift in finding the right kind of knowledge in the correct form for the organisation to share for optimal performance.

Effective knowledge sharing is supported by supportive organisational culture and trust between the people that are engaged (Newell *et al.*, 2002). Markus (2001) argues that this procedure could be passive or active. Markus (2001) explained that it could be passive in the area of newsletter publication or population of knowledge repository for users or active in the area of publishing knowledge via an electronic alert to those who needed it. Egbu and Robinson (2005) agree to this submission by stating that effective knowledge sharing/transfer knowledge between construction stakeholders can be achieved through organisational publications of recent project successes and failures, publication of best practices and lessons learned, mobile phones, pagers, telephones, faxes, storytelling, quality circles, mentoring and shadowing, coaching, and job rotation.

However, the appropriate way to share or transfer knowledge depends on both the source and the intended receiver (Herwing, 2003). Park (2007) argues that organisations could share or transfer knowledge intentionally and unintentionally. Explaining further, Park (2007) states that organisations intentionally transfer or share knowledge by written communications, training, internal conferences, internal publications, job rotation and job transfer, and mentoring. Unintentional knowledge transfer is referred to as a function of unplanned human interaction, i.e. job rotation, stories and myths, task forces, and informal networks. Knowledge needs to be shared throughout the organisation before it is exploited at a hierarchy level (Park, 2007).

3.4.6 Knowledge application

KM produces a competitive advantage in an organisation when the knowledge captured or created is applied in the delivery of products and services rather than the knowledge itself. The key point in KM is to make sure that the existing knowledge present in an organisation is applied productively to benefit the organisation (Probst *et al.*, 2000). Davenport and Klahr (1998) and Park (2007), in a similar vein, conclude that effective knowledge application activities focus on organising knowledge to be more active and relevant in producing better product and services, increase efficiency and reduce costs to improve organisation standards and principles. Therefore, knowledge application is used as guidance and the recommendation of organisational decision and action (Bercerra-Fernandez and Sabherwal, 2004). Pentland (1995) argues that it is challenging to attribute knowledge to an organisation that does not produce a competent performance.

A significant challenge in knowledge application in organisations is the absence of a collective mind and central memory. Due to cognitive limitations, no single individual can be aware of all that is known to the organisation as a whole, or can specify in advance what knowledge will be needed, when and where hence, the need to apply created and captured knowledge across the organisation. Knowledge application includes an application for decision-making protection, action and problem-solving, which can finally lead to knowledge creation. The created knowledge needs to be captured, stored, shared, and applied, hence, the cycle continues. KM systems support processes by which individuals make use of other people's knowledge (Sabherwal and Sabherwal, 2005). Information technology supports knowledge application in the organisation by using an organisational procedure (Gottschalk, 2008). Organisations distribute knowledge systems, hence, knowledge is continuously emerging from the corporate members' actions and interactions. Since knowledge is disseminated amongst multiple agents and is dispersed in time and space, knowledge integration is a significant facet of knowledge application in organisational settings. Knowledge application can be implemented in line with the available knowledge, for example, knowledge creation/capture and knowledge sharing process.

3.4.7 Knowledge reuse

Reuse of knowledge is stated to involve both recalls (that information has been stored, in what location, under what index or classification scheme), and recognition (that information that meets the users' needs (Lansdale, 1988). Szulanski *et al.* (2002) specify that knowledge reuse deals with the reapplication of knowledge such as best practice. Majchrzak *et al*. (2004) agrees with this by stating that it is the reuse of knowledge for innovation with necessary integration or adaptation of best practice. The reuse of knowledge encompasses conceptualising the issue or problem and selecting the best reusable ideas (i.e. knowledge) and by perusing and revaluating reusable ideas. Tan *et al*. (2007) enumerate various kinds of reusable knowledge to include process knowledge, costing knowledge, legal and statutory needs, knowledge of the best practices and lesson learned, and knowledge of who knows what. Expanding on knowledge reuse Markus (2001) states that reusing knowledge comprises four different stages.

The first stage is defining the search question, and this stage is necessary for successful reuse. One of the characteristics of separating experts from novices is that experts know what questions to ask. The second stage is the search for and the location of experts or expertise. The third stage is the selection of appropriate expert advice from the results of the search. The fourth stage is applying the knowledge, which may involve analysis of general principles against a specific situation and a process sometimes called 're-contextualisation' of knowledge that was decontextualised when it was captured and codified (Blair, 1984; Ackerman, 1994; Lansdale, 1988).

3.5 Knowledge management techniques: social and technological aspect

KM encourages learning at every opportunity. This concept is about learning before, during, and after, and can be applied to any activity including projects, tasks, and events (Leask *et al*., 2008). In supporting different knowledge management processes, different strategies are employed by individuals and organisations in construction projects. Non-IT tools are independent of IT although they can be facilitated by it. However, knowledge techniques are not new because many organisations have been using it to carry out projects for a long time under the umbrella of management approaches, such as organisational learning (Yuan, 2011). Different KM tools exist; however, this research summarises it in Table 3.1.

Table 3. 1 Summary of knowledge management tools and techniques (Leask *et al.*, 2008, Yuan, 2011)

IT-Tools	**Non-IT tools**
Data and text mining	Brainstorming
Groupware	Communities of practice (CoP)
Internet	Face-to-face interactions
Extranet	Post Project reviews
Knowledgebase	Recoupment
Taxonomies and ontologies	Coaching and mentoring
KM software	Apprenticeship
IT- databases etc.	Training, seminar, workshops, phone calls, cameras etc. Case studies, knowledge bank Rapid evidence review, retrospective review. Peer assistance, induction

3.6 Knowledge management in the construction context

Construction is a project-based industry in which each project is unique and brings stakeholders who collaborate at different stages during the project's life cycle. Each construction project can be considered a multi-discipline organisation, which may or may not continue to work together once the project is completed (Kamara *et al.*, 2002). This temporary nature of construction and heavy fragmentation makes construction a significantly complex process. Construction is also an information-intensive industry in which stakeholders communicate a large amount of information across the various stages of the project's life cycle. These make managing knowledge a very challenging task for the construction industry, hence resulting in reduced efficiency of the overall construction process. In this context, KM has been considered as a strategy to promote innovation and enable improvement of the construction process.

Numerous authors have suggested the role and relevance of KM as a key source of competitive advantage for construction organisations (see for example, (Egbu *et al*., 2004; Anumba *et al*., 2005b; Shelbourn *et al*., 2006; Tan *et al*., 2006; Udeaja *et al*., 2008a; Kanapeckiene *et al*., 2010a; Gluch *et al*., 2013; Forcada *et al*., 2013; Maduka *et al*., 2015f). The construction industry's poor record in managing project knowledge results in a huge wastage of resources, a detrimental effect on the quality of projects, and a constant 'reinventing the wheel' (Abdul-Rahman and Wang, 2010). A research survey conducted by Carrillo *et al*. (2004) on leading construction organisations in the UK show that about 42% have a KM strategy and 32% plan to have a strategy within the short-term. The percentages recorded indicate poor adoption of KM and the need for KM to be properly incorporated and utilised in the industry for optimal performance in project delivery.

The success of construction organisations in a competitive market rely critically on the quality of knowledge it possesses regarding its markets, products, services, and technologies (Faraj *et al*., 1999; Kamara *et al*., 2000). The industry is faced with different challenges ranging from tight time schedules, low-profit margins, and the complexity, diversity, and non-standard nature of construction projects (Zhang *et al*., 2009). To overcome these challenges and remain competitive, productive, and profitable and to adequately respond to the needs of clients, many authors suggest that the management of project knowledge is essential, for example, Carrillo *et al*. (2000); Clough *et al*. (2000); Pathirage *et al*. (2006); and Pathirage *et al*. (2007).

Many research studies have given examples of the potential benefits of adopting KM in construction activities. These include improved decision-making, improved efficiency of people and operations, and improved innovation (Boddy *et al*., 2007; Duah *et al*., 2014) Others include increased flexibility to adapt and change, reduced process cycle times, shared best practices, reduction of cost-overrun, improved management learning, and improved construction project delivery (Skyrme and Amidon, 1997; Davenport and Klahr, 1998). More benefits include the facilitation of the transfer of knowledge across a variety of project interfaces, increased intellectual capital, improved support for teams of knowledge workers (McCampbell *et al*., 1999; Soliman, 2000; Al-Ghassani *et al*., 2004), the capacity to retain the tacit knowledge and explore explicit knowledge (Anumba *et al*., 2005b, Shelbourn *et al*., 2006, Udeaja *et al*., 2008b, Duah *et al*., 2014), and, finally, risk minimisation

(Robinson *et al.*, 2005). The next discussion will focus on the need for managing knowledge in delivering sustainable retrofitting building projects.

3.7 Managing knowledge in sustainable retrofitted building projects

The lack of managing project knowledge as a hindrance to providing sustainable retrofitted building projects has been emphasised by Ala-Juusela *et al.* (2006), Shelbourn *et al*. (2006), Hakkinen and Belloni (2011), and Shari and Soebarto (2012). Egan (1998) suggests that managing knowledge from people, culture, technology, and training perspectives was important for the construction industry. The significance of KM in construction projects has been documented by various researchers in academic literature (Carrillo *et al*., 2000; Kamara *et al*., 2000; Robinson *et al*., 2001; Egbu and Robinson, 2005; Shellbourn *et al*., 2006; Tan *et al*., 2007; Udeaja *et al*., 2008b; Kanapeckiene *et al*., 2010b) and this is necessary particularly in sustainable retrofit (Maduka *et al.*, 2015a). KM has received a great deal of attention in recent years, especially in the construction industry. In their study, Miller *et al*. (2008a) identify that, whilst there is a genuine need for stakeholders to drive the embarking upon and delivery of sustainable retrofit, the level of managing knowledge in delivering specific sustainability features remain disappointingly low. This is because industry practitioners find it difficult to access core knowledge for highly knowledge-intensive activities, such as problem-solving and decision-making (Anumba *et al.*, 2005b; Egbu and Robinson, 2005).

Hakkinen and Belloni (2011) argue that knowledge management in retrofitted building projects enables the consideration of wide spectrum of aspects, including building performance, environmental issues, life-cycle costs and service life, and rapid adapting of the design to the specific requirement case. Robinson *et al*. (2005) agrees that a lack of managing knowledge in the industry has posed a threat to delivering sustainable building principles and best practices and goes on to conclude that KM principles are essential drivers for all improvements in construction organisations. Anumba et al. (2005b), Shelbourn *et al*. (2006), and Maduka *et al*. (2015f) agree that, to achieve sustainable construction, particularly sustainable retrofitted building projects, it is essential that the industry intensifies its efforts to move towards a knowledge-intensive mode. Eliufoo (2008) agrees to that suggestion and states that sustainable buildings would be best achieved if new resources of knowledge and expertise were employed in construction activities.

Dewick and Miozzo (2002) and Pitt *et al*. (2009) argue that institutional challenges and limitations (such as corporate governance structure and the extent of stakeholder ownership) are experienced because of the absence of KM in the industry and its reluctance to change this. Sayce *et al*. (2007) blame the lack of KM practices between construction stakeholders (which impedes the dissemination of knowledge and information) for the reluctance in embarking on sustainable retrofitted building projects. They argue that a lack of technical information and knowledge to manage them poses a challenge to the industry in their delivery. These further support the contention that KM is a necessity for improving the delivery of sustainable building projects (Shari and Soebarto, 2012). It is imperative to understand that to attain the goals of sustainable construction and sustainable development, it is essential to realise the need for KM to be adequately adopted and integrated into construction activities, and to manage knowledge issues and challenges in sustainable retrofitted building project delivery.

The need for KM in delivering these projects is vital to have an improved understanding of sustainability issues in the built environment and how key stakeholders grasp with varied technologies as a solution in achieving sustainable retrofitted buildings (Anumba *et al*., 2006; Sayce *et al*., 2007; Maduka *et al*., 2015g). Regarding fragmentation of the industry as aforementioned, Khalfan *et al*. (2002) and Shelbourn *et al*. (2006) argue that knowledge is usually lost with the movement of people from one project to the other. Hence, any knowledge that is gained in a project is often poorly organised and lack of details without any mechanism or technology in place to retrieve it. This problem has prompted researchers, such as Shelbourn *et al.* (2006) and Udeaja *et al.* (2008a) to champion KM strategies that properly manage knowledge through mechanisms that capture, store, share, and reuse it. Such an integrated solution would arguably increase the uptake and effectiveness (from their sustainability point of view) of retrofitted building project delivery (Zhang *et al*., 2009) despite the peculiar difficulties of these projects, which are articulated by, for example, Duah *et al.* (2014).

Furthermore, the construction organisations have been managing knowledge informally for years, but the challenges facing today's industry, particularly in the sustainable uptake and delivery of retrofit projects, means that most organisations need a more structured, coherent approach to KM to deliver projects (Kamara *et al*., 2002; Khalfan *et al*., 2002; Anumba *et al*., 2006; Udeaja *et al*., 2008a; Maduka *et al*., 2015d). Kamara *et al*. (2002) and Petri (2014) state that managing project knowledge in retrofit projects would help in reducing the project timeline, including quality and customer satisfaction. Robinson *et al*. (2005) agree that the role of effective KM assists in unlocking and leveraging different types of knowledge so it will function as an organisational asset. They further state that implementing KM principles enables an organisation to learn from its corporate memory, share knowledge, and identify competencies to become a standard forward thinking and learning organisation (Kanapeckiene *et al*., 2010a).

Kanapeckiene *et al.* (2010a) argue that, in construction projects, KM could improve communications within team members of a team by sharing best documents, lessons learned, project management, and system examination methodologies (e.g. reviewed packages and rationales for decision-making). Kanapeckiene *et al*. (2010a) enumerate the benefits of KM to include productive information use, intellectual capital storage, strategic planning and activity improvement, intelligence enhancement, flexibility acquisition, best practice gathering, success probability enhancement, and productive collaboration. However, various specific works suggest that KM should be managed through structured models, tools, and frameworks (Zhang and Lu, 2007; Petri, 2014). The need for managing knowledge in the process of delivering a sustainable retrofitted building is vital to have an improved understanding of sustainability issues in the built environment and to enhance key stakeholders' understanding of the existing wide-range of technologies in appropriate decision-making (Yudelson, 2009).

Ahmad and An (2008) and Design-Buildings (2016) highlight the benefits of knowledge management and its barriers in construction industry, particularly retrofit projects.

Benefits of KM in sustainable retrofit building projects:

- Provides accurate and timely knowledge and greater certainty that facilitates more effective and informed decision-making;
- Raises organisational competitiveness;
- Enhances work quality and reduces costs and time required for projects by providing problem solutions and reducing the probability of mistakes;
- Improves project teamwork;
- Fewer mistakes;
- Reduction of work duplication;
- Reduces waste generation;
- Reduces the reliance on the knowledge of key stakeholders/supply chain;
- Avails faster and easier access to the most relevant and up-to-date information;
- A reasonable level of client's satisfaction;
- Improves connections between stakeholders, projects and parts of an organisation;
- Creates more innovative thinking; and
- Promotes effective communication.

Barriers to managing knowledge in sustainable retrofit building project:

- Ignorance of the existence of knowledge;
- Challenges in identifying new and appropriate knowledge;
- The risk of knowledge becoming out of date;
- Awareness issues of knowledge management potential benefits;
- Lack of understanding of knowledge management strategy and implementation;
- Availability of time and resources;
- Senior management bottlenecks;
- A tendency to repeat past solutions;
- A belief that an organisation is too small to accumulate comprehensive knowledge;
- Unwillingness to share knowledge/intellectual property;
- Lack of awareness by staff that they hold valuable knowledge;
- Poor writing skills; and
- The apprehension that the use of recorded knowledge could result in liability for problems.

3.8 Chapter conclusion

This chapter has extensively reviewed existing KM approaches and relates them to the construction industry, particularly in retrofit project delivery. Considering the above discussion, it is well documented that a lack of KM remains a challenge for key stakeholders in making informed decisions in the embarking upon and delivery of sustainable retrofit projects. It is widely believed that the construction industry has a lacklustre attitude in managing knowledge in its project activities. It is ascertained, through this review, that the application of KM procedure/processes in any organisation brings competitive advantage. The need to apply KM processes/procedures creates innovation and opportunities for problem-solving, increasing productivity, optimal performance, profitability, and efficiency in every construction project, particularly retrofit projects. Thus, the benefits are significant to sustainable retrofit project delivery.

During the whole lifestyle of a construction project, particularly retrofitted building projects, a large quantity of knowledge will be generated, which are invaluable for future construction projects. However, in practice, only a small fraction of the knowledge can be identified, captured, documented, or stored for sharing within the project team and the larger construction industry, not to mention the amount of knowledge that is transferred, shared, and reused in subsequent retrofit projects. Valuable knowledge of retrofit projects is lost due to the fragmented nature of the industry. Thus, more efforts are needed to ensure new knowledge is identified, captured, stored, shared/transferred, and utilised to ensure that key stakeholders make informed and appropriate decisions, while delivering sustainable retrofitted building projects.

The flow of thought and discussion involved in the chapter presents concrete theoretical support regarding the adoption of a philosophical standpoint for the research design and research methodological considerations. The ensuing chapter reviews the definition of stakeholders in the construction industry and their influence in sustainable construction project delivery, particularly sustainable retrofitted building projects.

CHAPTER FOUR: STAKEHOLDERS' MANAGEMENT IN THE CONSTRUCTION INDUSTRY

4.1 Introduction

Given the variety of stakeholders and their interests in construction projects, stakeholder management endeavours to accomplish the coveted and productive use of the project and maintain a strategic distance from unnecessary clashes and debates with stakeholders (Olander and Landin, 2008). The primary essence of stakeholder management is decision-making (Donaldson and Preston, 1995). The PMI (2004) characterises stakeholder management as 'the systematic identification, analysis and planning of actions to communicate and influence stakeholders'. Identification, evaluation, and analysis of stakeholder demand and influence ought to be considered as fundamental and imperative steps in the planning, implementation, and completion of any construction project. Stakeholder influence can be either beneficial or conversely threaten the success of a project (Jin et al., 2017b, Chinyio and Olomolaiye, 2010) in construction projects particularly sustainable retrofitted building projects, hence, the need for stakeholder management.

This chapter also discusses the definition of key stakeholders: the importance, role, and influence of key stakeholders in retrofit projects and decision support tools, the importance of decision support tools, and a review of the existing decision support tools in the academic literature.

4.2 The need for stakeholder management

Stakeholder related issues/problems have been experienced in the construction management study. These issues are either within or around the project tasks and range from delay in planning and execution of projects; cost and conflicts escalate to litigation and claims (Winch, 2010; Ward and Chapman, 2008; Smyth, 2000, Olander, 2007; Olander and Landin, 2005; Karlsen, 2002). Stakeholders' issues range from their different interests and lack of consideration of their input from the planning stage of the project, which could also be due to a lack of effective stakeholder management. The need to engage stakeholders at the inception of any construction project has been documented (Aaltonen and Kujala, 2010; Mathur *et al.*, 2008; Smith and Love, 2004; Donaldson and Preston, 1995). It is imperative that stakeholders should be included in the planning of the project with the goal that the objectives of the project can be distinguished, understood, and achieved. Hence, assumptions are not made about stakeholders' necessities or needs (Thomson *et al*., 2003). Moreover, stakeholders are dynamic and their impacts on the project change after some time considering contingencies upon issues can prompt instabilities in any project if the stakeholder's needs and potential impact are not purposefully identified and managed (Chinyio and Olomolaiye, 2010; Newcombe, 2003a; Freeman, 1984). In addition, Wallbauma *et al.* (2010) enumerate the need for managing stakeholders in a construction project to include:

1. The construction projects are complex with many processes and parties involved;
2. The connections among stakeholders in development ventures are transitory;
3. Different stakeholders have diverse levels and sorts of interests;
4. Each stakeholder should know their particular obligations and roles in the project and the requirements needed; and
5. Poor stakeholder management is a potential factor for delays in project delivery, hence, causes cost overruns.

However, decision-making mistakes amongst the stakeholders during construction projects are documented (Maduka *et al*., 2015e). Appropriate decision-making is vital between stakeholders to reduce the conflict of interest that emerges in the delivery of retrofit projects. The need for knowledge management in developing decision support tools is vital for informed decision-making by stakeholders, especially key stakeholders.

This chapter also discusses the definition of key stakeholders and their importance, role, and influence in retrofit projects; and decision support tools, the importance of decision support tools, and a review of the existing decision support tools in the academic literature.

4.3 Who are the stakeholders?

A range of definitions and interpretations of who is a stakeholder can be found in the stakeholder literature. A stakeholder is defined as any individual or group who can affect, or is affected by, the actions, decisions, policies, practices or goals of the organisation, hence, they can be a threat or of benefit (McElroy and Mills, 2000; Gibson, 2000; Carroll, 1995). Other definitions refer to stakeholders as entities; having stakes in a project, can affect or be affected by a project in an organisation to fulfil project objectives (Olander, 2007; Freeman, 1984). Clarkson (1995) defines stakeholders as persons or groups that have, or claim, ownership, rights, or interests of an organisation and its activities in the past, present, or future. Considering the definitions of stakeholders about sustainable construction particularly retrofitting, the statements that stakeholders could be 'any group or individual' and that the interests could take place in the 'past, present, or future' is relevant and considerable in this study. This is due to the need to effectively manage stakeholders in the delivery of sustainable retrofitted building projects for today's and tomorrow's environmentally friendly society.

4.4 Identification of stakeholders in construction projects

Defining project purpose and constraints can sometimes be challenging. This is because stakeholders describe the characteristics of the proposed project. Hence, most challenges stem from project stakeholders and the environment. These explanations lead to the recognition of which stakeholders are needed in a particular construction project (Razali and Anwar, 2011). This necessitates the significance of identifying stakeholders in any construction projects, which has been documented by many studies (Jepsen and Eskerod, 2008; Walker *et al.*, 2008; Nauman and Piracha, 2016; Mitchel *et al.*, 1997). Stakeholder identification is usually considered as the first step in stakeholder analysis (Jepsen and Eskerod, 2008; Cleland and Ireland, 2007; McElroy and Mills, 2000) and when embarking on construction projects. However, the project stakeholders can be divided into different types according to various criteria (Pinto, 1998) the question of 'who are stakeholders?' (Frooman, 1999), is important before the project commences. The WBPS (1996) revealed that the World Bank, in its source book, expanded on the questions to ask in stakeholder identification by stating that while considering identifying the stakeholders of a particular project, some of these questions need to be answered:

1. Who might be affected by the development concern to be addressed?

2. Who are the ‘voiceless’ for whom special efforts may have to be made?

3. Who are the representatives of those likely to be affected?

4. Who is responsible for what is intended?

5. Who is expected to mobilise for or against what is expected?

6. Who can make what is expected more effective through their participation or less effective by their non-participation or outright opposition?

7. Who can contribute financial and technical resources?

8. Whose behaviour has to change for the effort to succeed?

The construction industry must be aware of the different roles and influence of stakeholders involved in a project to help in their identification and maximise the value of the creation of the projects. Project stakeholders are tied in such a way that they transform essential information, experiences, and resources at the beginning, during, and end of the project, hence, the essence of their early identification (Milosevic, 1989). Project stakeholders play vital roles during each phase of the project. Thus, some stakeholders have so much power that they can interrupt, change, and interfere at different times during the project delivery. Some can make a significant change at various times in the project, which can affect both the project and other stakeholders (Karlsen, 2002). Additionally, it has been suggested that setting universal goals, interests, objectives, tasks, and priorities are requisite for the successful management of stakeholders from the outset for project success (Jergeas *et al*., 2000). Stakeholders have decisive power to decide whether the project will be a success or not (Jergeas *et al.*, 2000). Hence, evaluation of the stakeholder’s area of interest during identification is the best consideration for the success of the project (Nauman and Piracha, 2016). The project identification will assist in ascertaining the role of each stakeholder.

4.5 The essence of stakeholders in construction projects

The essence of stakeholder engagement refers to the formal process of relationship management through which projects and organisations interact with stakeholders to support and promote their mutual interests, thereby reducing risk and advancing their current circumstances. The essence and impact of stakeholders in construction project planning and implementation have been accepted in different studies (Jin et al., 2017b; Yang and Shen, 2015; Bourne, 2011, Ward and Chapman, 2008; Olander, 2007; Olander and Landin, 2005). Freeman (1984) acknowledged that the essence of stakeholders emerged through an international memorandum in 1963 at the Stanford Research Institute. In any project, and especially in construction projects, many different and sometimes discrepant interests must be considered. As it has been revealed in this study that construction, sector is an important engine for economic development in every country and it has diverse stakeholders due to its fragmented nature. Representatives of these interests are referred to as project stakeholders.

A project stakeholder is a person or group of people who have a stake in the success of a project and the environment within which the project is being delivered. As a result of the diversity as regards profession, culture, educational level, gender, and spatial distance from the project, stakeholders often present a wide range of interests to be achieved during project delivery. Therefore, Stakeholders can, as aforementioned have a substantial influence on projects outcomes. They can contribute to or participate in decision-making, which the outcome will benefit or disadvantage the project. This may include some aspect of rights or ownership. There is both a direct and indirect reciprocal relationship between a stakeholder and an organisation; as each can affect and in return be affected by the activities of the other, hence stakeholder influence exists and needs to be managed.

However, there are numerous stakeholders and participants involved in construction projects activities. The list of possible stakeholders in construction is extensive and can encompass owners, managers and users of facilities, project managers, designers, shareholders, legal authorities, employees, main contractors, sub-contractors, suppliers, service providers, competitors, financial establishments, insurance companies, media organisations, neighbours and community representatives, the general public, government establishments, visitors, regional development agencies, the natural environment, pressure groups, and civic institutions (Chinyio and

Olomolaiye, 2010; Bourne and Walker, 2006). In every project, it is imperative that key stakeholders are fully engaged in construction projects. The importance of stakeholder engagement together with the integration of stakeholders' visions and goals have been well established in the literature (Doloi, 2013; Bourne and Walker, 2006).

4.6 The roles of construction stakeholders

The vital role of stakeholders in a construction project is essential particularly for the development and implementation of sustainable principles in construction projects. The obstacles to the uptake of sustainable construction practices interact in ways that reinforce stakeholders to create a formidable net with efforts to deliver projects. If the role of stakeholders were redefined and expanded, their presence in retrofit projects would be perceived as potential that would give birth to holistic sustainable solutions. The key role of stakeholders for the development and implementation of sustainable construction have been emphasised in a variety of publications (Pinkse and Dommisse, 2009b; Pitt *et al.*, 2009; UNEP, 2007). However, UNEP-SBCI (2007, p.55) state that the existing and potential roles of stakeholders include:

- regulating activities (government);
- the provision of financial sources (investor);
- the project, an asset;
- risk and firm management (developer, owner, commercial tenant, regulator);
- knowledge gaining (research);
- design (planner, architect, designer);
- construction (builder, manufacturer, supplier);
- marketing (real estate broker);
- facility management (facility managers); and
- use of the structure (occupant) to the observation and evaluation of design and construction process (professional association, regulatory, media, public).

The expansion of the stakeholder definition including the natural environment entails new roles, such as the provision of physical resources and strategies (e.g. regeneration), additional economic value, as well as a means for the application of political or civic pressure (Feige *et al.*, 2011).

4.7 Stakeholders in sustainable retrofit projects

Improving the decision-making processes within sustainable retrofit projects remains challenging, but attainable. Given the often-conflicting interests of stakeholders, for example different professional approaches, poor knowledge management strategy, and poor managerial strategies. Thus, it is difficult to integrate highly diverse stakeholders into a single process. The innovations prompted by the new requirements of sustainable construction particularly sustainable retrofits has created more challenges for the established practices and criteria for decision-making within the public and professional institutions at all stages of construction projects (Henry and Paris, 2009). Wallbauma *et al*. (2010) summarise that the inclusion of stakeholders in the processes of sustainable construction, particularly sustainable retrofit, presents difficulties. Hence, different reasons are presented:

1. High fragmentation of the building sector;
2. Different professional approaches;
3. Sustainability requirement challenges the status quo;
4. Complexity and interconnectedness of stakeholders;
5. Interest and value of stakeholders vary;
6. Market mechanism excludes some stakeholders; and
7. Adequate managerial strategies and vehicles for participation required.

The ensuing section discusses the influence of key stakeholders in sustainable retrofitted building projects.

4.7.1 The influence of key stakeholders in sustainable retrofit projects

Some studies acknowledge that some stakeholders have more influence and hold a position of some power in a project more than others hence, are referred to as key stakeholders (Jin et al., 2017b; Yudelson, 2010a; Olander, 2007). Yudelson (2010a) states that key stakeholders in this context are people who are directly, or indirectly, involved in a project, hence, have a stake in the building, its operation, and future outcome. Yudelson (2010a) also states that construction key stakeholders include the owner, tenants, investors, building operators, and designers. Key stakeholders play vital roles in promoting sustainable development within the context of the construction industry by assuming the responsibility to minimise the negative impacts of construction on the environment and society, while maximising its economic contribution. In the construction industry, delivering retrofit projects necessitates the need for the key stakeholders to champion and improve sustainable practices and principles and this cannot be over-emphasised.

McMahon (2013) stated and itemised the roles of key stakeholders:

1. Providing detailed requirements and a financial plan;

2. Committing the necessary resources;

3. Taking ownership of appropriate deliverables;

4. Keeping abreast of project progress and cascading information to others who need to know;

5. Establish training and support requirements;

6. Communicating throughout the life of the project; and

7. Being involved in project closure.

Key stakeholders, depending on their influence, are driven by a need to manage threats, opportunities and uncertainties. As regards performance, key stakeholders like to impose their 'will' in the project related to achieving the desired goal in delivering sustainable retrofitted building projects. Depending on their role, key stakeholders also have a level of legitimacy. This is often associated with a moral obligation and the bearing of risk, whether beneficial or harmful to the project (Olander, 2007). Each key stakeholder's work towards to display characteristics such as power, interest, influence in the project, education, and experience (Jin *et al*., 2017b). The importance of a key stakeholder will depend upon the needs of the project and the extent to which the project is dependent on that key stakeholder's attributes in meeting its obligations. As the project moves through the project's life cycle, key stakeholders change as they enter, move, or leave the project.

Consequently, in construction activities particularly retrofit projects, some key stakeholders are more important in a given project at a particular time than others, they can affect the project outcomes hence, their corresponding level of power, and influence varies (Bourne, 2011; Ward and Chapman, 2008; Olander, 2007; Bourne and Walker, 2006; Newcombe, 2003a, 2003b). Additionally, most studies indicate that understanding and integration of stakeholder requirements have an enormous potential towards increasing the sustainability perspectives that relate to social, environmental, economic and technical issues of buildings (Maduka *et al.*, 2016a). Hence, stakeholders' lack of interest for sustainable retrofit project uptake, improvement and delivery are crucial and a fundamental challenge that needs to be addressed if the goal of energy use reduction in buildings is to be achieved (Maduka *et al.,* 2015f).

Furthermore, there is a need to explore knowledge management (KM) processes/procedures to develop a decision support framework that will assist key stakeholders in making enhanced decisions in the embarking on and delivery of retrofit projects. This will help in the uptake of the retrofit projects and contribute to the reduction of greenhouse gas emissions. Exploring KM procedures will also assist key stakeholders in making an informed decision on the uptake and delivery of sustainable retrofitted building projects (Maduka *et al*., 2015f).

4.8 Section Summary

This section has discussed, in depth, stakeholders' management in the construction industry, particularly retrofit projects. The section defined who the stakeholders are on construction projects. It identified stakeholders and discussed the essence of key stakeholders in construction projects particularly retrofit projects. The roles and influence of stakeholders retrofit projects were also identified and discussed. In retrofit projects, stakeholders' management, particularly the key stakeholder cannot be over-emphasised because they are relevant to sustainable retrofit project outcomes. The need to manage project knowledge activities in decision-making in the uptake and delivery of the retrofit project is important; hence, consideration of a decision support framework in making decisions is vital. The next section will review the extant literature on decision support frameworks, models and systems developed for the construction industry in the scientific literature.

4.9 DECISION-MAKING AND DECISION SUPPORT TOOLS FOR CONSTRUCTION STAKEHOLDERS

4.9.1 Introduction

This section discusses decision support tools, and the use in sustainable construction particularly retrofit projects. Decision support tools are essential in the delivery of sustainable retrofit projects amongst construction stakeholders. The discussion in this chapter includes discussion on decision-making, definitions of decision support tools, and how it relates to knowledge management in assisting stakeholders in making informed choices in construction projects. It also examined some existing decision support tools in sustainable construction especially in delivering sustainable retrofit projects.

4.9.2 Decision-making

It is usually accepted that having relevant information increases the chances of discovering a good solution in making a rational decision, which can be improved if there is a defined and essential objective. Keeney (1992) argues that the relative interest of decision-making consequences is a concept based on values. Hence, the vital belief in decision-making should be based on values and information, not alternatives. Historically and theoretically, the idea of value by the key stakeholders in an organisation is closely related to financial (monetary) and productivity (Hansen and Vogel, 2010). Ericson (2010) affirms this and states that the rational choice notion is, however, only one dimension of the decision, as it does not account for the practical situations in which there are time pressures, diversity of demands, and the subjective nature of confronted problems. That is why decision makers use an intuitive decision-making process, which is based on personal experience that may satisfy minimum requirement whenever there is conflict concerning other needs due to available information (Zach, 2005).

The benefits of such decisions are quick and use less cognitive resources (Becker, 2005). Being informed about a particular phenomenon contributes to visualising decision-making as a progression along a range of specified objectives hence, leading to rational decision-making based on experience, biases, and the context of the decision (Eisendhardt and Zbaracki, 1992; Tello *et al.*, 2010). Therefore, to make an informed decision, the seeker will base their judgement on a subjective evaluation of the usefulness of managing knowledge (Menon and Pfeffer, 2003). Appropriate and informed choices are made with knowledge management approaches, particularly in sustainable retrofitted building projects (Maduka *et al*., 2015d).

However, it has been stated that frameworks are essential to guide in decision-making because it could address the fragmented needs and requirements within construction industry (Chen, 2012), for example, in sustainable retrofit projects (Maduka *et al*., 2015c; Kontokosta, 2016). In delivering sustainable retrofit projects, Kontokosta (2016) states that there are a lot of decision-making challenges involved and these include regulatory context and compliance risk, increased resilience and business continuity, awareness issues, and landlord and tenant demand for energy efficient space.

However, the complexity of building design, with its variety of stakeholders in retrofit projects, necessitates a broader understanding (Madsen and Fraser, 2015) and knowledge in the uptake and delivery of retrofit projects. Thus, the need to manage knowledge in construction activities is essential particularly in developing a decision support framework (Maduka *et al*., 2015e). The basis for developing decision support framework is to assist key stakeholders in knowing the right values and information for the decision-making (Komiyama and Takeuchi, 2006). Developing a decision support framework with knowledge management procedures is appropriate in assisting key stakeholders in making informed decisions in the uptake and delivery of retrofit projects (Maduka *et al*., 2015b). The next section reviews decision support tools linked to knowledge management and key stakeholders.

4.9.3 Decision support tools as it relates to managing knowledge and key stakeholders

Decision Support Tools (DSTs) are defined as any tool(s) used as part of a formal or informal decision process (Kapelan *et al*., 2005) or which informs the decision-making process by assisting the key stakeholders in understanding the consequences of different choices (CMHC, 2004). Brozova *et al*. (2008) state that decision-making is a mental process leading to the selection of the best strategy among several alternatives, and as such, every decision-making process produces knowledge for the successful solution to a given problem. While there is no shortage of DSTs to assist the key stakeholders in making decisions in the uptake and delivery of sustainable retrofitted building projects, Keysar and Pearce (2007) state that there is knowledge deficit regarding what tools are available and the potential benefits associated with their use. Key stakeholders in the industry need the right DSTs tools with knowledge management principles in the uptake and delivery of sustainable retrofitted building projects (Maduka *et al*., 2015f). Decision support tools are useful for identifying and determining optimal retrofit measures (Ma *et al*., 2012).

The complexity that emanates from retrofitted building projects can be addressed through a decision support framework that is knowledge driven; decision-making is considered an art because it is dependent on the experience, intuition, and creativity of the decision maker. The satisfactory solution of a single problem can be achieved through a variety of approaches mainly via decision support tools (Baba, 2013). In addition, the complex nature of delivering sustainable retrofit project demands high-quality information and the use of knowledge management procedures in developing decision-making framework. The next section reviews and discusses the DSTs in the scientific literature for the industry.

4.9.4 Appraisal of decision support tools in the scientific literature for sustainable buildings

An investigation of the relevant literature has revealed that some studies have developed decision support frameworks for construction projects, especially in sustainable construction as it regards to decision-making between the stakeholders. However, many decision-making tools have been developed to help deliver solutions to delivery of retrofit projects. These tools exist in various forms, including decision support systems, models, and frameworks, each suitable for particular decision challenges in construction projects.

Flourentzou *et al.* (2002) present an interactive decision support framework for office building retrofits. The framework comprises of seven modules including building description and dimensions, building diagnostics, indoor environmental quality, energy use, retrofit scenarios, cost analysis, and reporting results. It has the capability of supporting the user in establishing a complete building process and help to identify the actions required to upgrade building performance. Juan *et al*. (2009) developed an integrated decision support system that recommends a set of sustainable refurbishment actions for existing office buildings. This was developed based on the consideration of trade-offs among refurbishment cost, improved building performance and environmental impacts. The optimal solution was determined using an optimisation technique that combines a graph search algorithm with genetic algorithms (GA).

Anumba *et al.* (2006) developed an integrated decision support system to assess existing office building conditions and recommend an ideal set of sustainable retrofit actions, considering trade-offs between retrofit cost, improved building quality and environmental impacts. El-Gohary *et al*. (2006) developed a semantic model for capturing and incorporating stakeholder inputs in the design of the project. The model, which is for public-private partnerships (infrastructure) projects consists of five major entities: process, products, constraints, actors, and resources. Each of these entities is made up of different methods, which consider inputs that lead to the final project design. Although this model, which has the potential to act as a means for knowledge representation, is a vital contribution within the domain of stakeholder management in construction, it is limited to the events and considerations preceding and leading to the final design of the project.

Juan *et al.* (2009) developed a Generic algorithm (GA) based decision support system for housing condition assessment and refurbishment strategies. The GA is an online based decision support system (DSS) to assist residents and stakeholders efficiently conduct the housing condition assessment and offer optimal refurbishment actions considering the trade-off between cost and quality. The refurbishment decision models are developed to explore the relationship between the life cycle cost, restoration cost and improved quality. The decision support solves the problems arising from asymmetric information and conflicting interests between residents and contractors, as well as improving traditional housing condition assessment to be more efficient. Juan *et al*. (2010) developed a decision support system to assess existing office building sustainability conditions and recommend an optimal set of retrofit measures that consider the trade-offs between cost, resource consumption, energy performance, and greenhouse gas emissions reduction. Juan *et al.* (2010) developed a hybrid decision support system for sustainable office building renovation and energy performance improvement.

Entrop *et al.* (2010) investigated energy performance indicators in Dutch residential dwellings and developed a methodology that incorporated additional revenues within the financial analysis of energy-saving techniques. The research integrated a long-term financial gain as a benefit for pursuing sustainable retrofits into the decision-making process and revealed that much shorter payback periods in return on investment (ROI) methodologies could be realised. Yang *et al*. (2011) propose a framework for successful stakeholder management in construction projects based on the grouping of critical success factors for stakeholder management into five: the precondition factor, information inputs, stakeholder estimation, decision-making, and sustainable support. The framework suggests that information should be obtained, first, based on which stakeholders could be assessed to enable decisions to be made about the appropriate strategies for stakeholder management and sustainable support (from top management) needed throughout the stakeholder management process.

Bluyssen *et al*. (2011) present a quantitative approach that determines the value of single or multi-phase investment in sustainable retrofit projects by considering different uncertainties associated with the life cycle costs and perceived benefits of the project. The results from case study investigation in the research indicate that when risk is high, dividing the decision into several phases helps increase the value of the investment that provides stakeholders with the flexibility to abandon the retrofit project if necessary. Pan and Dainty (2012) developed a systematic approach for UK housebuilding organisations to identify value-based decision criteria and quantify their relative importance for accessing building technologies systematically.

Furthermore, Menassa and Baer (2014) developed a House of Quality (HOQ) model that assists in synthesising differences among the stakeholders and integrates their competing objectives to establish a hierarchy of retrofit solutions that meet stakeholders' requirements in retrofitting buildings. The developed model was tested on a decision to retrofit a building in US Navy case study: a building to assess the role of stakeholders in sustainable building retrofit decisions. Ibn-Mohammed *et al*. (2013) developed a decision support framework for evaluation of environmentally and economically optimal retrofit of non-domestic buildings, and in 2014, the same authors integrated economic considerations with operational and embodied emissions into a decision support system for the optimal ranking of building retrofit options (Ibn-Mohammed *et al.*, 2014).

Duah *et al.* (2014) developed a knowledge elicitation strategy to elicit and compile energy derived from homes for retrofit knowledge that can be incorporated into the development of an intelligent decision support system to help increase the uptake of home energy retrofits. Syal *et al*. (2014) developed an information framework for intelligent and decision support system for home energy retrofits. Zhang *et al.* (2014) developed a multi-criteria decision framework for the selection of low carbon building measures for an office building in Hong-Kong. Ibn-Mohammed *et al.* (2014) developed the integration of economic considerations with operational and embodied emissions into a decision support system for the optimal ranking of building retrofit options. Table 4.1 highlights more decision support tools that have been developed in the scientific literature.

Table 4. 1 Existing decision support tools in the scientific literature for sustainable buildings

Authors	Decision Support Tools Developed
Flourentzou *et al*. (2002)	Interactive decision and tool for office building retrofit
Anumba *et al*. (2006)	An integrated decision support system to assess existing office building conditions
Juan *et al*. (2009)	Integrated decision support system to recommend a set of sustainable refurbishment actions for existing office buildings.
Juan *et al*. (2009)	Decision support system for housing condition assessment and refurbishment strategies
Entrop *et al*. (2010)	The decision methodology that incorporated additional revenues within the financial analysis of energy-saving techniques.
Yang *et al*. (2011)	A successful stakeholder decision framework for management of construction projects based on the grouping of 5 critical success factors for stakeholder management
Bluyssen *et al*. (2011)	A quantitative approach to determining the value of single or multi-phase investment in sustainable retrofits for existing

Pan and Dainty (2012)	A systematic approach for UK housebuilding organisations to identify value-based decision criteria
Ibn-Mohammed *et al.* (2013)	Decision support framework for evaluation of environmentally and economically optimal retrofit of non-domestic buildings
Menassa and Baer (2014)	Decision framework to assess the role of stakeholders in sustainable building retrofit decisions.
Duah *et al.* (2014)	Ibn-Mohammed *et al.* (2013) Knowledge elicitation strategy to elicit and compile home energy retrofit knowledge decisions
Ibn-Mohammed *et al.* (2014)	Decision support system for the optimal ranking of building retrofit options.
Zhang *et al.* (2014)	Multi-criteria decision framework for the selection of low carbon building measures
Small and Mazrooei (2016)	Construction-specific decision support tool for sustainable construction operations
Nielsen *et al.* (2016)	Early stage decision support for sustainable building renovation
Li and Froese (2017)	A green home decision-making tool: Sustainability assessment for homeowners
Kamari *et al.* (2017)	Sustainability-focused decision-making in building renovation
Bansal *et al.* (2017)	Fuzzy decision approach for selection of most suitable construction method of Green Buildings

These studies have addressed some of the issues in delivering construction projects particularly sustainable retrofit projects, but have not addressed the need to manage project knowledge properly through decision support tools by key stakeholders. Having acknowledged the gap in knowledge as it regards decision-making, which is part of the focus of this study, Maduka *et al.* (2015f) argue that it is essential to develop a decision support framework with knowledge management principles and procedures that will enable key stakeholders involved in retrofit projects to make informed and appropriate decisions. They further state that making appropriate decisions would assist key stakeholders in avoiding post-decision project mistakes to facilitate the uptake retrofit projects within the built environment. In addition, the reviewed decision support frameworks contributed to having an insight of framework development in sustainable construction including consideration of different layouts of the existing decision tools/frameworks. Therefore, the review contributes to the aim of this study, which is the development of SRBDSF.

4.10 Section summary

This section has discussed what decision-making means and what prompts individuals in making decisions. It also highlighted that without KM inappropriate decisions would be made by key stakeholders in delivering sustainable retrofit projects. It is established in the review of the extant literature that proper managing of knowledge assists key stakeholders to make an informed decision. The relevance of decision support review is essential in developing the proposed framework particularly the framework system. Additionally, the study examined existing decision support tools in the literature, as it relates to construction. The review assisted the study to have an overview of decision support tools to enable the study in delivering its aim, which is developing a decision support framework with knowledge management procedures and principle to enhance decision-making of key stakeholder in the uptake and delivery of retrofit projects. However, there is a gap in developing a decision support framework with KM to inform key stakeholders on making informed and appropriate decisions in delivering these projects. This review on decision support framework was essential for the collection of empirical data that assisted in the development of SRBDSF, which is the aim of this study.

CHAPTER FIVE: RESEARCH METHODOLOGY

5.1 Introduction

This chapter presents the research design and methodology adopted to deliver the research aim and objectives and answer the research questions as discussed in Chapter 1. It is pertinent to state that when undertaking research, it is essential to choose the most appropriate methodology to ensure that the research objectives can be achieved and research findings can be validated. This chapter reviewed the theoretical underpinnings of the research philosophies, approaches and strategies based on the 'Research Process Onion' (Saunders *et al*., 2012) illustrated in Figure 5.1 and employed as a roadmap for the current research process. This review is required to facilitate the selection of the most appropriate techniques that were used to accomplish this research. Section 5.3 introduces the methodological considerations and research design of the current study. The rationale for selecting research methodology and design is discussed as it relates to research aim, objectives, and questions. This chapter also presents the adopted progressive question reduction sequence (PQRS) (see Figure 5.5). The need for its adoption was for a defined and clear strategy in collecting data through the mixed-method approach that was adopted. Section 5.3.5 presents and justifies the selected research methods/techniques as the research progresses from stage to stage. The chapter concludes with a summary of the contents and the next phase of the study.

5.2 Research aim, objectives and questions

Literature is a common starting place for a researcher (Dunleavy, 2003), especially for the 'initial mapping of the topic area' (Hart, 1998). As noted in many research methods texts, the research question and objectives set the scene for establishing a research methodology (Patton, 1990; Wildemuth, 1993). The research aims to develop a sustainable retrofitted building decision-support framework (SRBDSF) to enhance stakeholders' abilities to make appropriate and informed decisions in the uptake and delivery of sustainable retrofitted building projects. The aim was achieved with the following research questions and objectives.

5.2.1 Research questions

RQ1: Who are the key stakeholders in sustainable retrofitted building projects?

RQ2: How do the stakeholders rate the construction in improving sustainable principles and practices in delivering sustainable construction?

RQ3: Does the construction industry have a standard or regular building process and decision support framework for the delivery of a sustainable retrofit project?

RQ4: What are the social, economic and environmental benefits of sustainable retrofitted building?

RQ5: What are the environmental assessment method key stakeholders consider when delivering sustainable retrofitted building projects?

RQ6: What are the sustainable retrofit materials used in delivering sustainable retrofit projects?

RQ7: What does knowledge mean to individual stakeholders in the construction industry?

RQ8: What is the role of knowledge in delivering sustainable retrofit?

RQ9: How can project knowledge be captured in sustainable retrofit projects?

RQ10: How can managing project knowledge enhance decision-making in delivering sustainable retrofit projects?

RQ11: How can stakeholders avoid information overload as relates to sustainable construction?

RQ12: What criteria are used to determine the relevance of new knowledge?

5.2.2 Research objectives

1. To examine, through a literature review, the current practices in the uptake and delivery of sustainable retrofitted building projects.
2. To determine through literature review knowledge management principles and processes.
3. To establish through a survey the barrier and enabling factors to the uptake and delivery of sustainable retrofitted building projects.

4. To ascertain through semi-structured interviews the critical enablers and barriers to the uptake and delivery of sustainable retrofitted building projects.

5. To ascertain options that make decision-making easy and difficult in delivering sustainable retrofitted building projects.

6. To determine and report the extent to which key stakeholders capture knowledge during and after retrofitted building projects.

7. To establish a sustainable retrofit process order of application through a survey to assist in developing a sustainable retrofit building process (SRBP)

8. To develop a sustainable retrofitted building decision support framework (SRBDSF) with knowledge management principles and procedures.

9. To validate sustainable retrofitted building decision support framework

In delivering the research aim and objectives, six stages were employed as illustrated in the research design framework (see Figure 5.3), which are discussed further accordingly.

5.3 Research 'onion' and rationale for its adoption in the current research

Research methodology refers to the principles, procedures, and logical thought processes that are applied to a scientific investigation (Fellows and Liu, 2008). Methodological considerations help researchers to establish a theoretical foundation for the flow of thought in which the research objectives are formulated, and research questions are answered. Saunders *et al.* (2012) state that the main concept of research process 'onion', comprising of several layers (see Figure 5.1) is to consider the methodology and research design from the top down, starting from the outside layers (identifying the research philosophy), and, after that, peeling away each layer until the last inside layer (data collection and analysis) is reached. In the current research, this process was adopted to guide the review of different research elements (such as philosophy, approaches, strategies, techniques and procedures) and define the methodological approach.

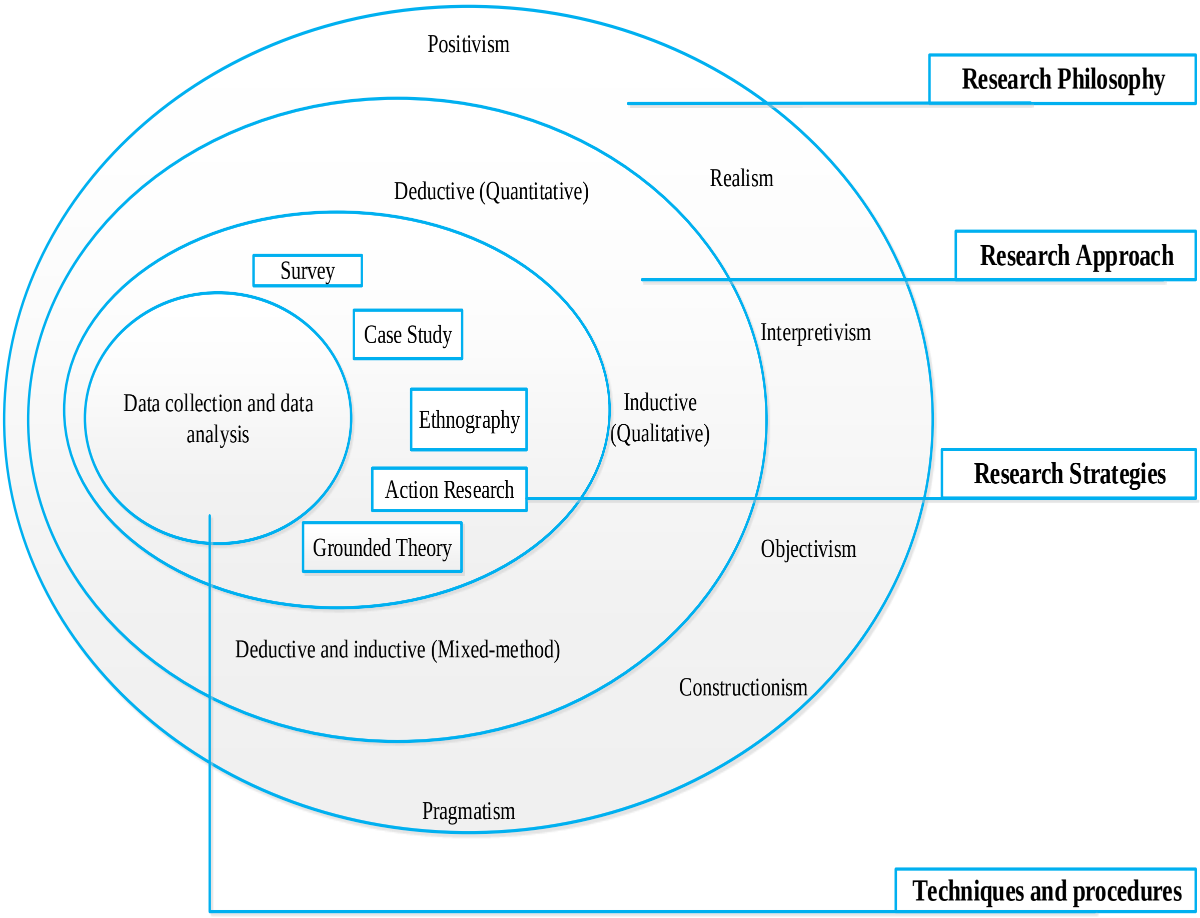


Figure 5. 1 Research Process based on 'Research Process Onion' (Adapted from Saunders *et al*., 2012, p.160).

5.3.1 Research philosophy

When undertaking research, it is vital to consider the perceptions, assumptions and beliefs of the researcher to ensure that biases or perspectives are made clear and viewed in the light of the research methodology, objectives and output (James and Vinnicombe, 2002). These influences may be classified as the ontological and epistemological paradigms or more broadly the research philosophy. Every philosophical position holds opinion view about social reality and that view, in turn, entails what can be regarded as legitimate knowledge. In other words, the ontological shapes the epistemological (Williams and May, 1996) and each informs and depends upon the other (Hatch and Cunliffe, 2006). It is for this reason that the two terms are often conceptually merged. A consideration of ontology is vital to understand how we position our variety of reality and what constitutes knowledge within that reality.

Management researchers contend that ontology and epistemology should be articulated in the research plan to provide the background for coherence and consistency (Hallebone and Priest, 2005).

Describing ontology, Crotty (2009) states that it deals with the 'science or study of being' or in other words the study of our view of the world and the nature of reality. The realist ontological perspective is derived from scientific tradition, whereas the relativist perspective arises from a tradition of humanism (Williams, 2003). Bryman (2004) suggest two main ontological considerations: objectivism and constructionism/constructivism. Objectivism is an ontological position that asserts that social phenomena and its meanings has an existence that is independent of social actors.

Constructionism interpretation as opposed to constructivism: Constructivism and constructionism are two main branches of constructive theory. These branches are comparable such that both viewpoints hold firmly to the postmodern idea that knowledge and reality are subjective. Constructivism and constructionism are usually lumped together as constructive theories and emphasise the captivating intervention approaches established within these paradigms (Rudes and Guterman, 2007). Constructivism stresses that knowledge is accomplished through individual and cognitive processes while constructionism emphasises that knowledge is achieved through social interchange and interaction (Gasper, 1999; Hay and Barab, 2001). Young and Collin (2004) explain that constructivism suggests that individual mentally construct the world of knowledge through cognitive processes. Thus, contrasts from the scientific belief of logical positivism in its argument that the world cannot be known directly. However, the world is known by the construction imposed on it by the mind (Young and Collin, 2004).

Whereas Constructionism takes the view that *'knowledge in some area is the product of our social practices and institutions, or the interactions and negotiations between relevant social groups*' (Gasper, 1999, p. 855). According to Young and Collin (2004), constructionism contends that social procedures sustain knowledge and that knowledge and social action go together. Hence, constructionism is not interested in the cognitive processes that accompany knowledge. Constructionism is the ontological position that argues that social phenomena and their implications are not only produced through social interaction, but are in a constant state of revision that is being continually set by social actors. Considering these two constructive theories, this research adopts constructionism as its ontological position because the researcher has to acquire knowledge about the research area through social interaction with key stakeholders. Further discussion on the adoption or rationale for the choice of constructionism can be seen in Section 5.3.1.1.

Epistemology is the nature of knowledge, its scope and bias (Hamlyn, 1995). Maynard (1994) defines epistemology in the context of a social researcher: *'Epistemology is concerned with providing a philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure that they are both adequate and legitimate'* (p.10). Crotty (1998) states that: *'epistemology is 'how we know what we know'* (p.8). Saunders *et al.* (2007) suggest four epistemological research positions in management research: positivism, realism, interpretivism, and pragmatism.

Bryman (2003) defines positivism as an epistemological position that adopts the philosophical posture of natural sciences to the study of social reality. Thus, researchers applying positivism deal with recognisable social reality and their research outcome can be law-like generalisations similar to those produced by the physical and natural scientists (Remenyi *et al*., 1998). Saunders *et al.* (2012) assert that positivism is associated with quantitative research. Gill and Johnson (2010) describe positivism as collecting data about observable reality. Furthermore, Flick (2009) asserts that positivism seeks an objective 'truth', which is seen to exist independently of the individual's perceptions. Realism is another epistemological position that relates to natural scientific enquiry. Realism position refers to a logical scientific investigation. The fundamental philosophy of realism is that there is a relatively liberated reality of the mind (Saunders *et al*., 2007).

In contrast to positivism, interpretivism stresses the differences between people and the objects of study in natural and physical sciences. It, thus, requires the social scientist to comprehend the particular or individual meaning of the observed (Bryman and Bell, 2003; Saunders *et al*., 2007). Researchers using interpretivism endeavour to describe, interpret and understand a situation from the perspective of the observer (Creswell, 2007).

Pragmatism is a belief that asserts that knowledge precedes action, circumstances, and consequences instead of experiences (Creswell, 2003) and it is concerned with applications (what works) and solutions to problems (Patton, 2002; Saunders *et al*., 2007). The next section discusses the ontological and epistemological positions of the current research.

5.3.1.1 Ontological position underpinning the current study

Regarding ontology, the reality is viewed as complicated, fluid and often ambiguous. It undergoes change as well as periods of permanence (Corbin and Strauss, 2008). As aforementioned, ontology deals with questions such as ‘what is the nature of being’ (Saunders *et al*., 2007). Hence, the current research considers discovering the knowledge involved in embarking, uptake and delivery of retrofit project through its stakeholders using a knowledge management approach. This is necessary to ascertain the level of understanding of key stakeholders from the knowledge perspective to recommend a workable solution to improve managing retrofit activities for project delivery. This belief is consistent with the philosophy of *constructionism*. Therefore, the ontological position of the current research is *constructionism*. Hence, this research attempts to unravel the knowledge gap behind the barriers and enable factors to the uptake of sustainable retrofit. For example, the investigation of the literature assisted in discovering barriers and enablers of retrofit projects that were used for further investigations. This is important to discover the critical success and barrier factors to make recommendations for adoption in the uptake and delivery of sustainable retrofit projects.

5.3.1.2 Epistemological position underpinning of the current study

Epistemology is about what constitutes acceptable knowledge in a research study (Saunders *et al*., 2007) as discussed in Section 5.3.1. The epistemological position of research signifies the relationship between researchers and their research. Thus, the epistemological position elucidates the researchers’ philosophical assumptions about how and what they will study during their investigations (Creswell, 2003a). The epistemology deals with questions such as ‘how knowledge is acquired’ (Creswell, 2009). To establish the epistemological position of the current research means that the question to answer, amongst others, is how knowledge management procedures can be applied to improve decision-making in the uptake and delivery of retrofit projects.

However, an epistemological perspective may be used to evaluate or justify a research methodology (Maynard, 1994; Miller and Tsang, 2010). Corbin and Strauss (2008) indicate that every method rests on the nature of knowledge and knowing. As earlier mentioned, epistemology concerns with what establishes adequate knowledge in a field of study. Hence, this research aims to develop a sustainable retrofitted building decision-support framework (SRBDSF) with knowledge management procedures and principles from the results of the investigation. The SRBDSF is developed to assist key stakeholders in making an informed decision on the uptake and delivery of sustainable retrofit. This is adequate knowledge because it is the outcome of the investigation. In achieving this, the research answers some research questions for example: what does knowledge mean to a stakeholder and how can knowledge management enhance decision-making in the uptake and delivery of retrofit project? In answering the research questions, including delivering the research aim and objectives, the research considers the epistemological positioning of positivism and interpretivism. Hence, positivism and interpretivism are the two epistemological approaches that inform the adopted research approach in this study.

The positivist prefers scientific, quantitative methods, while interpretivists prefer humanistic qualitative methods (Bryman, 2012) For instance, positivism is employed because it is a scientific framework that aims to generate empirical evidence that is objective and testable (Finlay, 2006). To achieve the positivism standing of the study, the researcher seeks to discover the what, who, where, and how that is related to the embarking on, uptake, and delivery of retrofit projects because the research involves a wide range of stakeholders. Thus, the assumption that these stakeholders hold a variety of understanding, beliefs, and attitudes toward the delivery of sustainable retrofit projects is attainable. This, in turn, leads to various actions, interactions and responses being examined quantitatively as it relates to informed decision-making to the uptake and delivery of sustainable retrofit projects.

Additionally, the epistemological underpinning of the case study approach in this study is interpretivism. Flyvbjerg (2011) and Yin (2012) that viewed the case study approach from interpretivist perspective support this. Interpretivism is considered because individuals to be investigated are not just puppets who react to external social forces as Positivists affirm (Creswell, 2009). Accordingly, social interpretivism research aims to develop culturally derived and historically situated interpretations of the social life and world (Crotty, 1998). This means that rather than relying upon only objective investigation, attention is on the understanding and interpretation of human actions and their products (Benton and Craib, 2001; Snape and Spencer, 2003). Such an approach is used to understand the world and can, in turn, lead to the development of 'subjective meanings' on certain objects or phenomena (Creswell, 2007). This is essential because to have an in-depth understanding of the barrier and enabling factors to the uptake and delivery of retrofit project, an interaction is needed between the researcher and the construction key stakeholders.

Interpretivism is essential because the current study needs to answer some research questions that cannot be answered quantitatively. To understand human action regarding answering some of the research questions, the research has to use the interpretivism approach to have informed knowledge of the 'why' and 'how' involved in the uptake and delivery of retrofit projects as it relates to the key stakeholders. This, in turn, means that situations in which perspectives are not shared, negotiation and compromise become necessary; this can be achieved through an interpretivism approach. This suggests an epistemology based upon symbolic interactionism (the distinctive study of stakeholders in embarking, uptake, and delivery of retrofit projects).

The above ontological and epistemological underpinnings call for a methodology or research approach that is capable of capturing as much complexity involved in sustainable retrofit building projects activities as possible as well as delivery solutions. However, to achieve these, the ontological and epistemological positions of the study have informed the researcher about the appropriate research approach adopted in this study to deliver the study aim and objectives and answer the research questions. Thus, the ensuing section discusses the research approaches and the approach adopted for the study.

5.3.2 Review of research approach

Bryman (2008) explains that the term research approach means 'a general orientation to the conduct of research'. Research approach assists to put the research paradigms into motion in the empirical world through specific methods of data collection (Denzin *et al*., 2005). Hence, research approaches act as links between research paradigms and research methods and comprise the ‘skills, assumptions, enactments, and materials practices’ of the researcher (Denzin *et al*., 2005). On the other hand, Dainty (2008) defines research methodologies/approaches as the rationale and philosophical assumption that underpin a particular study. However, Creswell (2007) describes the research approach as a useful strategy to increase the validity of social research.

Research approaches can be classified as deductive (quantitative) and inductive (qualitative) or a combination/mix of the both which is called the mixed method (Creswell, 2007; Fellows and Liu, 2008; Silverman, 2010; Bryman, 2012; Neuman, 2014). The significant difference between inductive and deductive methods is particularly on how they view the nature of reality (Maxwell 1998; Corbetta 2003). Onwuegbuzie and Leech (2005) assert that the quantitative theorists believe that: *‘in a single reality that can be measured reliably and validly using scientific principles*” *while qualitative theorists believe in multiple constructed realities that generate different meanings for different individuals, and whose interpretations depend on the researcher’s lens’* (p.270).

Quantitative research is concerned with explaining a phenomenon by collecting numerical data that is analysed using mathematical methods such as statistics (Aliaga and Gunderson, 2006). A quantitative approach is needed for research that test theories or explanations. Such an approach explains where the research problem involves identifying factors that influence the outcome or understanding the ‘best predictors’ of outcomes (Creswell, 2003b). Accordingly, quantitative research is underlined as fixated upon the four aspects of measurement: causality, generalisation, and replication (Bryman, 2008). On the other hand, qualitative research is designed to explore the human elements of a given topic, for which specific methods are used to examine how individuals comprehend and experience the world (Given, 2008).

Qualitative research provides an approach to understanding the ‘contexts and settings’ in which the participants address an issue. Whereas quantitative research aims to provide a ‘general picture of trends, associations and relationships’ focusing on cause and effect relationships, qualitative research aims to explain the mechanisms behind those relationships by exploring ‘why people responded as they did’ (Creswell, 2007). Qualitative research, by nature, is ‘interdisciplinary, trans-disciplinary, and sometimes counter-disciplinary’ and interlinks the natural and social sciences (Denzin *et al*., 2005). A qualitative approach also allows the innovative and flexible working within ‘researcher-designed’ frameworks (Creswell, 2003b). This is the significant advantage of qualitative research compared to quantitative research (Charmaz, 2006). This flexibility of qualitative research allows the researcher to explore clues generated during the research process. Figure 5.1 highlights more benefits of mixed-method research.

Table 5. 1 Quantitative vs. Qualitative research approaches. Sources: (Amaratunga *et al*., 2002a; Creswell, 2003b; Denzin *et al.*, 2005; Neuman, 2006; Creswell, 2007; Denscombe, 2007; Bryman, 2008; Neuman, 2011; Neuman, 2014).

Comparison Elements	**Qualitative research**	**Quantitative research**
Philosophical assumptions	Constructive, advocacy, naturalistic, participatory, ethnographic or interpretative.	Positivist, rationalistic or functionalistic
Objective/purpose	To have a depth understanding of fundamental reasons and drives. To unearth existing trends in thoughts and opinions It assists in providing insights into underlying facts of the problem hence generating ideas or hypothesis for quantitative research later. Subjective Inductive in nature Holistic (focus on complex interactions, multiple perspective and identification of various factors)	Objective Deductive in nature Quantifying data and generalising results from a sample to the population of interest Assessing the frequency or rate of diverse views and opinions in a specific sample. Specific (focus independent and dependent variables and cause and effect interactions)
Research strategies	Phenomenology Grounded theory	Survey Experiment

	Ethnography Case study Narrative research	
Research Design	Flexible and emergent design	Predetermined and structured design
Researcher participation/objectivity	The researcher is a fundamental instrument hence personal values are considered in the investigation	Unbiased approaches applied. Therefore objectivity data are generated
Data Collection methods	Participants observations Interviews (semi-structured and structured) Documentary analysis Audio-visual materials Focus group Conversation and discourse analysis Small sample size Informative	Closed-ended questions Large sample size Representative Structured interview Self-administered questionnaires Structured observation Content analysis
Type of data collected	Text or image data	Numeric data
Data Analysis/Display	Non-statistical Ethnographic prose Historic narratives, First person accounts still photographs Biographical and autobiographical materials	Statistical summarisations (tables and graphs) Mathematical models
The basic unit of analysis	Words and Images	Numbers

Role of theory in connection to the study	Generates theory	Tests theory
Outcome	Exploratory Investigative	Descriptive
Strengths	Generates theory Clarity in the understanding of people issues Ability to look at change process ultimately Data gathering approach unearths natural situations rather than artificial	Avails broader coverage of the varied problems Cost-effective and less time consuming Statistics from larger samples could be considered in strategic decision making
Limitations	Time-consuming Tedious in nature Consumes more resources Result analysis and interpretation may prove difficult Difficult to control speed, advancement and end point of the project	Difficult in generating theory Difficult in understanding or unearthing processes Looks more artificial and inflexible

A mixed-method approach is a combination of both quantitative and qualitative research approaches (Bryman, 2012). The mixed-method approach emerged during the mid-twentieth century with the premise that the inherent biases of one method could be eliminated by the use of other methods (Creswell, 2003b). Thus, in mixed-method research, quantitative and qualitative research methods can be used in one of three ways: (i) Sequentially (to elaborate on the findings of one method with the use of another method); (ii) concurrently (to collect both quantitative and qualitative data at the same time); and (iii) transformatively (using a theoretical lens to provide a framework for the research design, which encompass both qualitative and quantitative data collection).

5.3.2.1 Rationale for using mixed (both deductive and inductive) research approach for the current study

The choice of a research approach is a fundamental part of the research process. The main aim of choosing a research approach is to establish the best possible ways of answering the research questions (Blaikie, 2000) and delivering research aim(s) and objectives. This research employed a mixed method because the researcher is interested with the beliefs, understanding, opinions, and views of the stakeholders as it relates to current practices in the uptake and delivery of sustainable retrofitted building projects. What is essential is that the mixed-method approach fully addressed the research aim and objectives and assisted in answering research questions of the study.

The mixed-method approach can address the lack of knowledge management that informs poor decision-making in the uptake and delivery of sustainable retrofitted building projects through the decision support framework. Table 5.2 highlights more reasons that the study adopted a mixed-method research. Nevertheless, examples are in the research studies that used a mixed-method approach in addressing construction issues in the industry. Some of the examples include (a) Chen (2012) researched strategic implications of e-business in the construction industry employing mixed methods; (b) Zou *et al*. (2014) used a mixed-method research approach to bridge the gaps between research and practice in construction safety; (c) Babatunde (2015) developed a public-private partnership strategy for infrastructure delivery in Nigeria using mixed methods; and (d) Ibn-Mohammed (2017) used a mixed-method approach in reviewing of case study towards decarbonising the natural and built environment. Table 5.2 highlights a summary of reasons for employing mixed-method research.

Table 5. 2 Summary of reasons for adopting mixed-method research

Reasons	**Explanation**
Completeness and diversity of views	It availed the study the opportunity for comprehensive investigation of the study hence provides a diversity of both strategies

Bryman (2006); Creswell and Clark (2011) and Wisdom *et al*. (2012)	
Triangulation or greater validity Greene *et al*. (1989); Bryman (2006); Johnson *et al*. (2007); Creswell and Clark (2011) and Wisdom *et al*. (2012)	It enabled the study to combine qualitative and quantitative research to triangulate collected data for corroboration
Different research questions Bryman (2006)	It assisted the research in answering various research questions using qualitative and quantitative research
Unexpected results and emerging themes Bryman (2006)	Combining both qualitative and quantitative assisted the study in generating surprising results and emerging themes
Credibility Bryman (2006)	It avails credibility by increasing the integrity of the results
Complementarity Greene *et al.* (1989); Creswell and Clark (2011) and Wisdom *et al*. (2012)	It avails the elaboration, enhancement, illustration, and classification of findings from one method to the other
Offsets, Bryman (2006) Creswell and Clark (2011) and Wisdom *et al*. (2012)	It balances the limitations of both and capitalises on their strengths to increase the breadth and depth of understanding
Enhancement Greene *et al.* (1989); Creswell and Clark (2011) and Wisdom *et al.* (2012)	It closes the gap that exists between quantitative and qualitative findings hence augments or informs either strategy when data are gathered from both

However, a quantitative approach was used for the following: (a) to get an enlarged idea of the barriers and drivers to the uptake of sustainable retrofit; (b) investigate the knowledge gap in delivering retrofit projects; (c) the needed environmental assessment methods as it relates to retrofit project delivery; (d) examine environmental, economic; (e) investigate social benefits of sustainable retrofitted building projects; and (f) investigate the decision-making issues in delivering retrofit project. Quantitative data collection methods and statistical analysis were used to establish the level of lack of knowledge management and decision-making that exists in the delivery of sustainable retrofit projects and other investigated issues.

The qualitative approach was used to investigate critical barriers comprehensively and enable factors in the uptake and delivery of retrofit, a lack of knowledge management in delivering the project and how it affects the decision-making of the key stakeholders, addressed the remaining research questions, and discovered the risks and complications in providing retrofit projects. The qualitative approach through NVivo and qualitative content analyses were used to establish, in-depth, the diverse views of the key stakeholders as this relates to the investigations that were conducted. Additionally, both qualitative and quantitative approaches contributed to the development of a sustainable retrofit building process and decision support framework in this study. The next section discusses research strategies and the chosen strategies for the current study.

5.3.3 Review of the research strategy

The research strategy comprises a general method with the logic of design incorporating specific approaches to data collection and data analysis (Yin, 2009). Bell and Opie (2002) suggest five types of research strategies: 1) action; 2) ethnographic; 3) survey; 4) case study; and 5) experimental. Saunders *et al*. (2007) add one more research strategy: the grounded theory. Each strategy can be used for exploratory, descriptive, and explanatory research (Yin, 2009). For example, there may be exploratory case studies, descriptive case studies, or explanatory case studies; there may also be exploratory experiments, descriptive experiments, or explanatory experiments. Even though each strategy has its unique characteristics, there are large areas of intersection among them (Sieber, 1973). Yin (2009) suggests three conditions to distinguish different strategies: 1) the type of research question asked; 2) the extent of control an investigator has over actual behavioural events; and 3) the degree of focus on contemporary as opposed to historical events.

However, Saunders *et al*. (2007) reviewed the different research strategies and state that the choice of research strategy is guided by the research question(s) and objectives, the extent of existing knowledge, the amount of time and other resources the researchers have available, and the philosophical underpinnings. The subsequent paragraphs define each research strategy and briefly highlight the details of each strategy.

5.3.3.1 Action research

Action research is described as ‘a particular process concerned with developing practical knowing in the pursuit of worthwhile human purposes and seeks to bring together action and reflection, theory and practice’ (Reason and Bradbury, 2008). The action approach is characterised by ‘insider’ involvement and usually includes collaborative reflection on existing relevant practices (Cameron and Price, 2009). Action research focusses on a specific context with a clear purpose and requires the involvement of the researcher. Therefore, the researcher needs to be committed to all the actions throughout the process (Saunders *et al*., 2007). This could be time-consuming and draining, and the researcher has to be capable of handling such situations.

5.3.3.2 Ethnographic research

This research strategy has its roots in anthropology, and the approach suggests that the researcher must be part of the group under study hence, observes the individual or particular behaviours of the groups to gain insights into what, how, and why their patterns of behaviour occur (Fellows and Liu, 2008). Ethnographic research is particularly indicated when one is seeking insight into a new research domain and can provide valuable understanding that can guide later research using different approaches, therefore, depth rather than breadth of coverage is the norm, with a moderately small number of cases that are studied (Robson, 2011). One of the key, and yet most difficult, steps in ethnographical research is gaining access to a social setting that is relevant to the research problem in which the researcher is interested (Bryman, 2004). The role of the researcher can be a participant, observer, or both. In each circumstance and role, the researcher needs to have control over the time consumed (Saunders *et al*., 2007). However, the research process needs to be flexible because the researcher needs to be prepared for tests of either competence or credibility (Clair, 2003) and for changes in circumstances (Armstrong, 1993; Giulanotti, 1995).

5.3.3.3 Survey approach

This is a group of research methods commonly used to determine the present status of a given phenomenon (Connaway and Powell, 2010). The basic assumption of most survey research is by cautiously following certain scientific procedures with which one can make inferences about a large group of elements by studying a relatively small number selected from the larger group (Forza, 2002). Therefore, surveys operate through statistical sampling, and the information gathered from a sample of individuals is used to describe the characteristics of a defined population (Thomas, 1996).

The survey approach is used to gather contemporary data and is suitable for studying a large number of cases, including those that are geographically dispersed (Gray, 2009). In addition, survey research is generally considered to be more appropriate for studying personal factors and for exploratory analysis of relationships (Yin, 2009). Survey research can be exploratory, analytical, and descriptive (Connaway and Powell, 2010). The most crucial part of survey research is sampling (Thomas, 1996; Gray, 2009; Connaway and Powell, 2010; Robson, 2011). The mode of data collection and data validity are also critical for the completion of survey research (Birley and Moreland, 1998; Bryman, 2004).

5.3.3.4 Case study

This approach encourages an in-depth investigation of particular instances or phenomenon within a research subject (Flyvbjerg, 2006; Fellows and Liu, 2008) and concentrates on the examination of a single instance or event (Birley and Moreland, 1998). Instead of using large samples, case studies focus on observing an individual case (or a small number of multiple cases) to analyse the variables relevant to the subject under study. The case study approach is of greatest relevance when the study focuses extensively on exploring and understanding rather than confirming and quantifying (Kumar, 2011). When doing case-studies, the researcher can access a range and depth of information using multiple sources of data or multiple means of data collection, such as documentation, archival records, interviews, direct observations, participant-observations, and physical artefacts (Yin, 2009). It is critical for the researcher to decide what should be included and excluded when selecting the information and data in case studies (Cameron and Price, 2009).

However, Yin (2012) stated that one of the limitations of using case studies in data gatherings is its time-consuming nature.

5.3.3.5 Experimental research

This strategy makes observations and obtains measures using instruments at a pre- or post-test stage of the procedures (Creswell, 2003b). In experimental research, the researcher manipulates at least one independent variable, controls other relevant variables, and observes the effect on one or more dependent variables (Connaway and Powell, 2010). Experimental research is considered to be good for testing relationships and suitable for issues which variables involved are known or hypothesised with some confidence (Fellows and Liu, 2008). In experimental research, the independent variable can be observed, introduced, controlled, and manipulated by the researcher (Kumar, 2011). This approach aims to produce results that are objective, valid, and capable of replication by other researchers or by the initial researcher (Gray, 2009). The required resources are limited, but the time consumed is not predictable (Saunders *et al*., 2012).

5.3.3.6 Grounded theory

This is a systematic approach for gathering, synthesising, analysing and conceptualising qualitative data to construct theory (Chiara, 2011). This approach aims to formulate hypotheses based on conceptual ideas and to discover the participants' main concern and how they actually can resolve it (Saunders *et al*., 2007). The grounded theory approach develops models, hypotheses, and theory directly and primarily from the data without reference to pre-existing concepts or theories (Connaway and Powell, 2010). Grounded theory research values the process of continuously developing, refining, and enhancing theory in recognition of the contributions that other studies, perspectives, and minds can make to the original effort (Mann and Stewart, 2000). The explanations of these theories are 'grounded' in the 'details, evidence, and examples' of the data (Mellon, 1986). Originated by Glaser and Strauss (Strauss, 1987; Glaser, 1992), the grounded theory is viewed as both a strategy of developing theory and a category of theory (Covey, 2002). Coding and categories are used in grounded theory research, and the theoretical categories are critical for theory development (Strauss and Corbin, 1994). The required resources are limited, but the researcher has control over the time consumed

(Saunders *et al*., 2007). Table 5.3 summarises the points discussed in the previous paragraphs and highlights the main elements of each research strategy. The ensuing section explains the rationale that necessitated the selection survey and case study research strategies.

Table 5. 3 Main elements of different research strategies (Adapted from Saunders *et al*., 2007, Yin, 2009).

Name of strategy	**Main concerns**	**Required time and resources**	**Expected type of applicable questions**
Action research	A specific context and with a clear purpose	It requires the involvement of the researcher and the researcher needs to be devoted to all the actions throughout the process	How
Ethnographic research	Research process needs to be flexible and responsive to change	It requires limited resources, the researcher has control of the time consumed	What, how, why
Survey	Sampling Mode of data Collection Validity	It requires limited resources, the researcher has control of the time consumed	Who, what, where, how many, how much
Case Study	Case selection Reliability	In-depth investigation of research, requiring	How, why

		multiple kinds of resources, and it is time-consuming	
Experimental research	Sampling Validity	It requires limited resources, the time consumed is not predictable	How, why
Grounded theory	Category and coding Theoretical sampling	Requiring limited resources, the researcher has control of the time consumed	How, why

5.3.4 Rationale for adopting survey and case studies as research strategies

5.3.4.1 Survey

A survey is defined as a research method commonly used to determine the present status of a given phenomenon (Connaway and Powell, 2010). Pinsonneault and Kraemer (1993) defined a survey as *'a means for gathering information about the characteristics, actions, or opinions of a large group of people'* (p.77). The underlying assumption of most survey research is that it cautiously follows specific scientific procedures; one can make inferences about a large group of elements by studying a relatively small number selected from the larger group (Forza, 2002). Therefore, surveys operate through statistical sampling, and the information gathered from a sample of individuals is used to describe the characteristics of a defined population (Thomas, 1996). The survey approach is used to gather contemporary data that is suited for studying a large number of cases, including those that are geographically dispersed (Gray, 2009).

Additionally, survey research can be exploratory, analytical, and descriptive (Connaway and Powell, 2010). Survey research is said to be more appropriate for studying personal factors and for the exploratory analysis of relationships (Yin, 2009). A survey is acknowledged as a quantitative research instrument, which is useful in gathering a large sample size for quantitative data analysis (Cheung, 2009). Galiers (1992) and Czaja and Blair (1996) in similar studies argue that the survey is one of the most widely used methods in social sciences related to research, such as construction management, to provide a representative sample of the study area.

It also serves as an effective means of looking at a higher number of variables than is possible with experimental approaches. The most crucial part of survey research is sampling (Thomas, 1996; Gray, 2009; Connaway and Powell, 2010; Robson, 2011). The mode of data collection and the validity of the data are also critical in the completion of survey research (Birley and Moreland, 1998; Bryman, 2004). Isaac and Michael (1997) state that survey research is used to: '*answer questions that have been raised, to solve problems that have been posed or observed, to assess needs and set goals, to determine whether or not specific objectives have been met, to establish baselines against which future comparisons can be made, to analyse trends across time, and generally, to describe what exists, in what amount, and in what context'* (p. 136). Hence, this research employs a survey.

The research employs the use of the survey strategy to enable the researcher to collect quantitative data that can be analysed quantitatively using statistical analysis (descriptive and inferential statistics). The survey provides a broad capacity, which ensures a more accurate sample to gather targeted results. The survey is chosen to access the thoughts of key industry stakeholders in managing project knowledge and the issues that exist in making an informed decision strategically in the uptake and delivery of retrofit projects. This strategy will tend to answer the who, what, where, how many, how much (Saunders *et al.*, 2007) regarding the delivery of sustainable retrofit projects, as it involves knowledge management and decision-making. The outcome of the data collected through the survey suggests a particular relationship between variables. For example, identifying the construction organisations engaged in sustainable retrofit projects or construction; the need to manage project knowledge in making informed decisions in construction activities within the key stakeholders; establish barriers and drivers factors to the uptake and delivery of retrofit projects and the need to develop sustainable retrofit building process embarking, uptake and delivery of retrofit projects.

The next section discusses the case study research strategy and the rationale for choosing it. Case studies are relevant in order to develop a deeper understanding of specific knowledge issues and actual practices in delivering sustainable retrofitted building projects within some selected construction organisations in the UK.

5.3.4.2 Case studies

Yin (1989) defines a case study as *'an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not evident; and in which multiple sources of evidence are used'* (p.23). Ragin (1989) defines case studies as '*case-oriented studies, by their nature, are sensitive to complexity and historical specificity. The strategy highlights complexity, dexterity and uniqueness, and it provides a powerful basis for interpreting cases historically'* (pp.8–9). This research adopts Yin's definition because the definition is fundamental to the validity and reliability of qualitative research approach. This strategy concentrates on the examination of a single instance or event. Hence, instead of using large samples, case studies focus on observing an individual case (or a small number of multiple instances) to analyse the variables relevant to the subject under investigation. The case study approach is appropriate when the focus of research is on extensively exploring and understanding rather than confirming and quantifying (Kumar, 2011).

When doing case studies, the researcher can access the depth of information using multiple sources of data or various means of data collection, such as documentation, archival records, interviews, direct observations, participant-observations, and physical artefacts (Ragin, 1989; Yin, 1989). However, the use of multiple sources of data gathering makes the whole process very time-consuming. However, it is critical for the researcher to decide what should be included and excluded when selecting the information/data (Cameron and Price, 2009) hence, adoption of multiple-case studies in the current research under mixed-method research approach.

A case study research strategy was employed to investigate, in-depth, the actual practices of delivering sustainable retrofitted building activities and also, to ascertain the knowledge gaps that exist and what knowledge means to the key stakeholders. These were achieved with some selected construction organisations identified after the survey result analysis. It is argued that case studies focus on the understanding of the dynamics present challenges in the industry as regards to sustainable construction (Amaratunga *et al.*, 2002b) particularly retrofit projects. The strategy assisted in establishing the critical barrier and enabling factors and ascertained the risks factors prevalent in the delivery of retrofit projects. The researcher used semi-structured interviews with data collection techniques as regards case study based on the literature review and the gaps in the survey results. As aforementioned, this strategy seeks to answer ‘why’ ‘how’ and ‘what’ about issues behind the reality of research investigations (Calzadilla *et al.,* 2012). The ensuing section discusses further the data collection techniques adopted in this research.

However, some academics in their publications have criticised the use of case studies. For example, Miles and Huberman (1994b) warn against researcher bias in the use of a case study as it relates to the selection of participants and data. Both of these involves the subjectivity of the researcher during the data collection stage, which poses a threat to the validity of the data (Miles and Huberman, 1994). Moreover, Maxwell (2005) identifies reactivity (i.e. the researcher influence on the participants studied) as a threat in the case study method. Similarly, Hammersley and Atkinson (1995) affirm that the researcher’s control is unavoidable. Despite the criticism, the rationale for the use of mixed-method research as discussed in Section 5.2.2.2 was able to eliminate the perceived limitations that exist in the use of case studies thus, ascertaining the reliability and validity of the research.

Types of case studies: the rationale for adopting multiple-case studies

Yin (2009) states that case study research could entail either single or multiple case studies. A multiple case study enables the researcher to explore the differences between cases and replicate findings between each setting and across cases. When comparisons are to be drawn, it is imperative that the cases are chosen carefully so that the researcher can predict similar results across cases, or predict different outcomes based on a theory (Yin, 2003). Campbell and Ahrens (1998) in identifying the ‘case’ and the specific ‘type’ of case study to be conducted, suggested that it is essential for researchers to consider if it is practical and expedient to conduct a single case study or if multiple case studies are better since more understanding of the phenomenon is gained through the investigation of existing issues.

Yin (2003) describes how multiple-case studies can be used to either (a) predict similar results (a literal replication) or (b) predict different outcomes, but for predictable reasons (a theoretical replication). However, the disadvantages of multiple-case studies are that they are usually very time-consuming and expensive to conduct. In consideration of the literature, this research adopted multiple-case studies due to its overarching advantages that surpass the disadvantages.

5.3.5 Research methods: techniques and procedures

Strauss (1998) defined research methods as procedures and techniques used for data collection and analysis. There are two major categories of data: primary and secondary. This study employs both primary and secondary data collection methods. For example, the primary data collection was conducted through quantitative (questionnaire survey) and qualitative (case study) strands. The secondary data were collected through archival records, textbooks, journal articles, conference proceedings, government publications, institutional and professional bodies' publications, and internet materials.

5.3.5.1 Questionnaire as a research technique used in the collection of survey (quantitative) data

A questionnaire is a written list of questions (or sometimes, statements), the responses to which are recorded by participants (Kumar, 2011). A questionnaire works best with standardised questions that are interpreted the same way by all respondents (Robson, 2011). In quantitative research, the questionnaire-survey is recognised as an effective method to seek a large sample size for quantitative data analysis (Cheung, 2009). Furthermore, Blaxter *et al.* (2001) argue that the questionnaire survey is one of the most widely used social research techniques. Moreover, a questionnaire-survey approach has been employed by many reputable earlier researchers in construction management (see Li *et al*., 2005b; Zhang 2005; Chan *et al*., 2010a; Cheung *et al.*, 2012a). It is against this backdrop that the research adopted a questionnaire-survey in this study.

Saunders *et al*. (2007) stated that questionnaires are classified as self-administered or interview-administered. Internet-mediated questionnaires, postal questionnaires, and delivery and collection questionnaires are classified as self-administered and are usually completed by the respondents. In interview-administered questionnaires, the researcher records the interviews based on the interviewee's responses. Examples include an interview by telephone or face-to-face interview. Each type of questionnaire has its advantages and disadvantages. For example, the benefits of internet-mediated questionnaires are low cost, high speed, high confidence to reach the right target respondent, automated data for future analysis, and a potentially large sample size, but the response rate is typically lower than the other types of questionnaires (Witmer *et al*., 1999; Dillman, 2000; Hewson *et al*., 2003; Saunders *et al*., 2007).

Face-to-face interview questionnaires allow interviewers to solicit clarification, or use follow-up or branched questions and tend to have high rates of response. However, the data collection process usually requires travel, clerical support and a significant amount of time (Forza, 2002).

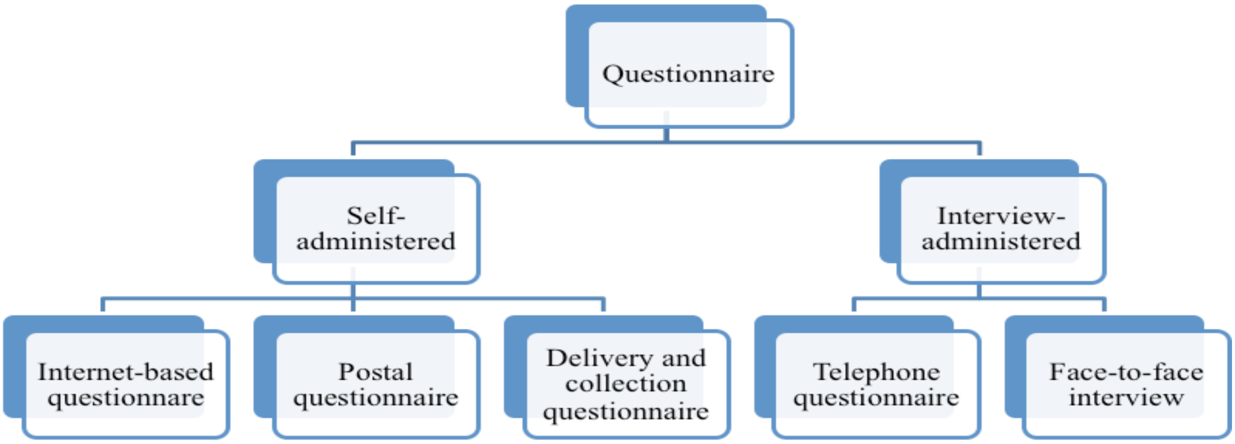


Figure 5. 2 Types of Questionnaire (Saunders *et al.,* 2007)

Figure 5.2 highlights types of questionnaire available in the extant literature. Chen (2012) argues that the decision of the researcher regarding the type of questionnaire to be used in the research is based on the need for the specific survey's consideration of time, cost, and human constraints. Saunders *et al.* (2007) suggest relevant factors to be considered in the choice of an appropriate questionnaire to be adopted, and these include:

1) characteristics of the respondents;

2) the importance of reaching a particular person as a respondent;

3) the significance of respondents' answers not being contaminated or distorted;

4) the size of the sample required for the analysis, taking into account the likely response rate;

5) types of question that must be asked in order to collect the necessary data; and

6) the number of essential questions.

Considering the benefits of the internet-based questionnaire as discussed and factors to be found in making the appropriate choice of the questionnaire, this research adopted an internet-based questionnaire *Survey Monkey* because of its low cost, broad reach, and delivery speed.

5.3.5.2 Interview as a research technique used in the collection of the case study (qualitative) data

An interview is defined as a verbal interchange usually face to face or through the telephone/Skype and other electronic instruments in which an interviewer tries to elicit information, beliefs, or opinions from another person (Burns, 1997). Interviewing is a widely employed method of data collection. Interviewing allows a researcher to investigate and prompt information that cannot be directly observed, such as thoughts, values, prejudices, perceptions, views, feelings and perspectives (Wellington, 2000). Interviews are categorised according to the degree of flexibility and specificity. Interview categories include unstructured, semi-structured and structured. Yin (2012) stated that in an unstructured interview, the interviewer typically only has a list of topics or issues (called an interview guide); furthermore, the style of questioning is usually informal, and the phrasing and sequencing of questions vary from interview to interview. In other words, the interview structure, contents, and questions are all flexible.

Bryman (2012) states that, in a structured interview, the interviewer asks a predetermined set of questions, using the same wording and order of questioning as specified in the interview schedule. It is usually a written question list prepared for use by an interviewer in person-to-person interaction. Longhurst (2009) defines a semi-structured interview as a verbal interchange in which the interviewer attempts to elicit information from an interviewee by asking questions. Semi-structured interviews unfold in a conversational manner offering participants the chance to explore relevant issues under investigation (Bryan, 2004a).

The choice of interviewing style is related to the researcher’s primary concern and the focus of the research objective. Unstructured interviews offer flexibility in structure, contents and questions, but require a high level of interviewer expertise and an in-depth understanding of the research objectives (Parsons, 1984). Structured interviews maximise the reliability and validity of measurement of key concepts, but are little more than a face-to-face questionnaire (Bryman, 2006). Table 5.4 highlights the differences between the three kinds of the interview.

Table 5. 4 Comparison of three styles of interviewing (Bryman, 2006).

Structured Interview	**Semi-Structured**	**Unstructured**
The interviewer has more control of the interview	The interviewer has more control of the interview	Both the interviewer and the interviewee have control
More predictable	It cannot be determined completely	Guided by the interviewee
May provide easier framework for analysis	Flexible	Very flexible
Guided by interviewer's pre-determined agenda		Unpredictable direction
Less flexible		Difficulty in analysis

In consideration of the literature, a semi-structured interview was adopted for data collection in this study. Reasons for the adoption is because semi-structured interview has been judged to be more valuable because it avoids the inflexibility of a structured interview and overcomes the problems inherent in the unstructured interview (Wellington, 2000). The choice of the semi-structured interview is valued for its accommodation to a range of research goals and typically reflects variations in its use of questions, prompts and accompanying resources to draw the participant more fully into the study topic (Galletta, 2013). Semi-structured interviews cover a wide range of instances and typically refer to a context in which the interviewer has a series of questions that form a general interview schedule. Additionally, it is used because the researcher can verify the sequence of questions or has some latitude to ask further questions in response to what are seen as significant replies (Bryman, 2004). This approach helps the interviewer/researcher the opportunity to pursue the interview in greater depths with flexibility, while the interview remains conversational (interactive) (Wilson, 2014). This will enable the researcher to ensure that the same information is obtained from a different number of participants hence allowing logical gaps in the collected data to be closed easily (Longhurst, 2009).

5.4 Sampling and sampling techniques

Sampling is the method of selecting an appropriate sample from a targeted population. There are two types of sampling: probability and non-probability (Kumar, 2011; Etikan and Bala, 2017; Maheshwari, 2017). Kumar (2011) includes mixed sampling, making it the third type of sampling. However, this study will discuss only probability and non-probability sampling. Figure 5.3 highlights the types of sampling aforementioned and their techniques.

5.4.1 Probability/random sampling

Probability sampling also is known as random sampling. This sampling allows every single item to have an equal chance of presence in the sample (Etikan and Bala, 2017). Probability sampling techniques use random selection to assist the researcher in choosing units from the researchers' sampling background to be involved in the sample (Blaxter *et al*., 2006, Kumar, 2011, Maheshwari, 2017). These procedures are clearly defined, making it easy to follow. In probability sampling, each member of the population has a known non-zero probability to be selected. Probability sampling includes simple random sampling; systematic sampling; stratified sampling; cluster sampling and disproportional sampling. The advantage of probability sampling is that sampling error can be calculated. In probability sampling, every individual in the population has an equal chance to be selected as a subject for the research. Figure 5.3 highlights sampling and sampling techniques in the existing literature. This figure was adapted because of the similarities and differences that exist between Kumar (2011), Etikan 2017, and Maheshwari (2017) regarding sampling and sampling techniques. Hence, the methods were integrated.

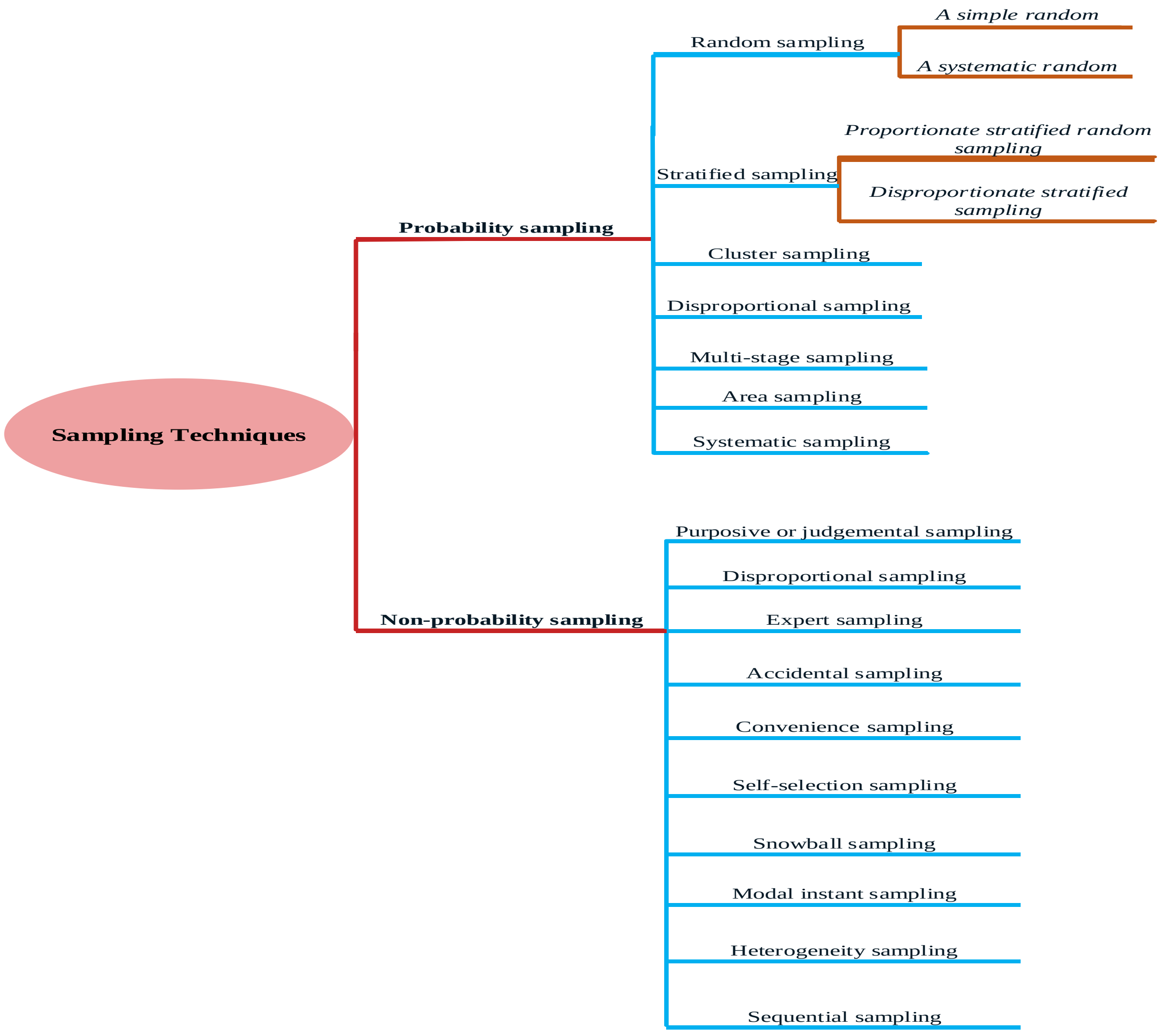


Figure 5.3 Sampling and sampling techniques (Adapted from Kumah, 2011, Etikan, 2017, and Maheshwari, 2017)

5.4.2 Non-probability sampling techniques

Non-probability sampling is also referred to as non-random sampling; thus, selection is not made randomly. In this type of sampling, members of the population do not have an equal chance of being selected (Marshall, 1996; Etikan and Bala, 2017; Maheshwari, 2017). Non-probability sampling techniques refer to the subjective judgement of the researcher when selecting units in the population to be included in the sample (Kumar, 2011). For some types of non-probability, there are clearly defined sampling technique and the procedures for selecting units to be included in the sample, for example, probability sampling techniques (Marshal 1996; Kumar, 2011; Erika, 2017). In non-probability sampling, members are selected from the population in some non-random mode. Thus, Blaxter *et al.* (2006) argue that non-probability sampling is adjudging appropriately when the researcher lacks a sampling frame of the target population for the study.

Non-probability sampling includes convenience sampling, consecutive sampling, judgmental sampling, quota sampling, and snowball sampling. The non-probability population sampling method is useful for pilot studies, case studies, qualitative research, and hypothesis development (Maheshwari, 2017). Hence, the research adopted non-probability sampling. *Purposive* sampling is called judgemental sampling, and this is obtained according to the discretion of someone who is familiar with the relevant characteristics of the population. In this sampling, individuals are selected based on the authority and knowledge of the researcher to obtain accurate results (Kumar, 2011; Erika, 2017). Hence the researcher adopted this sampling method under non-probability sampling. The rationale for the adoption of non-probability sampling is discussed further in the next paragraph.

5.4.2.1 The rationale for the selection of non-probability sampling for this study

This research adopted non-probability sampling because this study is concerned with key stakeholders in the construction industry as it relates to the barriers and enablers in the uptake of sustainable retrofit. Furthermore, the choice of non-probability sampling is to ascertain the level of knowledge management awareness and its adoption in the construction industry. It also sought to determine how the use of knowledge management affects the decision-making of the key stakeholders in the uptake and delivery of retrofit projects. A non-probability sampling technique is the best for the study because this study adopted a mixed-method research approach (Maheshwari, 2017).

Oisín (2007) and Kidder *et al.* (1991) assert that the distinguishing character of nonprobability sampling is that subjective judgements are relevant in the selection of the sample because the researcher decides which units of the population to include. Hence, the researcher has greater control over the choice of an appropriate sample size to deliver the research questions and objectives. Non-probability sampling is the most helpful for the exploratory stages of studies such as a pilot survey (Kumar, 2011). The choice of non-probability sampling affords the researcher the possibility to reflect on the comments that were descriptive as it relates to the sample (Maheshwari, 2017). It also helps in time-effectiveness compared to probability sampling (Oisin, 2007).

The study applied a purposive sampling method in the quantitative research strand (survey). The rationale for the selections is because purposive sampling is a selection method where the study's purpose and the researcher's knowledge of the population guide the process (Kumar, 2011). Kidder *et al*. (1991) suggest that with good judgement and an appropriate strategy, researchers can select the samples that suit the research. Thus, in this study the researcher has good knowledge of the stakeholders who influence the uptake of sustainable retrofit and decision-making process in delivering retrofit project; hence, informing the selection of appropriate sample size. Marshall (1996) affirms that the purposive sampling method enables the researcher to select the most productive sample actively to answer the research question(s). While Erika (2017) asserts that, the sampling is based on the judgement of the researcher as to who will provide the best information that is beneficial to the study to deliver research objectives and answer the research questions.

5.5 Research design

A research design is the set of procedures and techniques employed in collecting and analysing measures specified in the research problems. Crotty (1998) defines research design framework: *‘as the philosophical stance forming the methodology*’(p.3). The nature of a research topic, its aim(s) and objectives and the available resources determine its research design (Creswell, 2003b). Yin (1994) argues that research design is the logical structure that links the generated empirical data to the initial research objectives of the study and finally to its conclusions. Furthermore, research design is a general plan that describes a researcher’s attempt to answer research questions (Saunders *et al*., 2012).

Accordingly, research design delivers the plan and procedures of the research, covering decisions made about philosophical and methodological issues and research techniques. A pragmatic mixed approach was applied in this study as aforementioned. The mixed-method research approach combines both quantitative and qualitative approaches for data collection and analyses, and this has been justified as the most suitable approach for the current research (see Section 5.3.2.2 for a detailed discussion on the choice of mixed method). Figure 5.4 illustrates the research design of this study.

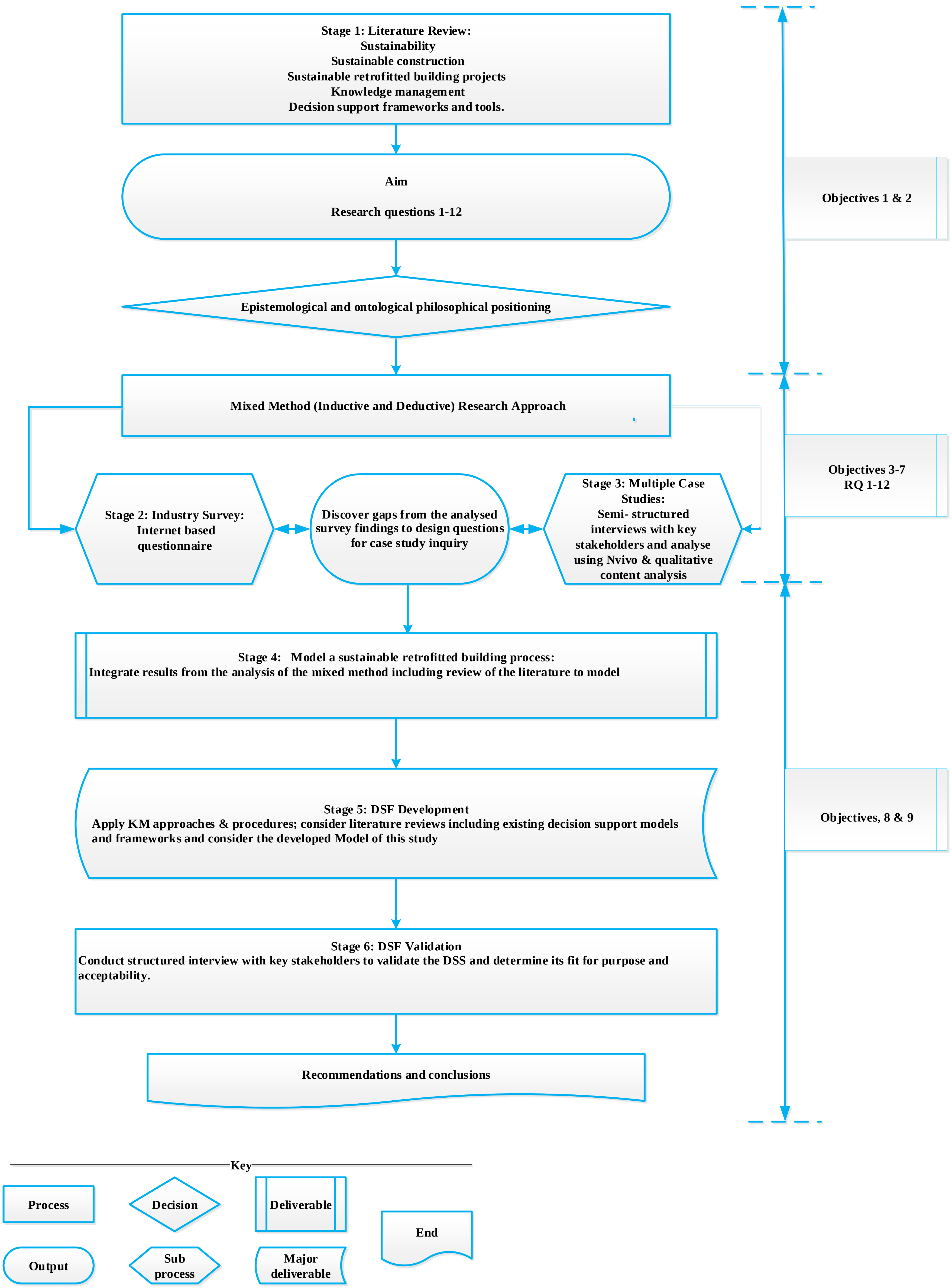


Figure 5. 4 Research design framework

5.5.1 Stage 1

This stage involves an extensive review of the literature on global and UK construction, sustainability, environmental impacts of construction, sustainable construction particularly retrofit projects, environmental assessment methods, sustainable principles and practices, benefits of retrofit projects, knowledge management and its procedures, stakeholder management and decision support models and frameworks. The literature reviews have been undertaken using published sources (journals, books, archival records, reports and online publications). The review of the literature is covered in Chapters 2, 3 and 4. At this point, the researcher has developed theoretical and philosophical underpinnings, which assisted in selecting the most appropriate approach. Hence, informed the choice of the mixed-method approach applied in this study. The mixed method involves combining qualitative and quantitative research approaches. The mixed-method approach involves exploratory and explanatory studies involving construction stakeholders from different construction disciplines.

5.5.2 Stage 2

This stage involves the conduction of quantitative data gathering through an industry survey. The industry survey was achieved using an internet-based questionnaire (Survey Monkey) used for data collection, and SPSS was employed for the statistical analysis of the results. The findings and analysis are presented in Chapter 6.

5.5.3 Stage 3

This stage involves conducting qualitative data gathering through multiple-case studies. A semi-structured interview was employed to collect data from multiple case studies. NVivo (computer-assisted software) and thematic content analysis were applied to analyse the results from the multiple-case studies investigation. The findings and analysis of this stage are presented in Chapter 7.

5.5.4 Stage 4

At this stage, sustainable retrofitted building process (SRBP) was developed with the knowledge gathered from literature reviews and findings from industry survey and multiple-case studies and its analyses. More details about this stage are seen in Chapter 7.

5.5.5 Stage 5

At this stage, the development of sustainable retrofitted building decision support framework (SRBDSF) was achieved and this delivered the research aim, which is objective. In delivering the research aim, this stage integrated the outcome of literature reviews particularly knowledge management principles and procedures; the findings from the questionnaire-survey and multiple-case studies and SRBP. The developed decision support framework was necessary to assist key stakeholders in making an informed decision in the delivery of sustainable retrofitted building projects. This stage is explained further in Chapter 8.

5.5.6 Stage 6

Validation of the SRBDSF was achieved at this stage, and this involves designing questions and sending it to the selected construction organisations that participated in the survey and interviews data gatherings. The research also employed some key stakeholders that were not involved in the questionnaire-survey to validate the framework. The views of the key stakeholders and construction practitioners assisted in determining whether the SRBDSF is useful and fit for purpose. This stage also summarised the benefits and limitations of the SRBDSF for future development. This contributed to the recommendations and conclusions of the current research. Further discussions are presented in Chapter 9.

5.6 Research methods applied in the current study

This section discusses the research methods used in the present study to deliver the research aim and objectives. Yin (1994) argues that there is neither a fast rule to selecting research methods, nor the best research method, as the use of each research method depends on the form of the research question, the research objectives, and contextual situation. The selection of the most suitable research methods relies mostly on the research objectives and the type of data needed for the research. The methods applied in this study are discussed below.

5.6.1 Literature review/archival analysis

Literature is a convenient starting place for a researcher (Dunleavy, 2003) especially for the preliminary mapping of the topic area (Hart, 1998). Hart (1998) outlines that it is helpful to map the topic area, but, does not how it is achieved. Adetunji (2005) argues that archival analysis is the most efficient, effective and cheapest method for gathering the existing wealth of literature on the subject of an investigation to form a thorough understanding of the concept of sustainable development and sustainable construction.

The first objective of this research is to review the central matters confronting organisations in the construction industry when delivering sustainable retrofit projects, particularly regarding the lack of knowledge management. There is a wealth of literature on the concept of sustainable construction, sustainable retrofit, knowledge management, and decision-making, but to a varying degree of quality. The literature review was undertaken extensively in this study to build up a solid theoretical base for the research area and a foundation for research questions and delivering other research objectives. The literature review as aforementioned assisted in determining the philosophical positioning of the study. The review assisted in identifying gaps in knowledge and formed the basis for developing the framework to aid the implementation and adoption of knowledge management in making informed decisions in the delivery of sustainable retrofitted building projects. The review of the literature has been accomplished using information drawn across various sources including industrial and academic publications, institutions and university databases, the internet, seminars, workshops, and conference notes attended.

Furthermore, information was gained by attending relevant developmental courses in delivering the research. Information obtained from these sources were analysed critically. The findings are presented in Chapters 2 and 3 of this study and five published conference papers (Maduka *et al*. 2015 a, b, c and d, and 2016).

5.6.2 Industry survey

Section 5.3.4 discussed the rationale for the adoption of a survey for data collection in the current study. Using a survey is essential in achieving some of the research objectives and serves as a stepping-stone for conducting the semi-structured interview. Saunders *et al.* (2007) identify types of questionnaires such as self-administered through the internet or online based, postal-based, and through delivery and collection (see Section 5.2.4.1). The survey was delivered through internet/online-based questionnaire 'Survey Monkey' as mentioned previously. Survey monkey was adopted because it is internet based, cheap, and a faster way to reach participants because the researcher discovered that the targeted population are computer and internet compliant/users. In addition, Survey Monkey was used because the researcher receives an instant alert when any participant responds to the survey.

The study accomplished the questionnaire-survey using the seven steps highlighted in Figure 5.5. The activities involved in each step were carried out concurrently as deemed necessary. The seven steps for conducting the survey include:

1) Identifying the objectives of the industry survey;

2) Defining the study population and sample size;

3) Adopt Progressive Question Reduction Sequence (PQRS) in designing a structured questionnaire;

4) Selecting ways to deliver the questionnaire-survey;

5) Conducting a pilot study;

6) Delivering the questionnaire-survey; and

7) Analysing the survey findings from the questionnaire-survey and present the results.

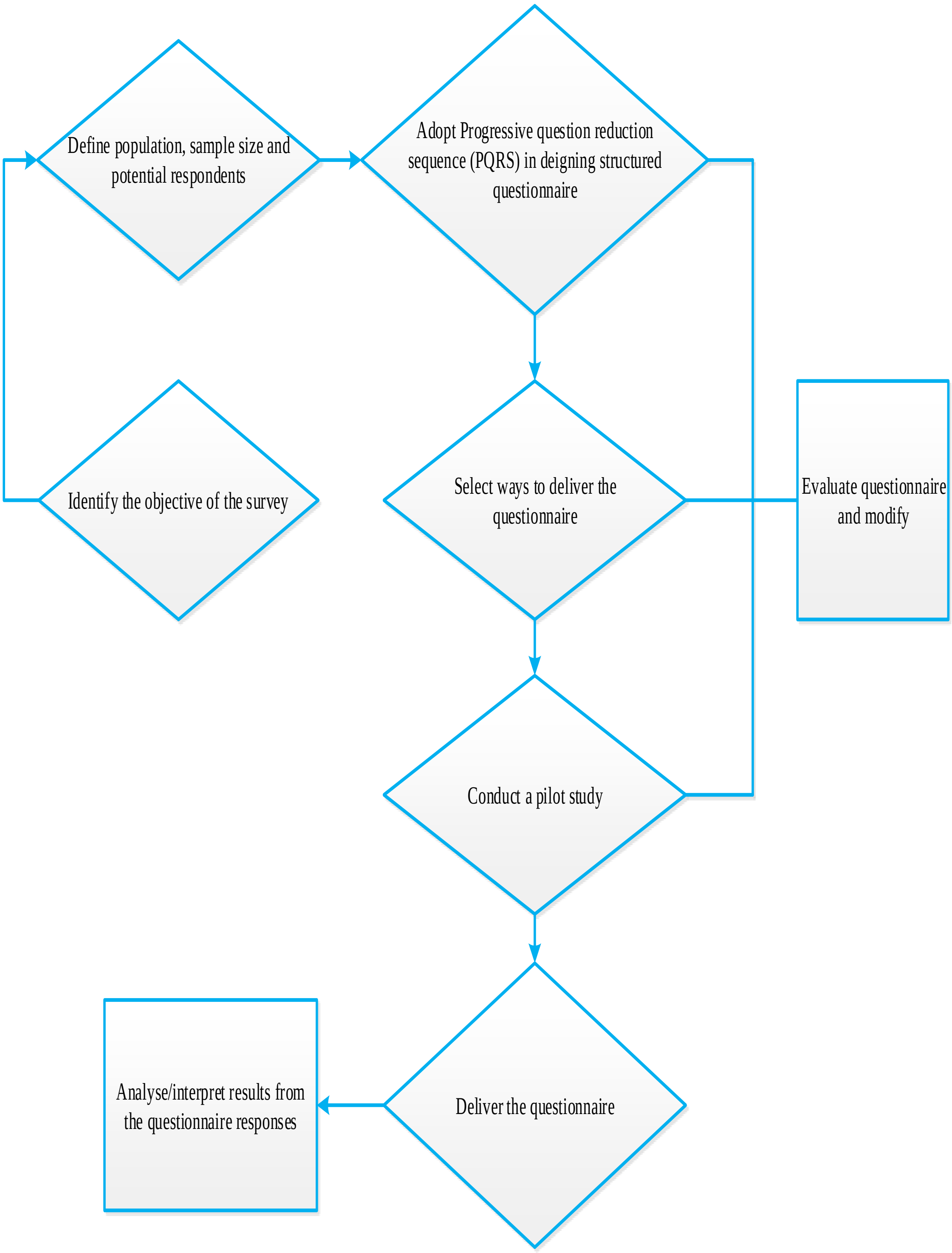


Figure 5. 5 Steps for conducting an industry survey

5.6.2.1 Step 1: Identify the objectives of the survey

The research questions were identified for investigation after a literature review. This step considered how some of the research questions would be answered. The objectives of this research were identified in the literature review, and the survey delivered some of them.

Additionally, the questionnaire-survey aims to answer some of the research questions and sets the parameters to enable the researcher to conduct a semi-structured interview that assisted in delivering the remaining objectives, including the research aim. A cross-sectional questionnaire-survey is designed explicitly to achieve the following:

- Investigate the involvement of construction organisations in a sustainable retrofitted building project;
- Environmental assessment method and its essence/application in retrofit project delivery in the UK;
- Establish a retrofit process that can be adopted in delivering sustainable retrofitted building projects;
- Establish the key stakeholders in sustainable retrofitted building projects;
- Establish environmental, economic and social benefits of sustainable retrofitted buildings;
- Barriers and enablers to the uptake and delivery of sustainable retrofitted building projects;
- Knowledge management issues in sustainable construction particularly retrofitted building projects;
- Decision-making challenges in delivering sustainable retrofitted building projects; and
- The need for sustainable retrofitted building process and decision support frameworks and models

5.6.2.2 Step 2: Adopt PQRS in designing the structured questionnaire

A structured questionnaire was designed with the aim and objectives of the survey. Altogether, the questionnaire-survey included questions covering five sections. Kumar (2011) states that questionnaire-survey layouts should be communicated in such a way that respondents perceive that the researcher is talking to them directly. Saunders *et al*. (2012) argue that the design of the questionnaire is based on the research questions, objectives, and time available to complete the data collection. This literature necessitates the adoption of PQRS (see Figure 5.6), which consists of four sections.

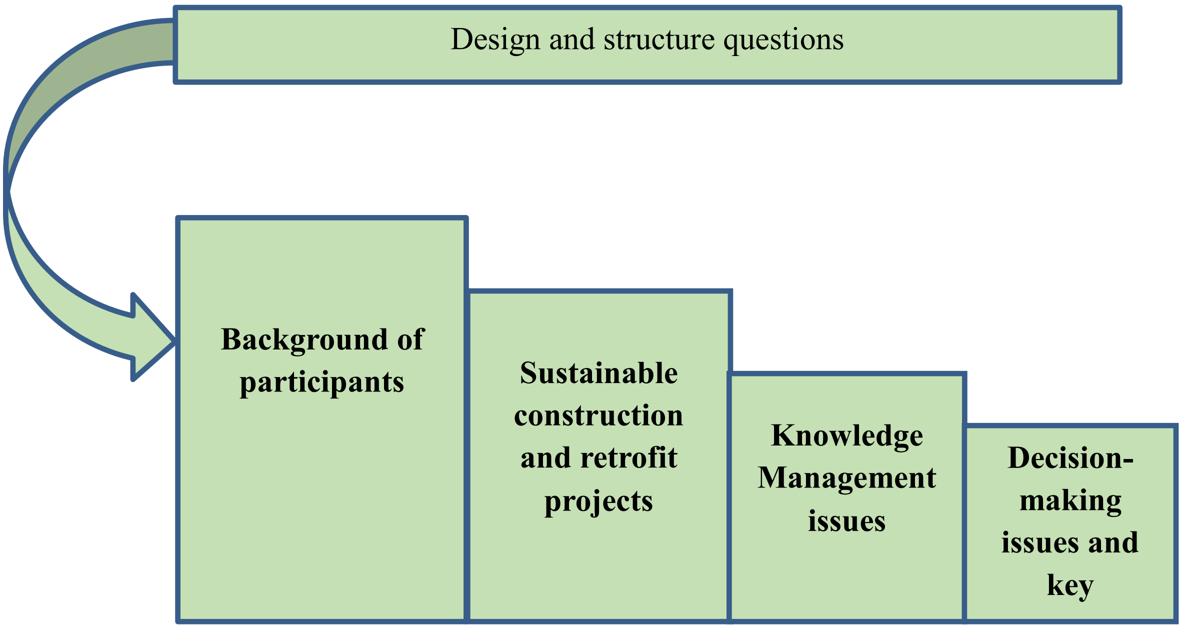


Figure 5. 6 Progressive question reduction sequence (PQRS)

The need for the adoption of PQRS is to avail the respondents a better understanding of questions arrangement and to answer questions in sequence. Hence, it facilitates progress in delivering the aim and objectives of the survey. This helped in reducing minimally unanswered questions. It is relevant to state that the questions were designed as closed questions (Fellows and Liu, 2008) and some of the questions had the function for the respondents to leave comments and recommendations.

However, using PQRS considered the background information of the survey respondents. The background information was designed to assist in analysing the survey results later and specifically for revealing the distribution of survey responses and the quality and relevance of the respondents to the study. *The background of participants* covered organisation type, organisation size, job positions/titles, professional background, years of experience, regular clients, company turnover, and involvement in sustainable retrofit projects. *Sustainable construction and retrofit* covered the current practices in sustainable construction, particularly sustainable retrofitted building projects. *The knowledge management issues* ascertained the central challenge of lack of managing knowledge in delivering sustainable retrofitted building projects amongst industry practitioner's/key stakeholders. It also investigated the perception of what knowledge means to individual stakeholders. It examined what constitutes knowledge in construction activities particularly retrofit projects and covered the status of the industry and its key stakeholders in applying knowledge management (KM) approaches in making an informed decision in construction activities, mainly in delivering sustainable retrofitted building projects. *Decision-making issues and stakeholders* covered questions regarding the decision-making issues experienced by the key stakeholders in providing projects and the role of KM in making an informed decision. Appendix A highlights the design of the questionnaire

5.6.2.3 Step 3: Define the study population and sample size

Study Population

This study is based on eliciting information from key stakeholders involved in the delivery of sustainable retrofitted building projects within the UK. It guided the researcher in determining the right study population. Therefore, the target population for this study is primarily key stakeholders in the UK construction industry, who engage in delivering sustainable retrofit projects across the UK. The rationale for choosing UK construction organisations is because the research is conducted in the UK. Hence, it is cheaper to contact the key stakeholders regarding data collection. Moreover, the UK construction industry is concerned about climate changes issues, thus have made recognisable efforts in retrofitting existing buildings across the UK.

Furthermore, the relevance of choosing the UK construction industry is the availability of substantive retrofit project experts in order to conduct survey to obtain the essential data. The target population includes the public sector and private construction organisations. The public consists of government agencies while the private construction organisations involve consulting companies, contracting companies, architectural companies, civil engineering companies, low carbon material manufacturers and suppliers, and quantity survey organisations, involved in sustainable construction projects.

To define an appropriate sample and its size, previous studies on sustainable construction, mainly building retrofitting, knowledge management, and stakeholder decision-making in the construction industry, were reviewed for referencing and benchmarking. The study obtained general information about how the previous studies adopted different strategies to reach potential respondents, and this set a solid theoretical base and provided a practical guide for the current research.

In finding the right population to determine the sample size, the researcher engaged and networked with industry professionals/stakeholders involved in sustainable construction, and, in particular, retrofit projects. This networking was achieved primarily through different industry fora/conferences across the UK at the beginning of the study. At those fora, the researcher engaged practitioners from different construction organisations (ranging from medium scale to big construction companies and academics) in discussions about the research, and implored their support to be part of the study by participating in the research questionnaire-survey and the semi-structured interview.

The researcher's reasonable understanding of the research area with detailed explanations generated interest amongst stakeholders. Thus, the researcher was able to convince them, and necessitated their interest in exchanging contact details with them. The attendant challenge in data collection in the UK required the need for regular engagement with the key stakeholders, for example, sending weekly emails and making phone calls to update them of the research activities. Thus, robust and cordial professional relationships were built and maintained. Over the years of study, the researcher remained consistent in reminding the industry professionals, through emails and phone calls, of the need to respond to the research questionnaire-survey and participate in the interview when appropriate.

Sample Size

It is advisable to use a reasonably large sample to obtain results that are representative of the population. To decide upon the appropriate sample size for this research, the researcher reviewed some of the sample sizes used in similar research as a guide. For instance, Akadiri (2011) in the development of a multi-criteria approach for the selection of sustainable materials for building projects a total of 490 questionnaire-surveys were deployed to participants. However, only 99 questionnaires were returned. Chen (2012), in research of strategic implications of e-business in the construction industry, deployed a 250-sample size; yet, only 49 responses were received. Babatunde (2015) in the study of developing a public-private partnership strategy for infrastructure delivery in Nigeria distributed 173 questionnaire-surveys to targeted organisations, and obtained 113 responses.

Furthermore, the following two points were considered before deciding the sample size to be used in this research (Nachmias and Nachmias, 1981):

1. A larger sample size is needed for the sample to be representative; and
2. A sample size should meet the statistical requirements of a particular statistical analysis that the researcher decides to carry out.

Given the above reviews in the literature, the researcher considered using a sample size of 217. The 217-sample size was due to the research-targeted organisations involved in sustainable retrofitted building projects. Nevertheless, 107 stakeholders and practitioners were in the researcher’s sphere of contact. Additionally, 10 academics in the construction management department at Northumbria University and other universities comprised the number of potential respondents to the survey. However, that was not enough for the needed sample size; hence, the consideration of potential respondents. The consideration of potential participants was a strategy to achieve an increased sample size. This was accomplished through the search of construction organisations involved in sustainable construction in the UK via the internet and the researcher discovered top 100 construction companies with contact details. The researcher started contacting the organisations through emails and phone calls using Northumbria University facilities. The researcher explained the research area, its importance in the UK construction industry, and the built environment and need to collect data to achieve the study aim, objectives, and answer the research questions. On the whole, the researcher documented 217 contacts that were used in deploying the questionnaire-survey.

5.6.2.4 Step Four: Select ways to administer the questionnaires

Different modes for administering questionnaires were considered to choose the suitable one for the current study. An internet-based questionnaire was selected, as previously mentioned, as it serves as the most effective medium to administer the questionnaire-survey. This is because all the members of the selected construction organisations can be contacted via email. As aforementioned, an internet-based questionnaire-survey has the advantages of low cost, high speed, wide reach, and a reasonable response rate (Chen, 2012).

5.6.2.5 Step Five: Conduct a pilot study

A pilot study was conducted to finalise the content and format of the questionnaire. It is vital to determine clarity and ease of understanding. Munn and Drever (1990) argue that a pilot study is necessary to demonstrate the methodological rigour of a survey. Saunders *et al*. (2012) affirm this by stating that before deployment of the questionnaire on a large scale, it is necessary for it to be pilot studied. The areas of investigation in the pilot study include:

1) Required time for completing the questionnaire;
2) The questionnaire format;
3) The wording of the questionnaire; and
4) The limitations of the survey-questionnaire;

Recommendations from both industry practitioners/stakeholders and academics were collected for further enhancement of the questionnaire. The industry practitioners/stakeholders are within the range of the following construction disciplines: property owners, contractors, consultants, and designers, while the academics (five of them) were university lecturers in construction management disciplines. These participants assisted in completing the questionnaire and were encouraged to give suggestions and recommendations to modify the questions and structure of the questionnaire. The questionnaire was then administered to 20 selected stakeholders/industry practitioners, but 15 were returned after several attempts were made to get feedback. The 75% response rate achieved compares satisfactorily with the 20% response rate achieved in the pilot survey reported in Xiao (2002) and 33% reported in Abidin (2012). Regarding the feedback and recommendation from the pilot study, 15 respondents did not consider time as a challenge in responding to the questions. The longest time for the completion by one of the respondents was 25 minutes, which the key stakeholders were satisfied with. There was, therefore, no apparent need to reduce the number of questions in the survey.

The majority of the key stakeholders recommended that the questionnaire-survey should be modified. They suggested modifications in these areas (a) layout of the questionnaire; (b) some rewording, especially in the knowledge management questions, to avoid ambiguity; (c) changing some section titles to specifics; and (d) keeping the questions optional instead of making some compulsory, which will likely stop some respondents from navigating to another section. The suggestions and recommendations were used to modify the questionnaire-survey to meet the requirements of the participants and for its deployment. Having satisfied the requirement to pre-test the questionnaire (Babbie, 1990; Munn and Drever, 1990; Czaja and Blair, 1996) and having accomplished the revision of the questionnaire-survey using the feedback from the pilot study respondents, the next stage was to deliver the questionnaire survey.

5.6.2.6 Step Six: Deliver the questionnaire-survey

After the pilot study and determination of the sample size, the modified questionnaire was sent out via Survey Monkey, an internet-based questionnaire as earlier stated. E-mails with a survey-monkey link were sent to the participants of the selected construction organisations to respond to the modified/main questionnaire-survey. The e-mail invitations were marked as important messages.

Additionally, the e-mail invitations were tracked to ensure messages were delivered to the recipients successfully. Subsequently, e-mails were also sent to the targeted participants to remind them to respond to the survey. Literature suggests a two-time follow-up in achieving high response rates (Babbie, 1990, Creswell, 2003b). Therefore, this study followed up three times per participant by sending e-mails three times each to the participants at different times to remind them to respond to and submit the questionnaire-survey. On some occasions, phone calls and text messages were employed. Questionnaires were administered successfully to 217 (107+10+100) participants.

5.6.2.7 Step Seven: Analyse/interpret results from the questionnaire-survey responses

Of the 217 questionnaires deployed to the targeted sample, 86 were returned. This represents a response rate of 39.6%, which was considered to be acceptable and compares favourably with the publications of Chinyio *et al.* (1998), Akintoye (2000), Black *et al.* (2000), Dulami *et al.* (2003), Ofori and Chan (2001), Vidogah and Ndekugri (1998), Shash (1993), Akadiri (2011a), and Takim *et al.* (2004) all of whom acknowledge the expected response rate for questionnaires in the construction industry to be around 20–30%.

After the responses were received, the next step was to interpret/analyse the result descriptively and with inferential analysis using SPSS. A report was produced after analysis of the findings, and it served as part of stepping-stone for phase two of the data collection, which is a multiple-case study research strategy. Before discussing the case study data collection applied in the current study, it is essential to examine the methods applied in analysing the survey findings.

5.7 Ensuring validity of the questionnaire-survey

Validity in data collection implies that your results truly represent the phenomenon you are claiming to measure. Leedy and Ormrod (2005) describe validity as an indication of how sound and effective the measuring instrument used in the research area, through the functionality of the instrument and the accuracy of the reading by the instrument. There are various ways in which the validity of measurement is tested to establish the quality of empirical social research (Yin, 2009). These include content validity, face validity, data splitting, construct validity, external validity, degenerate validity, and historical validity, among others. However, this research will discuss the face validity, content validity, and data splitting validity (which was used to determine the internal consistency and reliability of the questionnaire survey) employed in establishing the validity of the survey-questionnaire.

5.7.1 Face validity

Face validity is achieved by asking people who are knowledgeable about the system to determine whether the model or framework’s performance appears to be reasonable. This method can be used in ascertaining whether the logic in the conceptual framework is correct and if the input and output relationships are vital. Parsian and Dunning (2009) assert that face validity is achieved when the questionnaire is proper in the circumstances of the study purpose and content area. Parsian and Dubbing (2009) contend that face validity is weak compared to other types of validity. However, Haladyna (1999), Trochim (2000) and DeVon (2007) argue that face validity assesses readability, consistency, formatting, and the clarity of the questionnaire. In this study, doctoral students knowledgeable in the research area and the researcher's supervision team achieved face validity through peer reviews of the survey-questionnaire.

5.7.2 Content validity

Fayers and Hand (2002) describe content validity as the extent to which items of a scale completely measure the relevant concepts without additional features. Content validity indicates that the content of the questionnaire is appropriate for the study. In view to ensuring content validity in this study, a comprehensive literature review was conducted and the dimensions from measuring the relevant constructs and variables from past studies were derived. After that, the research conducted a pilot-study administered to 20 key stakeholders, as previously stated. The outcome of the pilot testing was used to modify the questionnaire-survey (see Figure 5.5). These efforts were aimed at achieving a level of understanding for the survey questions and establishing a logical link between questions and the objectives of the study. Thus, the content validity of the scales was ensured (Kumar, 2005).

5.8 Data splitting

In consideration of the research questions that need to be answered in this study and to check the internal consistency of some questionnaire-survey responses, this research employed data splitting. Therefore, the proportion of the data collected was selected for validation. This approach is in line with the second of the three methods of validation described by Good and Hardin (2003), which suggested the splitting of data by using one part for calibration and the other part for verification. This approach is described as an effective method of validation (Snee, 1977).

Regarding how much is set aside for this purpose, the evidence from other research varies. For example, Xiao (2002) set aside 12.20% and Omoregie (2006) set aside

9.03%. This seems to suggest that there is no fixed number or percentage required for validation. The recommendations by Good and Hardin (2003) and Picard and Berk (1990) indicate that between one quarter (1/4) and one third (1/3) should be set aside for validation purposes. In this study, using data splitting, a reliability test was conducted using Cronbach's alpha statistic (see Table 5.5). The reliability test of the whole scale indicates evidence of internal consistency and the reliability of the scales in the questionnaire responses. Thus, the results in Table 5.5 confirm that the data instrument used in this study was significantly valid and reliable.

Table 5. 5 Summary of reliability coefficients for the measuring scales using SPSS

S/N	Measuring Scales	Cronbach's alpha	Internal consistency
1	Economic benefits of sustainable retrofitted building	0.743	High
2	Social benefits of sustainable retrofitted building	0.818	High
3	Environmental benefits of sustainable retrofitted building	0.785	High
4	Barriers to sustainable retrofit projects	0.787	High
5	Enablers for sustainable retrofits projects	0.763	High

5.9 Methods applied in analysing industry questionnaire-survey data

Most of the responses were ratings measured on a Likert scale. Hence, data obtained for this research conformed to either the nominal or the ordinal scale (Siegel and Castellan, 1988). The subject of ordinal scale data has been contentious. In some previous studies, large ordinal scales have been considered equivalent to measuring continuous variables (Orme and Buehler, 2001), enabling parametric testing. In other cases, it is claimed that such data cannot be analysed using parametric methods unless precarious and, perhaps, unrealistic assumptions are made about the underlying distributions (see, for example, Siege and Castellan, 1988).

In the present study, the former position was accepted, and it was considered appropriate to analyse the survey data using parametric statistics via Statistical Package for the Social Sciences (SPSS). This included descriptive data analysis, Pearson correlation, a reliability test, Cronbach's alpha, and Factor analysis. The ensuing sections will discuss these inferential analyses. However, before the data analysis, it is essential to edit data to replace missing values for quality and bias reduction. Thus, data editing precedes the questionnaire-survey analysis and it can be argued that it is part of the analysis.

5.9.1 Data editing and missing value

Data editing is a process comprising the review and adjustment of collected data. The purpose is to control the quality of the collected data (UNEC, 2016) and to reduce bias (Allison, 2001; Kang, 2013). The responses received from participants contained some missing data. Missing data (or missing values) is defined as the data value that is not stored or a question that is not responded to in the observation of interest. In this study, the missing data that occurred are a few (but not all) variables for a few cases (Allisson, 2001). It is stated that it is an exceptional study that has no missing data (Lopresti, 1998). Even in a well-designed and controlled study, missing data occurs in almost all researches (Kang, 2013). Missing data can be problematic in analysis and happens for many reasons. According to Lopresti (1998), in some essential studies, analysis of missing data is required to improve the validity of the study. Therefore, to achieve a useful data set and to be able to use all the data collected in the analysis, the researcher spent some time examining and resolving the missing data problem. The SPSS Missing Values Analysis option was used to analyse the patterns of missing data. It was decided through considering Hair *et al.* (1998), who state that missing data were not excessively high (in the order of 50% or more) cases and variables cannot be excluded from analysis. In this study, the missing data experienced was less than 5%. Hence, no case or variable was excluded before data analysis.

However, where appropriate, the Replace Missing Values option was used to replace the missing values with the mean of all valid responses. In a mean substitution, the mean value of a variable is used in place of the missing data value for that same variable (Kang, 2013). While several options exist for replacing missing values, substitution with the mean has been adjudged to be the most widely used (Xiao, 2002). Statcan (2013) corroborates this by stating it is more suitable to calculate mean scores based on the number of answers from each participant. Thus, it replaces missing values with the mean of valid close values of the responses. This is considered the best single replacement value (Hair *et al.*, 1998). Besides, it is easy to calculate and effect the replacement, hence, its use in this study. To ascertain the appropriateness of this approach, *regression* method and *multiple imputation* (MI) techniques were employed to estimate alternative replacement values. The series means calculations were consistent with these estimates (regression and MI), especially the regression estimates. Hence, it means value is demonstrated to be appropriate and this prepared the data for analysis.

5.9.2 Descriptive statistics analysis

An essential preliminary to any statistical analysis is to obtain some descriptive statistics for data analysis and presentation. Descriptive analysis is useful for describing the basic features of data in quantitative procedures; for example, the summary statistics for the scale variables and measurement of the data. It is usually used in summarising data frequency measure or measures the central tendency that includes the use of frequencies, percentages, means, average, mode, and standard deviations for presenting a description of the findings of the survey. In a research study with large data, these techniques assist in managing the data and present it in a summary table, graphical representation in the form of the histogram, bar charts, and pie charts. This research employed descriptive analysis for analysing data related to the background information of the respondents, their organisations, and some other findings from the survey.

5.9.3 Reliability Test

Reliability refers to the degree of consistency of results and the extent to which the measurements are free of random and unstable errors (Cooper and Schindler, 2006). Garson (2009) emphasises that reliability is the correlation between an item, scale or instrument and argues that reliability is measured in one of four ways:

(a) Internal consistency;

(b) Split-half;

(c) Test-retest; and

(d) Inter-rater.

DeCoster (2005) claims that Cronbach’s alpha is the most useful estimates of reliability. Garson (2009) suggests that more than one reliability coefficient may be used in a single research setting.

This study used Cronbach's alpha to measure internal consistency because it is mostly used to measure internal consistency (‘reliability’). Cronbach's alpha determines the internal consistency or the average correlation of items in a survey finding to gauge its reliability. Cronbach's alpha is used when multiple Likert questions in a questionnaire-survey form a scale to determine if the scale is reliable. Cronbach's alpha test is one of the most popular reliability statistics in use (Cronbach, 1951). This is acknowledged by Kothari (2009), who argues that one of the most generally used and recognised reliability coefficients is Cronbach’s alpha. Alpha is based on the internal consistency of a test, which is interpreted as a correlation coefficient; it ranges in value from 0–1. Therefore, some survey data in this study was taken to measure the internal consistency of the data (Cronbach’s alpha). The reliability of the 5-point Likert scale used in the questionnaire-survey was also examined using Cronbach’s alpha test (see Table 5.5). More discussions on reliability/Cronbach’s alpha is seen in Chapter 6.

5.9.4 Factor analysis

Factor analysis is a statistical method used to define variability between observed correlated variables regarding a potentially lower number of unobserved variables called factors. Factor analysis is described as a multivariate analytical technique for examining the underlying structure or the structure of interrelationships (or correlations) among a large number of variables (Cattell, 1952; Gorsuch, 1983). Child (2006) defines factor analysis as a collection of methods used to examine how underlying constructs influence responses to the variables measured. This analysis yields a set of factors or underlying dimensions which, when interpreted, describes the data in a miserly but more meaningful number of concepts than the original individual variables (Glynn *et al.*, 2009). In the absence of any standard lists of material selection criteria, there was a considerable risk of the analysis regarding responses yielding diverse results. Thus, in establishing the list of criteria, it was essential to ensure that the requirements are of adequate relevance and independence. Therefore, the research employed factor analysis in the current study.

However, DeCoster (1998) states that there are two types of factor analysis: (a) exploratory; and (b) confirmatory. Exploratory factor analysis (EFA) is a technique within factor analysis, for which the predominant goal is to identify the underlying relationships between measured variables (Norris and Lecavalier, 2009). While confirmatory factor analysis (CFA) is used to test whether measures of a construct/concept are consistent with a researcher's understanding of the nature of that construct or factor (Li, 2016). Principal component analysis (PCA) is a more straightforward version of exploratory factor analysis (EFA) developed at the start of high-speed computers (Child, 2006; Polit and Beck, 2012). Hence, the research employed PCA using SPSS. Chapter 6 has more discussions on factor analysis.

5.9.5 Pearson correlation

Karl Pearson developed the Pearson correlation from a related idea introduced by Francis Galton in the 1880s (Stigler, 1989). Pearson correlation was used in this study to measure the level of relationship of variables from the respondents. In statistics, the Pearson correlation coefficient (PCC) is also referred to as the Pearson's r and the Pearson Product-moment Correlation Coefficient (PPMCC) or bivariate correlation (KSUL, 2017). Pearson's correlation coefficient, when applied to a population, is usually symbolised by the Greek letter ρ (rho) and may be referred to as the population correlation coefficient or the population Pearson correlation coefficient (Stigler, 1989). However, when applied to a sample is usually symbolised by the letter r and may be referred to as the sample correlation coefficient or the sample Pearson correlation coefficient. Pearson's correlation coefficient is the covariance of the two variables divided by the product of their standard deviations. It has a value between +1 and −1, where 1 is a total positive linear correlation, 0 is no linear correlation, and −1 is total negative linear correlation (Stigler, 1989; Pallant, 2010). It is widely used in data analysis. More discussion on the Pearson correlation can be seen in Chapter 6.

5.10 Data collection process for multiple case study

This research adopted multiple case study research strategy to help in delivering research aim and objectives and answering research questions (see 5.3.4.2). To achieve Objectives 5, 6, 7, 8, 9, 10, 11, and 12, a multiple-case study approach was employed when collecting data. The multiple-case studies were achieved using semi-structured interviews with key stakeholders from selected construction organisations based on the literature, but mostly from the survey findings. Twelve organisations represented the multiple case studies used for the inquiry. Hence, it was essential in assisting the researcher in identifying what knowledge means to the individual stakeholders and key stakeholders, the most important or critical barriers and enablers to the uptake retrofit projects, the decision-making issues, the need for retrofit building process and framework, in the embarking on, uptake, and delivery of retrofit projects.

However, semi-structured interview discussions are highlighted in Section 5.3.2.2**.** The choice of the semi-structured interview is valued for its accommodation to a range of research goals, which typically reflects variations in its use of questions, prompts and accompanying resources to draw the participants or interviewees wholly into the study topic (Galletta, 2013). Moreover, a semi-structured interview was used because of its ability to explore in-depth questions with the interviewees. This approach availed the interviewer/researcher the opportunity to pursue the interview in greater depths with flexibility while the interview remains conversational (interactive) (Wilson, 2014). This enabled the researcher to ensure that the same information is obtained from a different number of participants, hence, allowing logical gaps in the collected data to be closed easily (Longhurst, 2009).

Furthermore, Nonaka *et al*. (1996) and Smith (2001) argue that the idea of using semi-structured interviews is because knowledge in organisations can exist as both tacit (existing practical, action-oriented or ‘know-how’ based on practice, acquired by individual experience rarely) and explicit knowledge (dealing with an academic document or ‘know-what’ described in a formal language often based on established work process documented by individuals experience rarely expressed openly). Hence, both tacit and explicit knowledge was acquired in this study. This helped in analysing the data, assisted in developing the decision support framework, and created some recommendations. Figure 5.7 highlights steps employed in achieving multiple case studies.

5.10.1 Steps used in performing multiple case study

The research used the three steps below to accomplish the data collection through multiple case study:

- ***Defining and designing:*** identifying the case study aim, the rationale for choosing the target organisations and the methods for carrying out the case studies;
- ***Preparing, collecting, and reporting:*** involves preparing for conducting the case studies which include selecting population and sample size, performing the first case study and writing the individual case report, and carrying on the same process to the end; and
- ***Analysing and concluding*:** this involves interpreting the results, drawing cross-case conclusions, and writing a cross-case report.

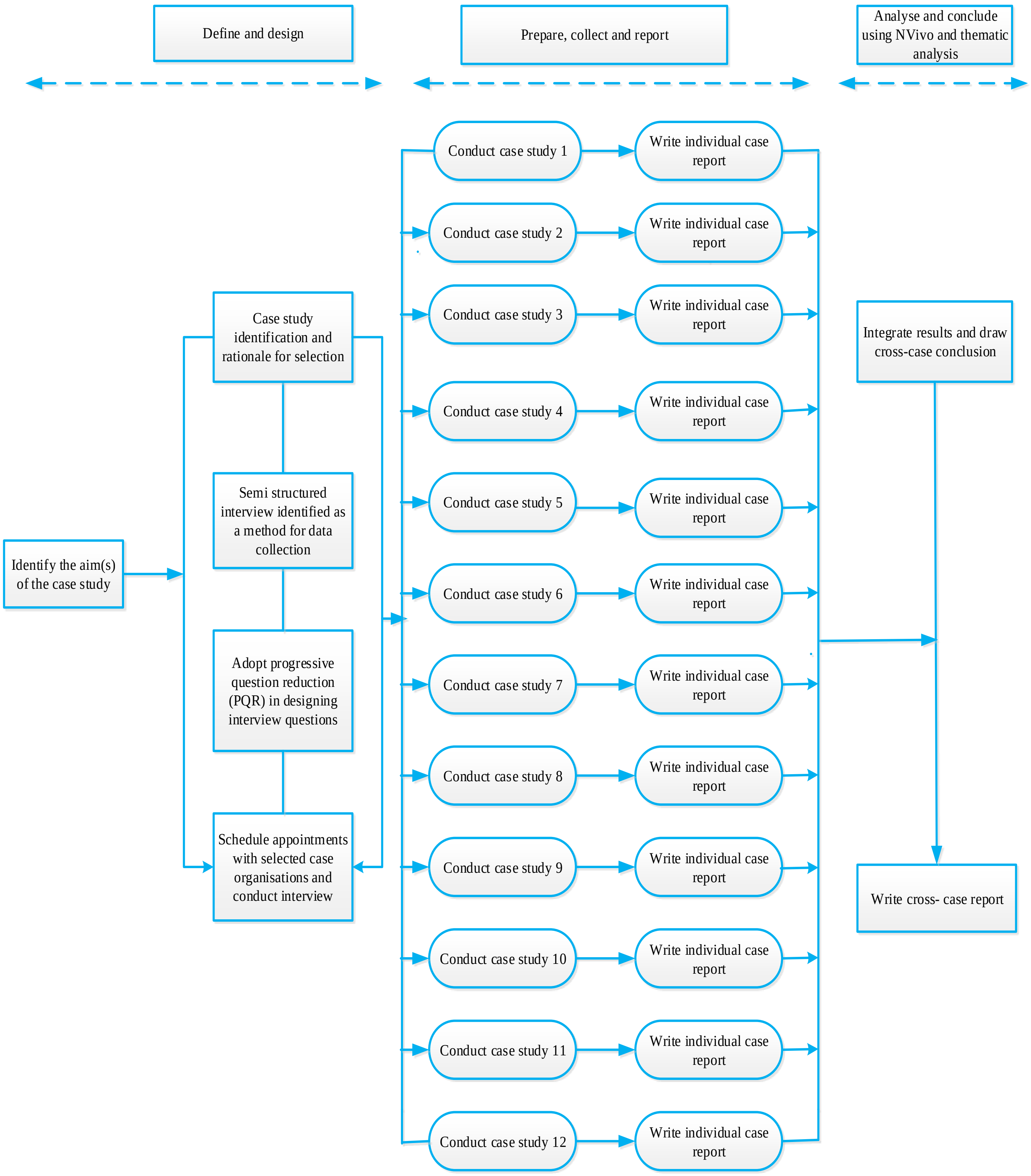


Figure 5.7 Defined steps for multiple case studies (Adapted from Yin, 2009)

Figure 5.7 highlights the defined steps employed in multiple-case studies. The research adapted from Yin (2009) because of its simplicity and clarity in conducting semi-structured interviews. The ensuing section offers detailed discussions in Figure 5.7.

5.10.2 Step 1: Defining and designing

This step identified the gaps that exist after the survey outcome. Taking into cognisance the questions that emerged from the survey was necessary, for example, some respondents asked the researcher to find out through interviews the risks involved in the delivery of retrofit projects, and themes that emerged from survey results all contributed to the design of questions for the conduction of multiple case studies. The step also considered the questions that could not be answered in-depth using the survey, for example, knowledge management (KM) questions. The terms used in KM questions were not adequately understood while completing the survey and survey respondents were not able to answer questions in detail due to time constraints.

Progressive Question Reduction (PQRS) (see Figure 5.6 and Section 5.5.2.) was employed to guide the researcher on the steps needed to present the questions. These were considered in designing the semi-structured interview questions. The flexibility and interaction involved in the semi-structured interview were also considered in designing the interview questions. Hence, the study did not employ a pilot study before the actual case investigation/data collection, because semi-structured interviews avail the researcher t flexibility in asking questions (Yin, 2009); it also provides more interactive sessions for the interviewer and the interviewees to understand the sentences used; hence, the ambiguity of questions or words will not pose a challenge.

5.10.3 Step 2: Preparing and conducting the multiple-case studies

The documented contacts the researcher maintained in relation to participants and the responses received from the survey informed the researcher’s decision in targeting relevant participants for the interviews. However, 20 top executives of small, medium and large construction organisations and academics involved in sustainable retrofitted building projects, with a reasonable amount of years of experience, were contacted for the interview. From the stated number, the researcher was able to interview 12 participants who provided their availabilities. Two of the interviewees were engaged in face-to-face interviews since it was most acceptable and convenient for them. Out of the two, one was an academic and the other a director of a medium construction company. Another two key stakeholders were interviewed through phone calls while the remaining eight key stakeholders were interviewed using Skype video calls (see Chapter 7 for the background of the interviewees).

The research employed a voice recorder during the interviews to capture the information and avoid the loss of data. All the recorded interview conversations were then transcribed manually. Initial reports were produced to describe the case and its context based on the collected data. The reports mainly concentrated on demonstrating how the target organisations view knowledge management and how they have managed project knowledge and its influence on decision-making. It also highlighted critical barriers and enablers to embark upon, uptake, and deliver the retrofit projects.

5.10.4 Step 3: Analysis of the multiple-case study findings and conclude

The twelve initial multiple-case study reports were organised with NVivo a computer-assisted qualitative data analysis software (CAQDAS), analysed, and interpreted further using thematic/qualitative content analysis. Zamawe (2015) states that CAQDAS are data management packages (NVivo included) that support researchers during analysis. However, expanding further, Zamawe (2015) affirms that the key message is that unlike statistical software, the main task of CAQDAS is not to analyse data, but assists in the data analysis process, of which the researcher must always remain in control. NVivo was used in the organisation of the transcribed documents, for example, coding was used to form themes that set an acceptable pattern that was utilised in further analysing the results. In other words, researchers must equally know that no software can comprehensively analyse qualitative data. Hence, the research employed qualitative content analysis. In the qualitative content analysis, the task of the researcher is to identify and categorise some themes that adequately reflect their textual data (Howitt and Cramer, 2007).

To adequately reflect the required level of analysis, the texts (transcribed from the interview conversations) and documentation (collected from the interviewees) were thoroughly read to generalise the main themes discovered in the texts and coding, which were interpreted to deliver the research aim, objectives and questions. Herein, themes are referred to as units resulting from patterns such as conversation topics, vocabulary, recurring activities, meanings, feelings or folk sayings, and proverbs (Bogdan and Taylor, 1989).

Themes that emerged from the coding were further analysed, interpreted, and integrated to form a comprehensive picture of interviewees collective experience/views (Aronson, 1994; Guest *et al*., 2012). The analysed results contributed to the development of a decision support framework. The analysis of the findings from the multiple-case study is presented in Chapter 7. Accordingly, the preceding sections of this chapter have detailed rationale underpinning the rationale for choosing qualitative content analysis and NVivo for qualitative data analysis.

5.10.4.1 Rationale for choosing thematic/qualitative content analysis (QCA)

The aim of selecting QCA is to establish the correct reflection and interpretation of the findings. Interpretation of data is necessary to unravel an under-lying coherence or sense' in a text, which is, in some ways, 'confused, incomplete, cloudy, or seemingly contradictory' (Langhelle, 1999). Examination of literature on research methods discloses a variation of approaches available to analyse textual data for the above purpose. These include methods such as content analysis, semiotics, deconstruction, and hermeneutics. The selection of an appropriate analysis method depends on the type of text to be analysed, and the purpose of conducting the analysis. Hence, this stage suggests an approach that could analyse data appropriately with the intents and goals of the investigation. This entails searching for themes from textual data is achievable through content analysis.

Qualitative content analysis (QCA) is defined as a research method for the subjective interpretation of the content of text data through organised classification process of coding in order to identify patterns or themes (Bradley, 1993). QCA is a research tool or technique for 'making replicable and valid inferences from data to their context' (Krippendorff, 1980). It is a highly flexible research method that could be used to analyse a wide range of unstructured information, such as words, meanings, pictures, symbols, ideas, and themes or any message that could be connected through written, visual, or spoken form (Neuman, 2006; Bryman, 2008). It is also an unambiguous research method as the coding scheme can be set out to enable replication and follow-up studies.

QCA could be conducted as a quantitative or qualitative study using an inductive or deductive process (Elo and Kyngas, 2008). In quantitative content analysis ‘objective and systematic counting and recording processes’ are used to produce numerical descriptions of the content within a text (Neuman, 2006). This procedure of quantitative content analysis is viewed regularly as a method for ‘quantitative analysis of qualitative data’ (Morgan 1993 cited Hsieh and Shannon, 2005). In contrast, ‘understanding’ the investigated issues with the key stakeholders requires a ‘retrospective’ approach (Hsieh and Shannon, 2005). Additionally, QCA involves allowing categories or themes to emerge from the examination of the findings and assuming an inductive (qualitative) approach to analyse the data.

An inductive procedure entails ‘drawing generalisable inferences out of observations (Bryman, 2008). This is accomplished using QCA. However, the coding system is an essential part of data analysis in QCA. The ‘coding system’ is defined as a set of rules on how to systematically observe and record content from the text (Neuman, 2006). David and Sutton (2004) emphasise that coding is the ‘single most significant act’ in the process of qualitative analysis of texts. Coding allows the identification of themes within the data to be analysed and can be used to develop concepts, theories or ideas. The latter is achieved through a ‘recursive and reflexive’ movement between data coding, analysis-interpretation, concept development (Bryman, 2008), and integration of findings. Accordingly, Neuman (2006) observes that, instead of a clerical data management task, qualitative coding is an integral part of data analysis. In this context, coding aims to attain two objectives: mechanical data reduction and analytic categorisation (Neuman, 2006, 2014).

To achieve the coding, the research employed NVivo a Computer-Assisted Qualitative Data Analysis Software (CAQDAS). The ensuing section discusses the rationale for the use of NVivo to support qualitative content analysis.

5.10.4.2 Rationale for using NVivo to support qualitative content analysis

To support QCA particularly with regards to the efficiency of the collected data and data organisations, NVivo was employed. NVivo is supportive in managing large amounts of data available for qualitative researchers providing a methodological framework (Blismas and Dainty, 2003). Dainty *et al*. (2000) observed three ways the use of computer software in qualitative content analysis can improve the research process by: (a) Assisting in data management; (b) providing the facility code and retrieve all data on a particular topic; and (c) bringing the researcher closer to simultaneous study of phenomena, both extensively and intensively, by using large sets of data. The NVivo indeed reduces a significant number of manual tasks and avails the researcher more time to discover tendencies, recognise themes, and derive conclusions (Wong, 2008).

Moreover, using CAQDAS essentially guarantees that the user is working systematically, meticulously, and assiduously (Bazeley, 2007). This study is aware of the possible disadvantages of using CAQDAS to analyse qualitative data as discussed by Atherton and Elsmore (2007). The main reason for using NVivo is to manage large volumes of data (about 220,000 words) from 12 semi-structured interviews, reduce the level of manual work, support work effectiveness, data organisation (Atherton and Elsmore, 2007; Silverman, 2009), provide the facility code, and retrieve all data. Kvale (2007) notes that CAQDAS assists in the analysis of interview transcripts by organising or structuring them for advanced analysis. However, the task and responsibility for the interpretation remain with the researcher. This study shares the point of view that CAQDAS is not a substitute for researchers' responsibility of interpreting and making sense from complex data, hence, interpretation responsibilities remain with the researcher (Weitzman and Miles, 1995; Atherton and Elsmore, 2007; Kvale, 2007; Easterby-Smith *et al*., 2008). Therefore, after achieving the coding process, the researcher further analysed the coding making consistent themes and meaningful interpretations.

5.10.4.3 Audit trail employed in using NVivo

An audit trail in qualitative research is described as a record and ongoing process of transcribing, documenting, emerging thinking, and decisions made while developing the patterns, codes, and themes initial to the final interpretation of the data (King, 2007, 2012; Miles *et al.*, 2014). Miles *et al.* (2014) argue that without an audit trail, the researcher could not determine the dependability or the confirmability of the findings (see Section 5.9). This practice is relevant in assisting researchers to have an overview of how data interpretations were accomplished (King, 2007). An audit trail was realised through saving of template or pattern files by serial numbering and putting dates on versions of NVivo, hence, assisting in keeping records of the changes made while coding and themes are generated in a journal log. Figure 5.8 deduces the steps employed using NVivo.

5.10.4.4 Steps employed in using NVivo

Step 1: Start a project: A project was created in NVivo and was assigned a name to remind the researcher; after that, the project was saved in the computer.

Step 2: Transcription document: Having created a project on a computer and given it a name, the next step was to import or upload the transcribed documents into the project under internal sources.

Step 3: Work with nodes: From the internal sources, nodes were created. The function of nodes is to store a place in NVivo for references to code text. A node is described as a collection of references about a precise theme of importance. Hence, references are congregated or grouped by coding the interview transcripts (Bazeley, 2007).

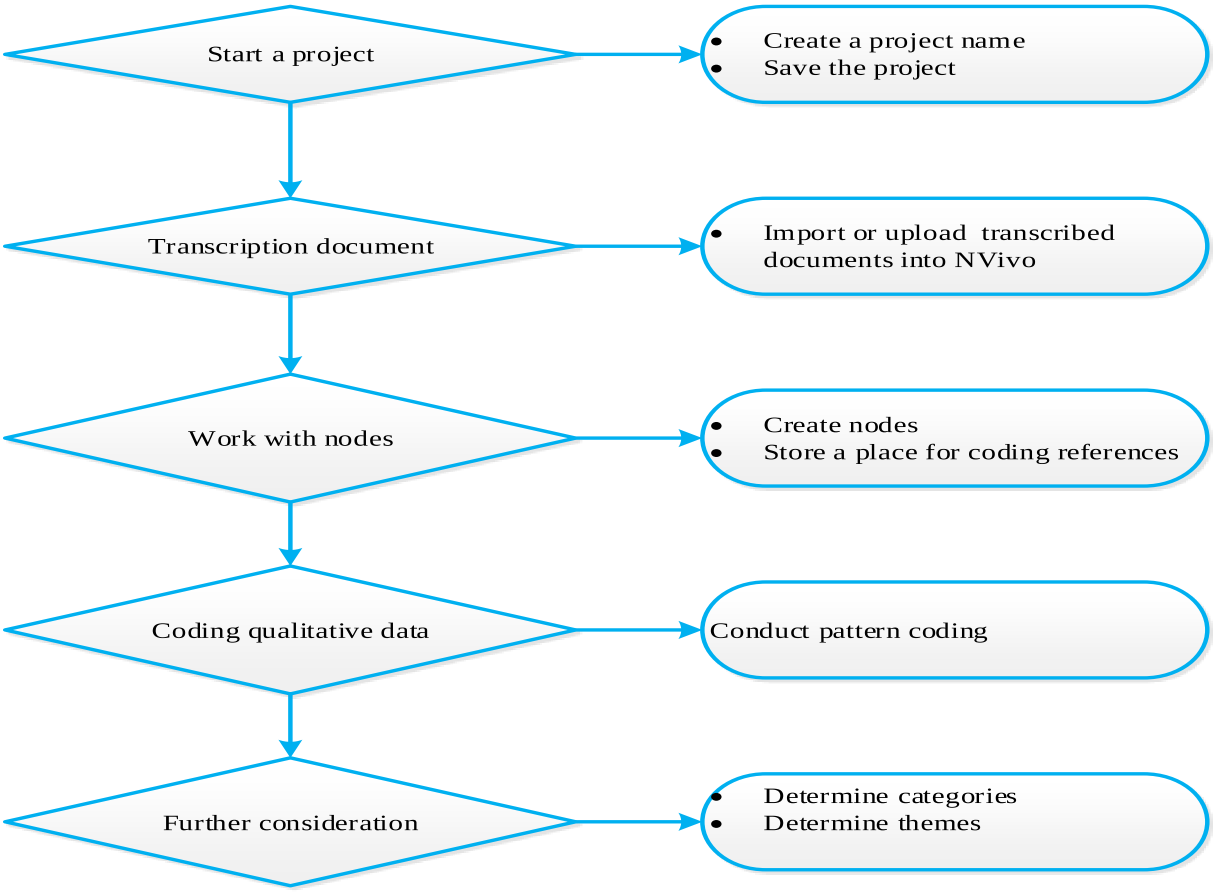


Figure 5. 8 Steps employed in using NVivo

Step 4: Coding qualitative data: Coding involves trailing related words or phrases mentioned by the interviewees. Thus, these words or phrases are combined to realise the connection between them (Adu, 2013, Saldana, 2013). Data analysis progressed by coding the full set of interview transcripts, coding one interview transcript after the other in serial numbering (Interviewees 1–12). The pattern code was in the coding process because it can group summaries into a smaller number of categories, themes, or constructs (Miles *et al*., 2014). Pattern codes can be exploratory or inferential and are capable of identifying emergent themes, configurations, or explanations (Miles *et al*., 2014). Miles *et al*. (2014) identify the usefulness of pattern codes, which are: (a) they summarise a large amount of data; (b) they help the researcher elaborate a cognitive map, which integrates the data; and (c) they assist in multiple case studies by laying groundwork for cross-case analysis by surfacing common themes and directional processes. In the sequence of this procedure, initial coding was generated in an array of individual codes that involve a precoding stage. The precoding stage was applied using the 'Query' command in NVivo. The query command was used to know the kind of words that the interviewees used more and how it was used. Hence, the ‘Word Frequency’ was opened after the query result was displayed as a ‘Word cloud’ (see Figure 5.9) with different words depicting the number of times, those words were used.

Figure 5. 9 NVivo output: Word cloud depicting the frequency of the used words in the interview

The Word cloud availed the researcher the opportunity to understand how a specific word or phrase was used by interviewees in their responses. The bolder the word, the more it was used or mentioned in the interviews. Subsequently, the first coding patterns developed and new themes emerged; new nodes were added, merged, and renamed continuously. Nodes are referred to as containers for the coding to collect associated items in one place looking for emerging patterns and concepts. The coding started after nodes were created, as mentioned previously.

The coding procedure included hierarchical and parallel coding (King, 2012). Hierarchical coding clusters compose or groups similar codes to produce more common higher-order codes. Coding also documents as many stages of themes as deemed useful (Hilal and Alabri, 2013). Multiple or parallel coding was used where the same segments of text can be coded within two or more different codes (King, 2007; Hilal and Alabri, 2013). Multiple coding was used on those occasions in which more than one theme or sub-theme was acknowledged in a context, and it was deemed useful to code this section of text to more than one node. By the end of the coding process, about 407 themes and codes (nodes) were produced. After finalising the coding to the full set of interview transcripts, the pattern and its nodes were reviewed by examining the coding arrangement and excluding the overlapping nodes. Additionally, the pattern arrangements were adjusted one more time by going through each of the 407 nodes and observing whether the coded text fits in the node. Figure 5.10 highlights coding similarities, which assisted the research in generalising the result. The colour text, as highlighted in Figure 5.10, indicates or suggests how closely related the interview responses were.

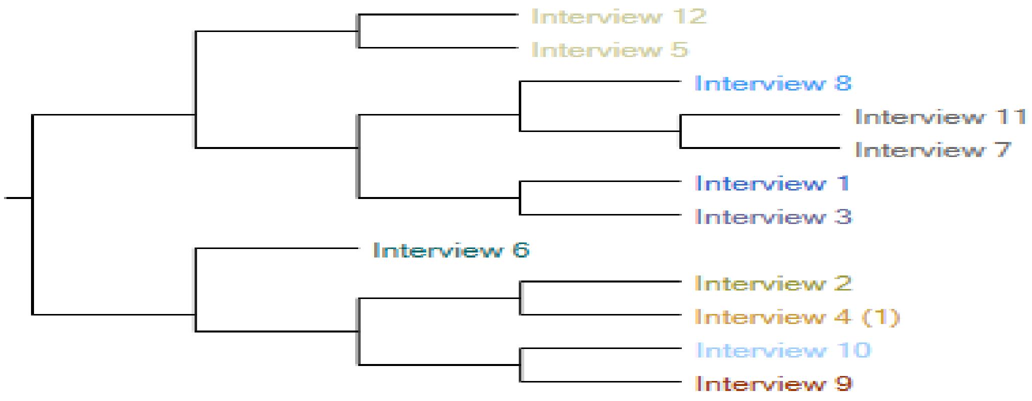


Figure 5. 10 NVivo output: clustered by the coding similarity of the interviewees

Step 5: Further consideration: At this stage, the findings (coded text) in each node was summarised. The summary was achieved by merging the findings from respective nodes into the new structure. However, the summarised findings do not represent the end of the data analysis and interpretation procedure. Thus, it is referred to as a flat explanation of the data (King, 2012). Based on the summarised findings via coding, the starting point for in-depth analysis was considered a structure that offers an opportunity to analyse coded text at different levels of specificity (King, 2012; Hilal and Alabri, 2013). Hence, qualitative content analysis avails the opportunity for in-depth analysis since the data organisation has been achieved through coding. In this study, numbers in the pattern (number of interviews coded per node and how often they are referenced) is not the rationale or a factor for analysing and interpreting the data. These numbers are distorted as parallel/multiple, and no distinct coding was used. Thus, the coded text might ‘appear’ in several nodes (Neuendorf, 2002).

In contrast to content analysis, the approach taken in this study is not interested in the quantitative aspects of the interviewees’ accounts. Instead, the study is more interested in the emphasis, intensity, and significance of what the interviewees communicated within the context of the investigation. This means that the number of accounts in one node is not the dominating criteria for assigning importance to several findings. It just infers an indication for a closer examination of significant themes or sub-themes. Therefore, the analysis requires comprehensive reading, understanding, and interpreting the coded texts and themes, which were were considered. The coded texts and generated themes were analysed in-depth (see Chapter 7).

5.11 Establishing the trustworthiness, quality and validity of case study findings

Validity, reliability, and objectivity are criteria used to appraise the quality of research. Lincoln and Guba (1985) suggest four criteria for evaluating interpretive research work to establish the trustworthiness and validity of the research findings, including credibility, transferability, dependability, and confirmability.

Ascertaining the ***credibility*** of the document analysis process ensures the ‘truth-value’ of the research results. Credibility ascertains the extent to which the research results are reflective of reality (Shenton, 2004; Miles *et al*., 2014). This corresponds to the research criteria of ‘internal validity’. Yin’s (2009) study emphasises the significance of adopting ‘correct operational measures’ throughout the research process to improve the credibility of the research findings. In this research, credibility of the research process was established by clearly stating and justifying the transcription process (see Section 7.3.4), the use of NVivo and how the coding process was conducted including audit trail. Keeping audit trails (see Section 5.10.4.3) and providing rich explanations of phenomena were useful in establishing the credibility criteria. These improve the credibility of the research by enabling the research question to be addressed in a more productive manner (Graneheim and Lundman, 2004). Furthermore, peer scrutiny of the research project has been stated to be a way of establishing credibility (Shenton, 2004). Four doctoral students listened to the recorded audio version of the research findings. Hence, a peer-review was achieved. They confirmed increased knowledge of retrofitting issues and knowledge management.

In achieving ***dependability***, which ascertains the accuracy of the coding exercise, this corresponds to the positivist research criteria of ‘reliability’. The issue of dependability is to ascertain the data do not change over time; hence, avoiding disparities that could occur in the researcher’s decisions during the analysis process (Graneheim and Lundman, 2004). The dependability of the research findings was established after the transcript documents were sent to the participants, who agreed that it reflected their views. Thus, there was no possibility of data changing over time. Therefore, data was revisited regularly throughout the coding process to minimise variations during analysis, and the generated coding categories were checked continuously for their consistency (i.e. regarding internal homogeneity and external heterogeneity). According to Miles *et al*. (2014), indicating the credibility of research, as mentioned, assists in establishing the dependability of research.

Transferability ascertains the extent to which the findings of qualitative research can be generalised or transferred to other contexts. This study used semi-structured interview to collect data in a recorded audio format, which was subsequently transcribed. Hence, the research findings were well documented and traceable (Prior, 2008) to the interviewees, thus transferability was established. Moreover, clear explanations of the background of the multiple-case studies (see section 7.3.2) illustrate the context of the study (Shenton, 2004). Additionally, providing rich descriptions of how the case organisations were selected assisted in establishing the transferability of the research.

Confirmability co-relates to the quantitative research criteria of objectivity. In the context of qualitative research, ascertaining the conformability of research results requires the researcher to ensure that the findings are reflective of the ideas of the informants (in this case, transcribed data) rather than the views and experiences of the researcher (Shenton, 2004). The research established confirmability when the transcribed documents were sent to the interviewees to ascertain whether it reflects their intentions and feelings, for which their feedback agreed with the transcription (see Section 7.3.4). In addition, recognising the predispositions of the researcher has been stated as serving as a key criterion for demonstrating conformability (Miles and Huberman, 1994a).

5.12 Development of sustainable retrofit building process and decision support framework

After the analysis of both the questionnaire survey and multiple case studies findings, the next step was to develop sustainable retrofitted building process as stated in the research design (see Figure 5.4). The research achieved the development of the retrofit building process by integrating the results from the literature reviews and mixed-method research findings (see Chapter 8). The development of the retrofit process preceded the development of SRBDSF (see Figure 5.4), which is the aim of the research. To develop the decision support framework, the retrofit building process assisted in developing the framework particularly in suggesting the framework layout. Additionally, the analyses of the industry survey and the multiple-case studies were examined and integrated to generalise themes. Furthermore, an inclusive literature on the current available approaches, which incorporate necessary tools and technologies (e.g. search engines, sustainable technology options, decision framework and models etc.) relevant to the study, contributed to the framework development that elucidates knowledge in assisting key stakeholders in making enhanced decision towards the uptake, embarking upon, and delivery of sustainable retrofitted building projects. Chapter 8 has more details on SRBDSF development while Figure 5.11 deduces the main themes that contribute to the framework development. The SRBDSF delivered Objective 8.

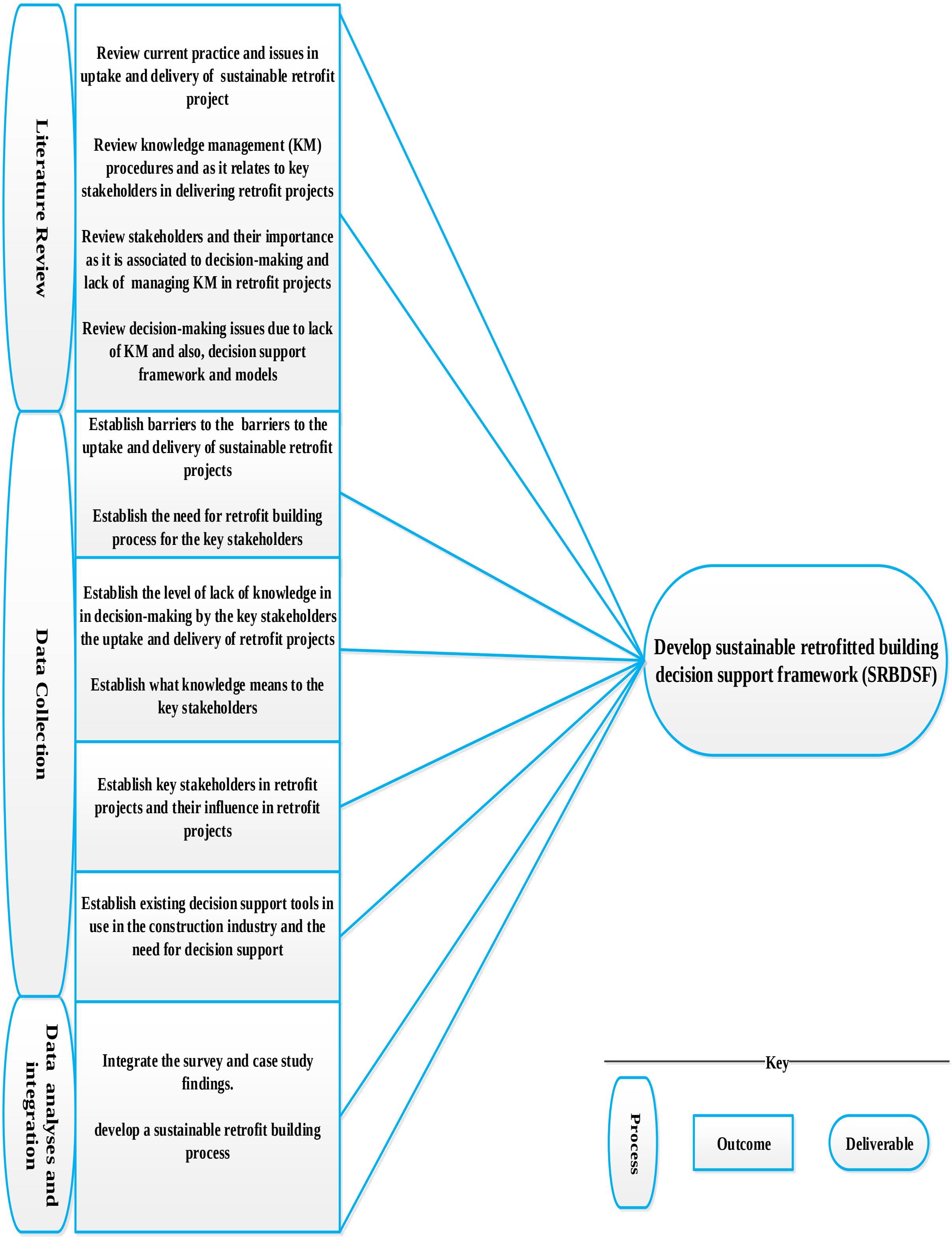


Figure 5. 11 Contributors to the development of sustainable retrofitted building decision support framework (SRBDSF)

5.13 Validation and Recommendations

After the sustainable retrofitted building decision support framework was developed, the next step was to reach out to the key stakeholders in the industry to validate the framework according to research design (see Figure 5.4). Key stakeholders validated the SRBDF establishing that it is fit for purpose and stating that it will encourage the adoption of knowledge management in the delivery of the retrofit project. They also reviewed the framework and gave feedback for its improvement. The research made some recommendations in line with the research design (see Figure 5.4) to the key stakeholders on the uptake, embarking upon, and delivery of sustainable retrofitted building projects. Notably, the recommendations stressed on the need to use knowledge management process in overcoming critical barriers to delivering of retrofitted building projects by the key stakeholders.

5.14 Ethical considerations

The research needed primary data collection from the industry key stakeholders/practitioners involved in sustainable retrofit projects. Hence, some ethical standards were put in place. The nature of this study involves interactions and obtaining of information from respondents. Thus, the researcher is required to address the potential ethical issues that might arise from the study (Bryman *et al*., 2007; Kvale and Brinkmann, 2009; Silverman, 2009). The primary data collection and other professional research practices were undertaken according to the research ethics code as specified by the Research Ethics and Governance Handbook (Northumbria University, 2009–2010). No physically challenged, disadvantaged, or minors participated in the interviews and data was kept by the data protection act of 1998. Towards the end of 2015, the University Research Ethics Committee approved the ethical dimension of this research.

Prior permission was given to the researcher by the interviewees to record and transcribe the interviews (Silverman, 2006). The anonymity of the interviewees was guaranteed. Reasons to keep the interviewees anonymised include the fact that transcripts will be used for further data analysis, for example, journal publications. The interview recordings were documented, while the transcripts and narrative analyses were all coded upon evaluation; the names of the participants were held separately on a personal computer (password protected) of the researcher at the University. Therefore, interview data is secured and available to the researcher.

5.15 Chapter summary

This chapter outlines the methodology of the current research. The research 'onion' process was adopted to guide the researcher on the steps needed to deliver the research aim and objectives and to answer the research questions. The research 'onion' steps include the investigation of research philosophies, approaches, strategies, techniques, and procedures. The investigations set a solid theoretical foundation for the methodological considerations and research design. Research philosophical considerations of the current research were justified to guide the thought of the logic flow of the researcher in the selection of research approaches, strategies and data collection methods, and the overall research design. The choice of a mixed-method research approach combined both the quantitative (survey) and qualitative (case study) data collection is defined and justified in this chapter. The survey strategy was chosen to address the breadth of the investigation, and the case study strategy was identified to achieve its depth. In addition, the qualitative strand (the case study research method) includes the selection criteria for cases, criticisms of the case study, and steps taken in achieving the case study. The validity and reliability of the research were discussed in this chapter. The survey findings were statistically analysed using SPSS while NVivo and qualitative content analysis were employed to analyse multi-case study findings. The next chapter presents the results of the survey, analysis, and discussions, while Chapter 7 presents multiple-case studies findings, analysis, and discussions.

CHAPTER SIX: SURVEY: DATA ANALYSIS, PRESENTATION AND DISCUSSION

6.1 Introduction

This research employed a questionnaire survey to collect data on issues in sustainable retrofit projects that include barriers and drivers; key stakeholders; knowledge management and decision-making challenges. Detailed information on the design of the questionnaire, answered research questions and sampling of the organisations are presented in Chapter 5. The questions contained in the questionnaire survey were informed by the review of the literature reported in Chapters 2, 3 and 4. This chapter presents the results and analyses of the responses to individual questions as it relates to uptake and delivery of sustainable retrofitted building projects. The collected data were analysed using Statistical Package for Social Science (SPSS): descriptive statistics; mean score; reliability test; factor analysis and Pearson correlation. Microsoft Excel was also employed as regards the graphical representation of the analysis. The analysed data were summarised and presented in tables with frequency distribution and percentages (among others). This was aimed at giving a clear and concise illustration of each of the variables and the associations between them. Correspondingly, efforts were made to discuss and relate the results achieved with previous studies, and a summary of these findings was itemised in line with the study objectives and research questions. Furthermore, this analysis is undertaken to contribute to the development of a sustainable retrofit building process, and decision support framework with knowledge management approaches.

6.2 Demographic data of respondents and analysis

This section considered the background information of survey respondents. The respondents were asked to identify the type of organisation; job titles; professional background; years of experience; the size of their regular clients; the age of organisation; organisation annual turnover and the kinds of sustainable construction project they engage with.

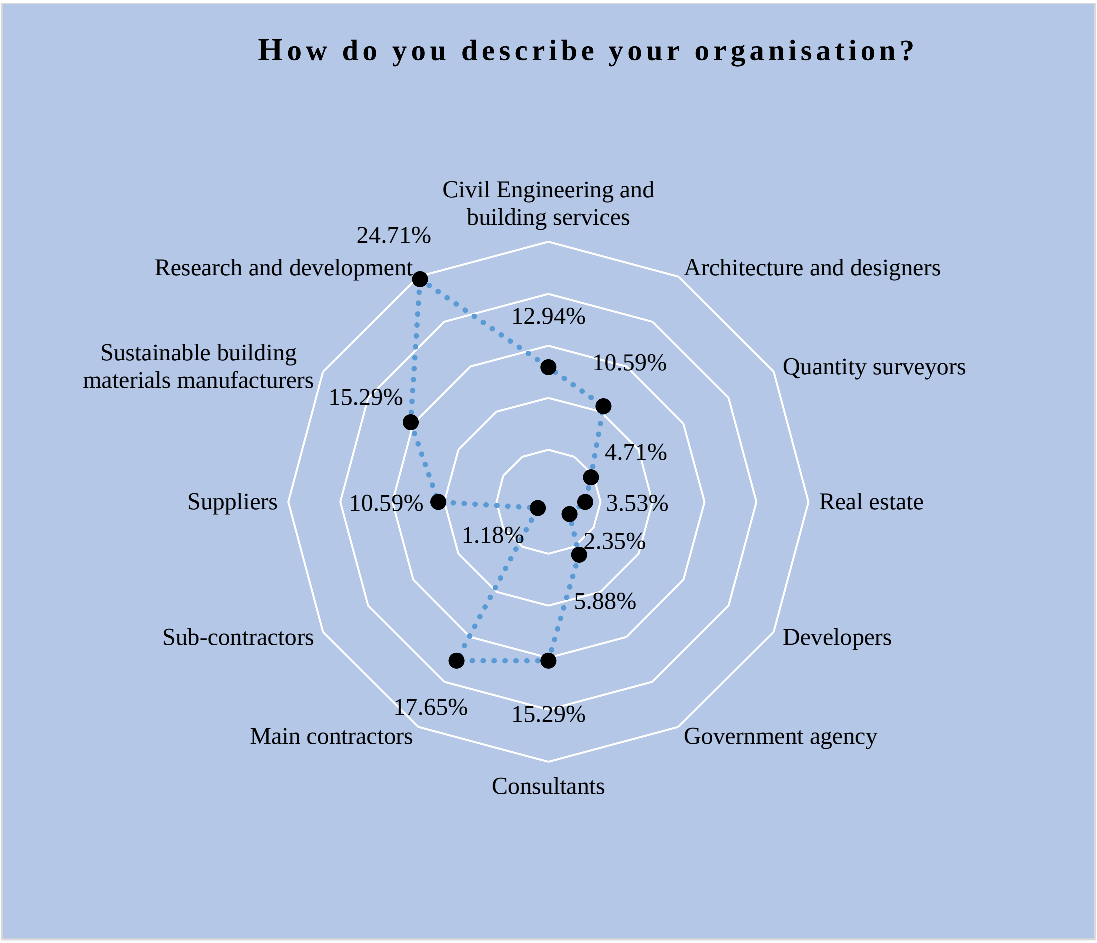


Figure 6. 1 Distribution of respondents by organisation description

Figure 6.1 shows that the different organisational disciplines in the construction industry were well represented. However, the result shows that 15.29% (14) of the respondents were sustainable building materials manufacturers and they represent the highest number of respondents. This is followed by main contractors, representing 15.12% (13) of the respondents.

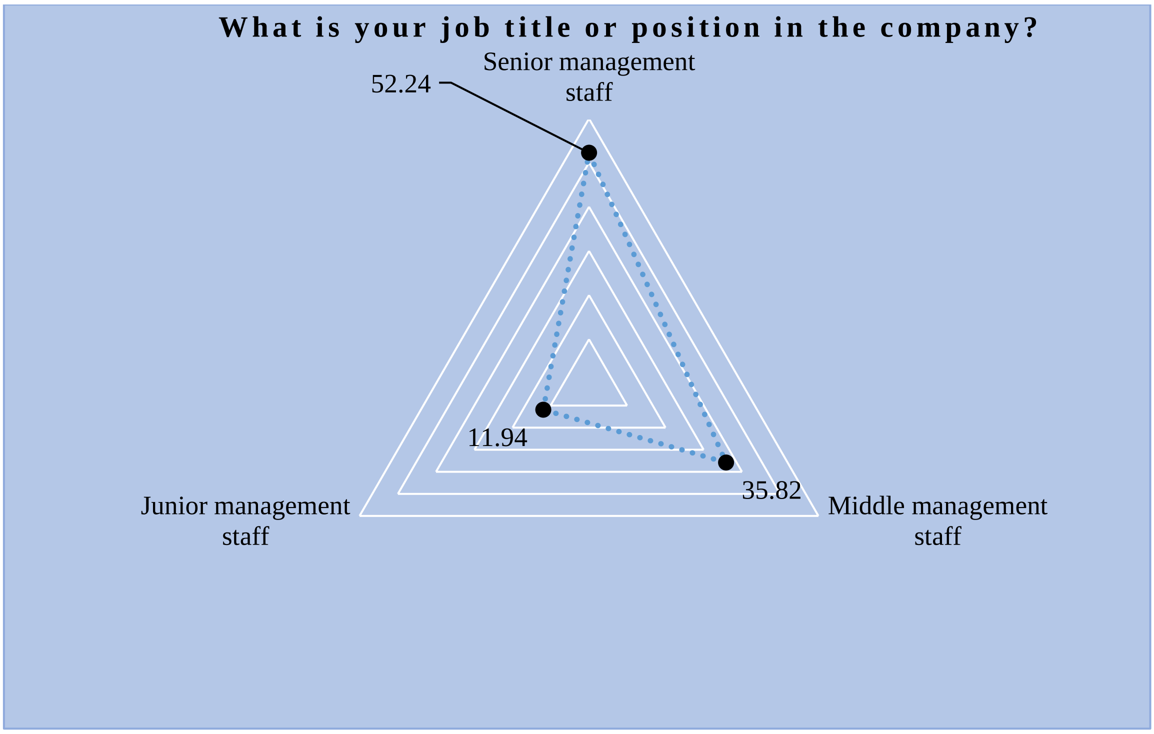


Figure 6. 2 Distribution of respondents by job title

From Figure 6.2 it is evident that senior management accounts for 58.14% (50) of the respondents. This is followed by middle management, which accounts for 31.40%, while the junior management category is 10.47%. The amount of senior management staff involvement underpins the significance of the industry survey.

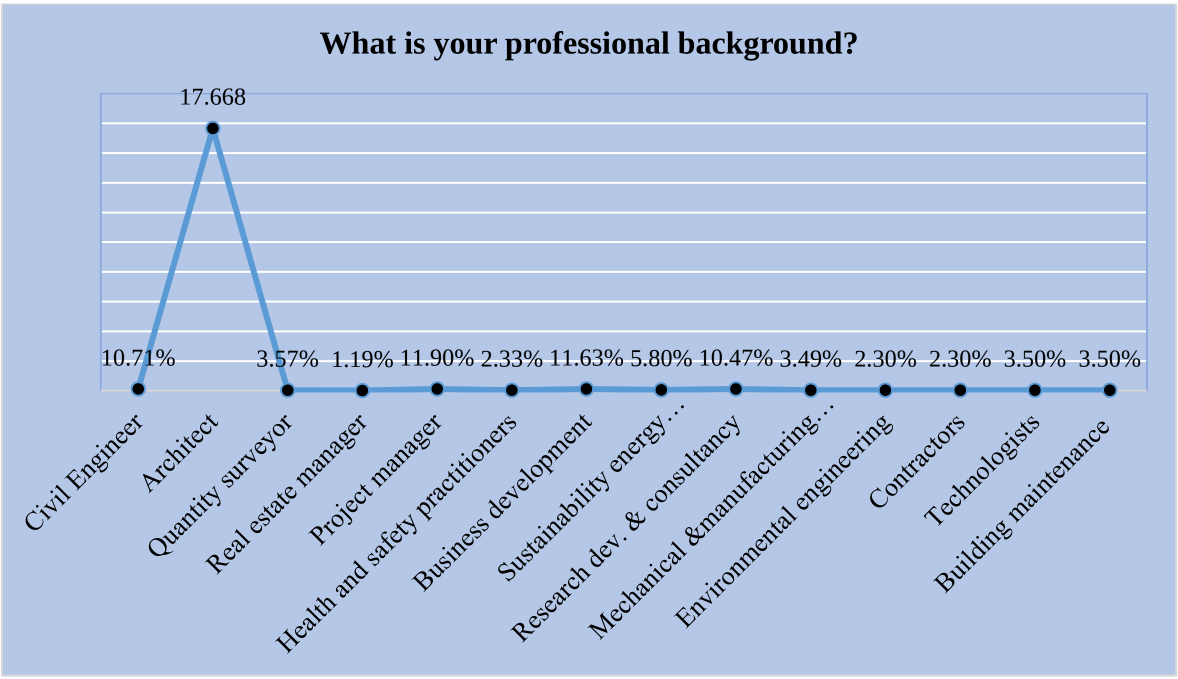


Figure 6. 3 Distribution of respondents by their profession

Figure 6.3 highlights the professional backgrounds of the stakeholders and illustrates that all relevant stakeholders are well represented. Architects have the highest number of respondents which accounts for 23.26%, followed by civil engineers (12.79%).

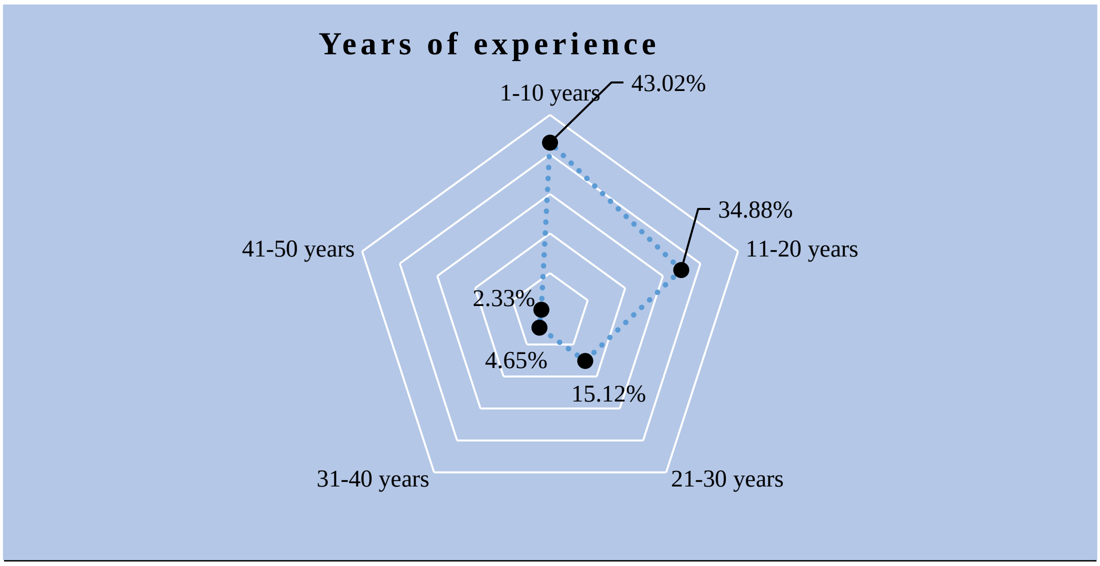


Figure 6. 4 Distribution of respondents by years of experience

It was important that this study had respondents who had gained a good number of years of experience in their respective fields in construction. Figure 6.4 illustrates the years of experience of the respondents and most (43.02%) have between 1–10 years’ experience while 34.88% have 11–20 years of experience in the construction industry.

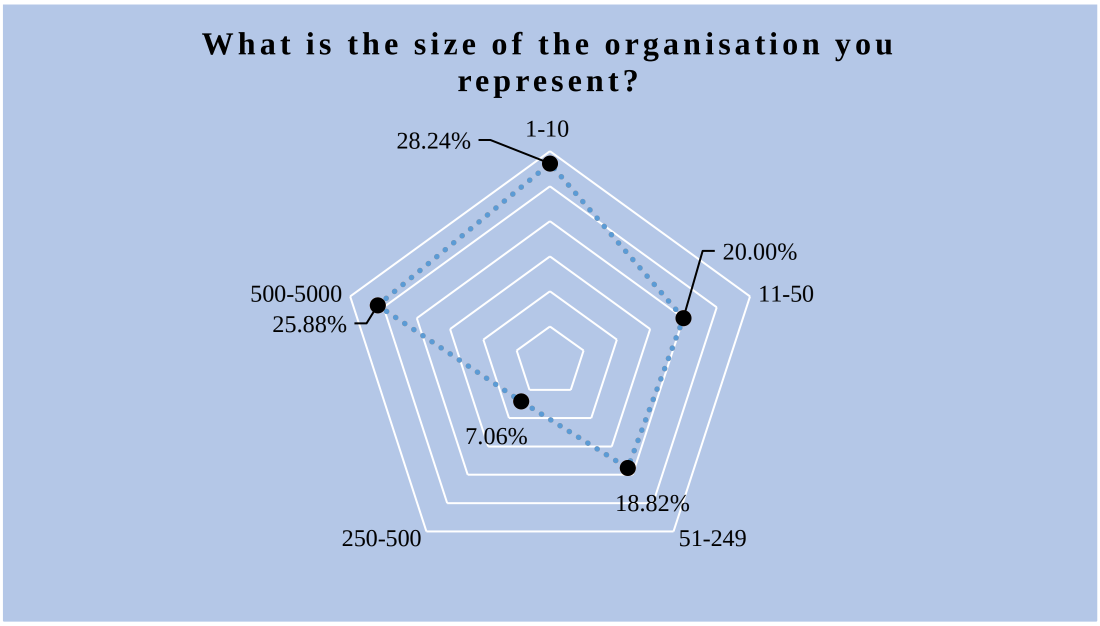


Figure 6. 5 Distribution of respondents by the size of the organisation

Figure 6.5 illustrates the number of employees of the respondents' organisations. Of these, 29.07% have 1–10 employees, and these represent the highest number of respondents followed by companies with 501–1,000 employees and above, representing 24.42% of the respondents.

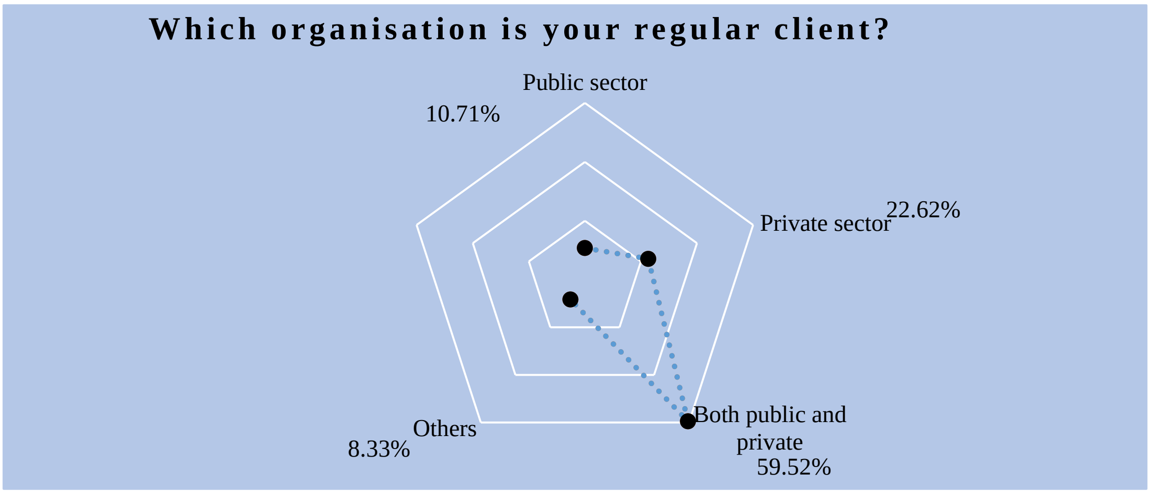


Figure 6. 6 Distribution of respondents based on organisations' regular clients

Figure 6.6 shows that most of the respondents' organisations (65.12%) work for clients in both the public and private sectors. Very few have a public-only or private-only client base. Experience with both sectors was a positive feature of the respondents' suitability for the survey.

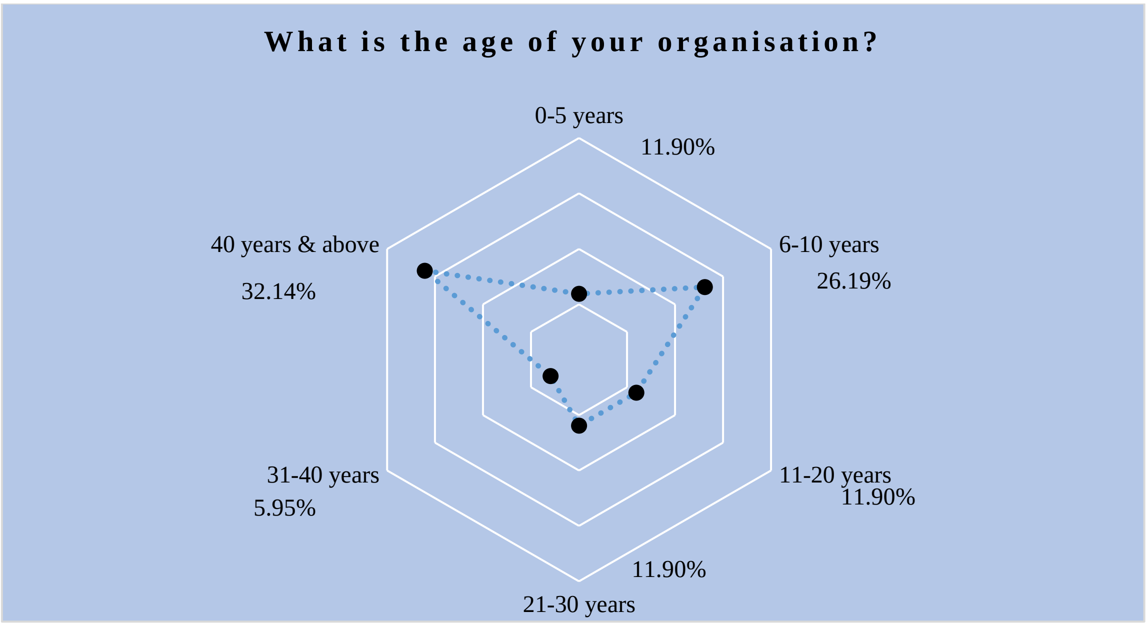


Figure 6. 7 Distribution of respondents based on age of the organisation

Figure 6.7 represents the age of organisations. The result highlights the fact that the majority of respondents worked in construction organisations with an age range of 40 years and above.

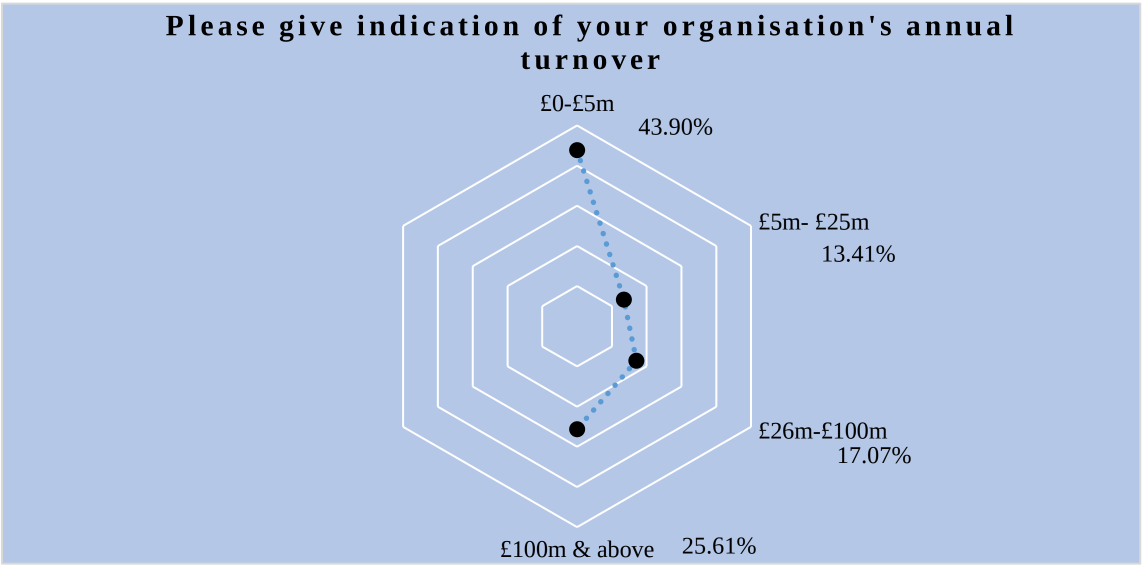


Figure 6. 8 Distribution of respondents based on organisations' annual turnover

Figure 6.8 illustrates the annual turnover of the participants' organisations. This figure shows that the respondents from small construction organisations have the highest number of representation because they account for 39.53% (34) of respondents with an annual turnover of about £0–£5 million. However, participants from bigger companies account for 20.93% of the entire respondents with an annual turnover of approximately £100 million and above.

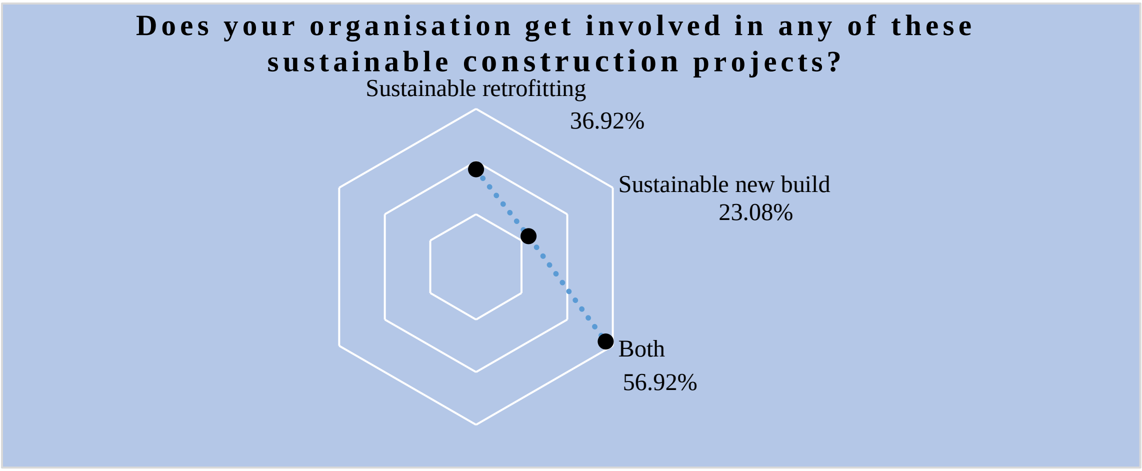


Figure 6. 9 Respondents' organisations involved in sustainable construction

Figure 6.9 reveals that the majority (67.44%) of the participants are from organisations that engage in both sustainable retrofit projects and new build, and this is important for the reliability of the data. In addition, 23.26% of respondents came from organisations that engage only in sustainable retrofitted building projects while 9.30% participate only in the new build.

6. 3 Data analysis based on sustainable construction, particularly sustainable retrofitted building projects

6.3.1 Reliability test

Respondents were asked to respond to the comment using a five-point Likert scale ranging from 1 (Strongly Agree) to 5 (Strongly Disagree). Reliability test refers to the consistency of a research study or measuring test. According to Tavakol and Dennick (2011), a reliability test looks at the degree to which an assessment tool produces stable and consistent results. If findings from the research are consistently replicated, they are reliable. They further stated that research would not be considered reliable if there is no consistency in the measurement of scales. Reliability for this study was measured in a variety of ways that include Cronbach's alpha coefficients (measurement of internal consistency) and inter-item correlation matrix (correlations between an item and the remaining items in the measure).

This research employed Cronbach's alpha to measure internal consistency because that is what it is mostly used for in a reliability test. Cronbach's alpha determines the internal consistency or the average correlation of items in a survey finding to measure its reliability. Tavakol and Dennick (2011) revealed that Cronbach's alpha is a measure of internal consistency; that is, how closely related a set of items are as a group. Internal consistency describes the extent to which all the items in a test measure the same concept or construct and hence, it is associated with the inter-relatedness of the items within the test as aforementioned in Section 5.9.3. Cronbach's alpha is used when multiple Likert questions in a questionnaire survey form a scale to determine if the scale is reliable. Further discussion on reliability test and Cronbach alpha are in Section 5.9.3.

However, the criteria used in establishing the level of internal consistency in research are summarised in Table 6.1. The choice of reliability test is similar to studies that were conducted in construction management using reliability test notably Cronbach's alpha. The following are examples carried out reliability tests. Yang and Peng (2008) carried out a reliability test in the development of a customer-satisfaction evaluation model for construction project management using Cronbach's alpha. Alinaitwe et al. (2013) investigated the causes of delays and cost overruns in Uganda's public sector construction projects using Cronbach's alpha. Lingard *et al*. (2009) examined the group-level safety climate in the Australian construction industry, as well as the within-group homogeneity and between-group differences in road construction and maintenance using Cronbach's alpha. Li *et al.* (2012) researched the homogeneity of transaction-related issues and construction project performance using Cronbach's alpha. Table 6.1 highlights the internal consistency criteria using Cronbach's alpha.

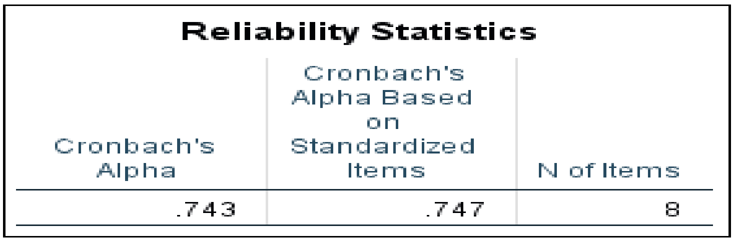
Table 6. 1 Internal consistency criteria using Cronbach's alpha

Reliability statistics	**Criteria for a good scale**
Cronbach's alpha (α)	Greater than or equal to .70
The range of inter-item correlation	Between .150 and .85
Average inter-item correlation	Between .15 and .50
The range of corrected item-scale correlation	Greater than or equal to .50

Adapted from BrckaLorenz *et al.* (2013)

Tables 6.2, 6.3 and 6.4 illustrate that the number (N) of items or variables tested is eight. The satisfaction of reliability test is achieved when the measured items or variables have an internal consistency of 0.7 and above of Cronbach's alpha coefficient (Cronbach, 2004, Tavakol and Dennick, 2011, BrckaLorenz *et al.*, 2013, Pallant, 2016).

Table 6. 2 Cronbach's alpha value for economic benefits for sustainable construction

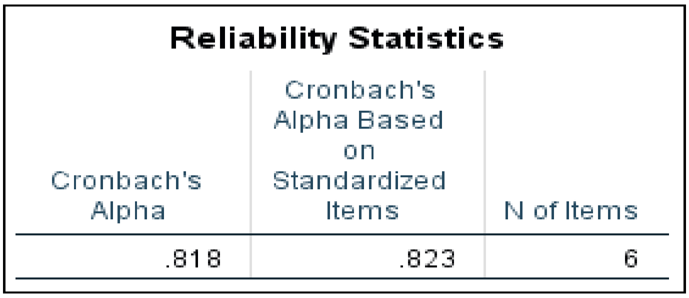


Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.743	.747	8

In the current study, the Cronbach alpha coefficients (α) was 0.74 for Figure 6.2, 0.819 for Figure 6.3 and 0.776 for Figure 6.4. These figures indicate an internal consistency within the respondents on the measured items because they measured the same underlying construct.

Table 6. 3 Cronbach's alpha value for social benefits for sustainable construction

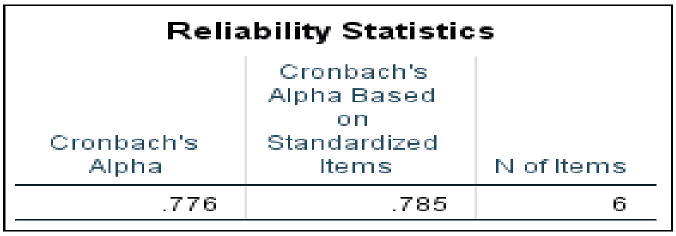


Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.818	.823	6

Table 6.3 indicates a high Cronbach's alpha coefficient of 0.818. This means there is a high level of internal consistency in the measured construct because it is higher than the .7 that is generally accepted.

Table 6. 4 Cronbach's alpha value for environmental benefits of sustainable construction



Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.776	.785	6

Table 6.4 highlights that there is a high internal reliability construct within the respondents, which are the key stakeholders. As previously explained, the Cronbach's alpha coefficient is 0.776, which is higher than the acceptable ratio of 0.70. Therefore, the reliability of the internal construct is satisfactory.

To further check for internal consistency of respondents and the relationship of the variable inter-item correlation matrix values for Appendices (C), (F) and (I) ascertains a good correlation amongst the measured variables. Hence, according to Pavot *et al*. (1991) and Pallant (2016) for correlation matrix any item less than r = 0.30 indicates that the question may not belong to the scale and in this case, the items belong to the range.

Appendices (D), (G) and (J) represent item-total statistics mainly 'if Cronbach's alpha is deleted' because this is the most important column in the table. Thus, it represents the scale of Cronbach's alpha reliability coefficient for internal consistency if the individual item is removed from the scale. Clark and Watson (1995) and Cronbach (2004) stated that this column infers that the Cronbach's alpha if deleted scores in the column should be less than the Cronbach's alpha reliability coefficient to make the questions reliable. However, if any of the scores are higher than the generated alpha coefficients, then that particular score(s) will be deleted to improve the alpha coefficient. In this case, the scores generated in Appendices (D), (G), (J) are all lower than the alpha coefficients in Figures 6.2, 6.3 and 6.4, hence, deletion of any item is not considered so all items are retained.

According to Pallant (2016), item statistics will be fairly similar if all the items are tapping into the same or similar scale. They further argued that any item that has scores that are a lot higher or lower than the others needs to be removed from the variables to make the scale reliable. Appendices B, E and H highlight that the scales are in the same sequence, hence, there is no need to remove any item, and this confirms again that there is strong reliability in the measured variables.

It is relevant to state that the internal reliability test has answered one of the research questions which is to ascertain how reliable the social, economic and environmental benefits of sustainable retrofitted buildings are.

6.3.2 Descriptive results analysis

One of the research questions was designed to ascertain who the key stakeholders are in the delivery of sustainable retrofitted building projects. The participants were asked to indicate from the selection provided which stakeholders they consider to be key stakeholders in sustainable retrofitted building projects. Figure 6.10 highlights the options provided for the participants to choose from and reveals that they are all key stakeholders in sustainable retrofit projects because each of the stakeholders enumerated in the options provided scored more than 50% as highlighted in Figure 6.10.

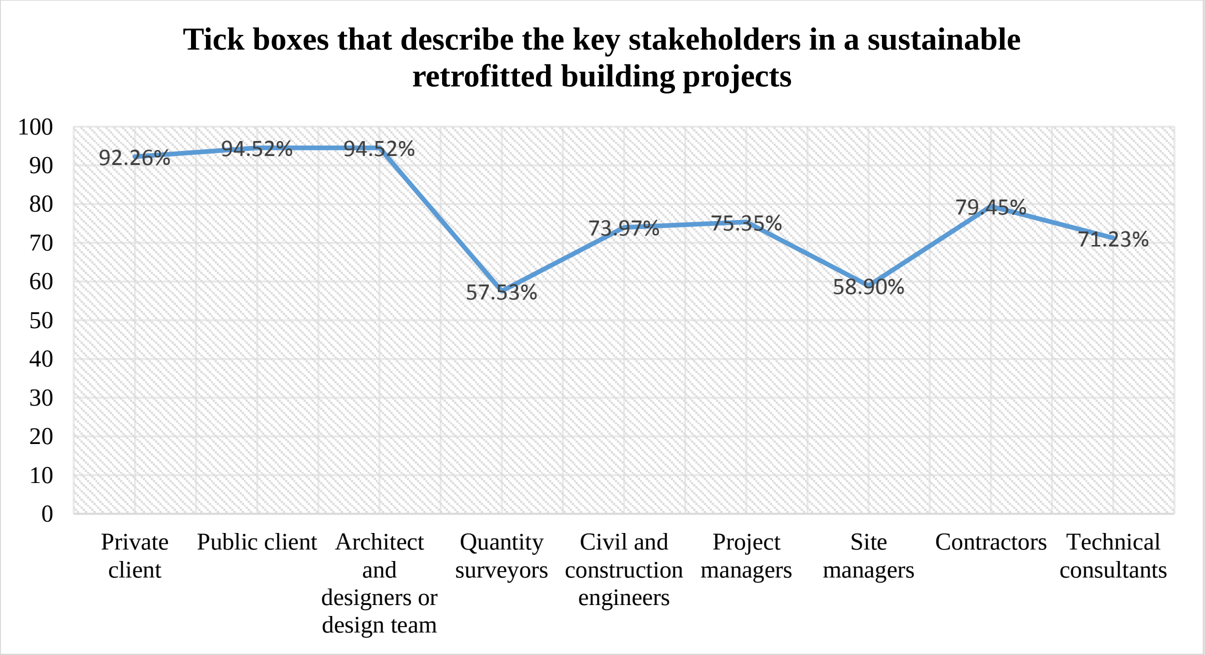


Figure 6. 10 Respondents' ranking and ascertaining of key stakeholders in sustainable retrofit projects

The respondents were given a chance in the survey to identify key stakeholders that were missing from the options provided to them. Thus, they identified residents, NGOs, building users, funding agencies, energy companies, low energy advisors and planners as more key stakeholders in the uptake and delivery of retrofit projects. This has answered one of the research questions that tend to identify key stakeholders in a sustainable retrofit project because of limited literature on the subject. Further details on key stakeholders in sustainable retrofit projects can be seen in Sections 4.2, 4.3 and 4.6. The result from this study is similar to studies such as those by

Kaklauskas *et al.* (2004); Olander and Landin (2008); Yudelson (2010b) and *Jin et al.* (2017a) on key stakeholders in sustainable construction.

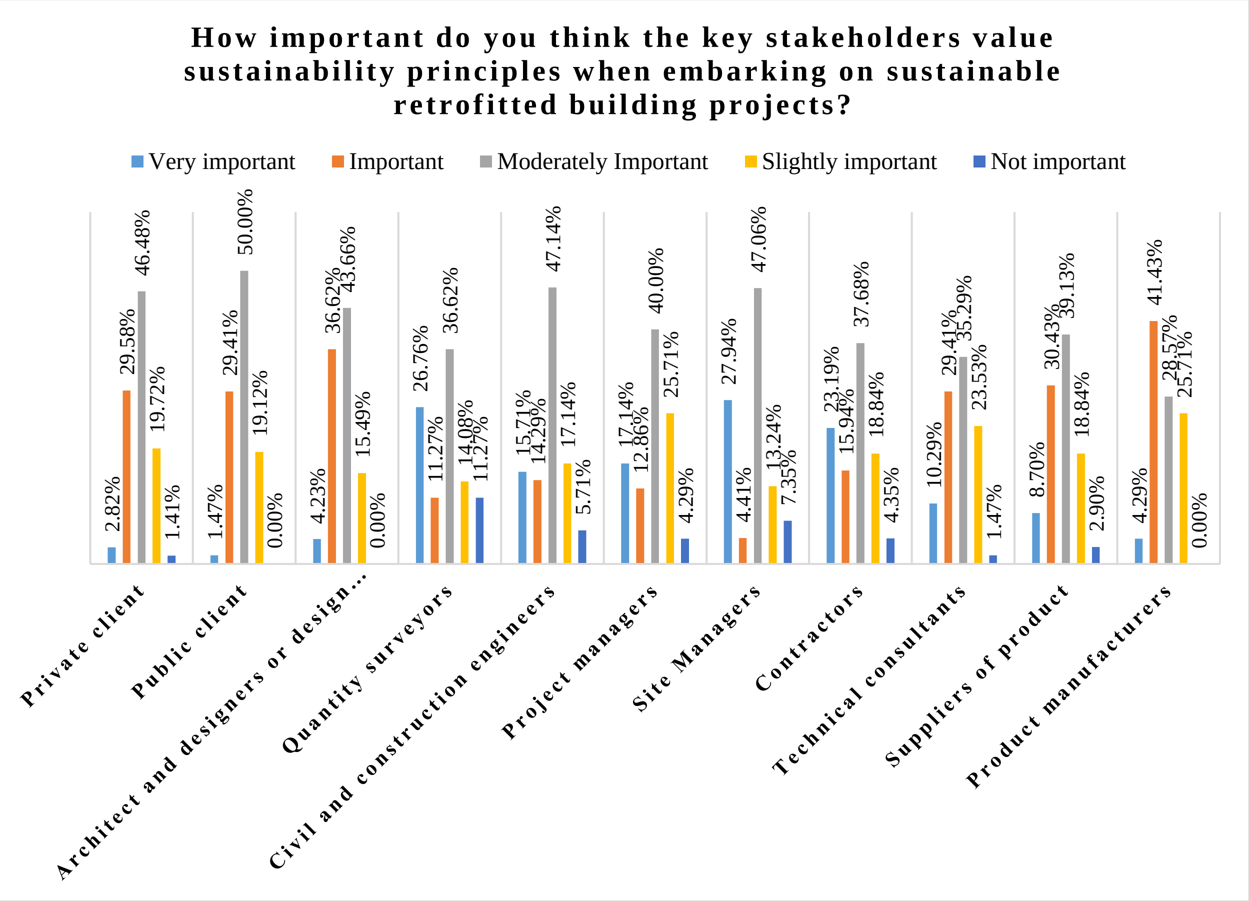


Figure 6. 11 Key stakeholders’ value of sustainable principles when embarking on sustainable retrofit projects

From Figure 6.11 it is evident that key stakeholders’ value for sustainability principles is moderately low when embarking on and delivering sustainable retrofitted building projects. Looking at Figure 6.11, the majority of the stakeholders voted *moderately important* more than any other rating. For a moderately low category/ranking, for example, public clients were rated highest (50.00%) followed by private clients (rated 46.48%) and thirdly architect and design teams (rated 43.66%) with the rest rated as shown in Figure 6.11. However, the ranking of *not important* was too low, followed by *very important* and *slightly important*. The findings deduce that stakeholders in the industry do not value as important the need to implement sustainable principles and practices when delivering retrofit projects. The attitude of the stakeholders needs to improve if the industry is to experience an increased uptake of sustainable retrofit projects. Figure 6.11 confirms that the industry is bad at promoting sustainable principles and practices in the construction industry, particularly sustainable retrofit projects. Hence, the studies of Abidin and Pasquire (2005) and Pitt *et al.* (2009) on economic principles argued that value management could help to reduce the environmental and social damage that will affect the industry economically while sustainable construction is being delivered. Relating to social principles, Wyatt *et al.* (2000), Shah (2007), Pitt *et al.* (2009) and Maduka1 *et al.* (2016) discussed the need for the industry to adopt social principles of sustainability in construction project activities. Finally, on environmental principles, Edwards (2002), RICS (2005a) and Pitt *et al.* (2007) emphasised the need for the industry to get committed and promote principles of sustainability, particularly in environmental issues in sustainable construction. Furthermore, this result has revealed that the industry does not improve, promote or value sustainable principles and its processes in sustainable construction, particularly the uptake and delivery of retrofit projects.

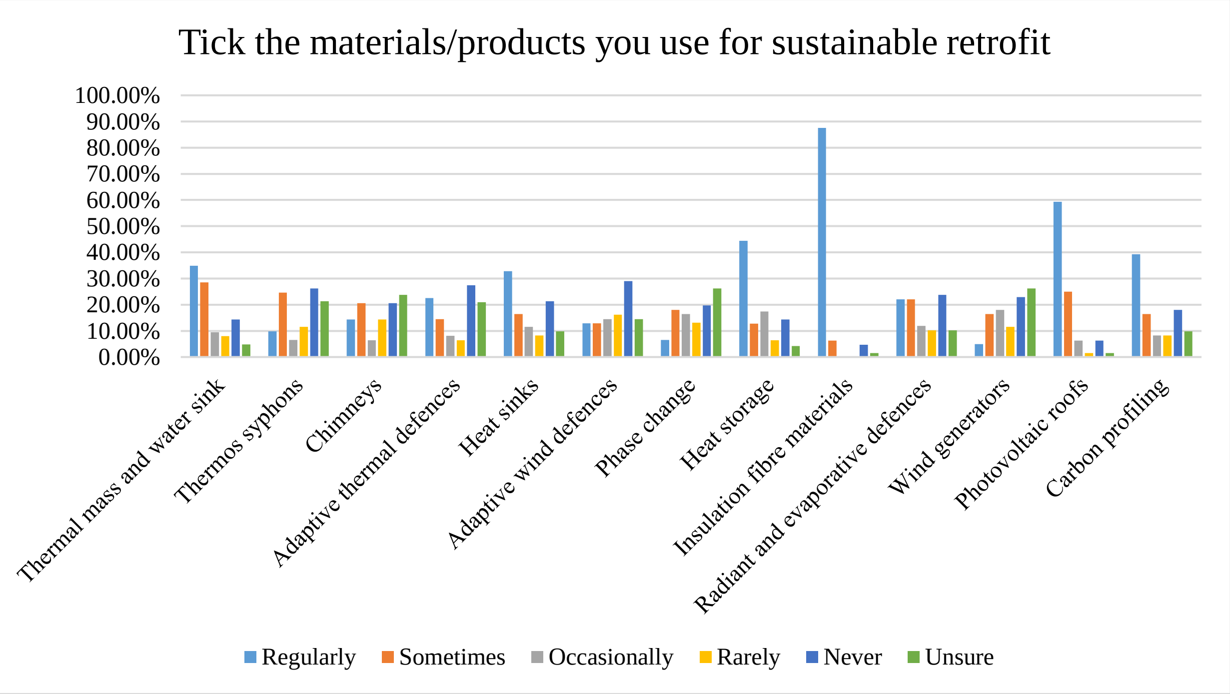


Figure 6. 12 Sustainable retrofitted building materials

The key stakeholders were asked to tick the materials they have used for sustainable retrofit building projects. The result highlighted in Figure 6.12 reveals the popularity of insulation fibre materials followed by photovoltaic roofs, carbon profiling, and thermal mass and water sinks. In the comment section of the survey, key stakeholders recommended the following materials for retrofit projects: mechanical ventilation heat recovery (MVHR) solar thermal heating, technology system integration and water sinks.

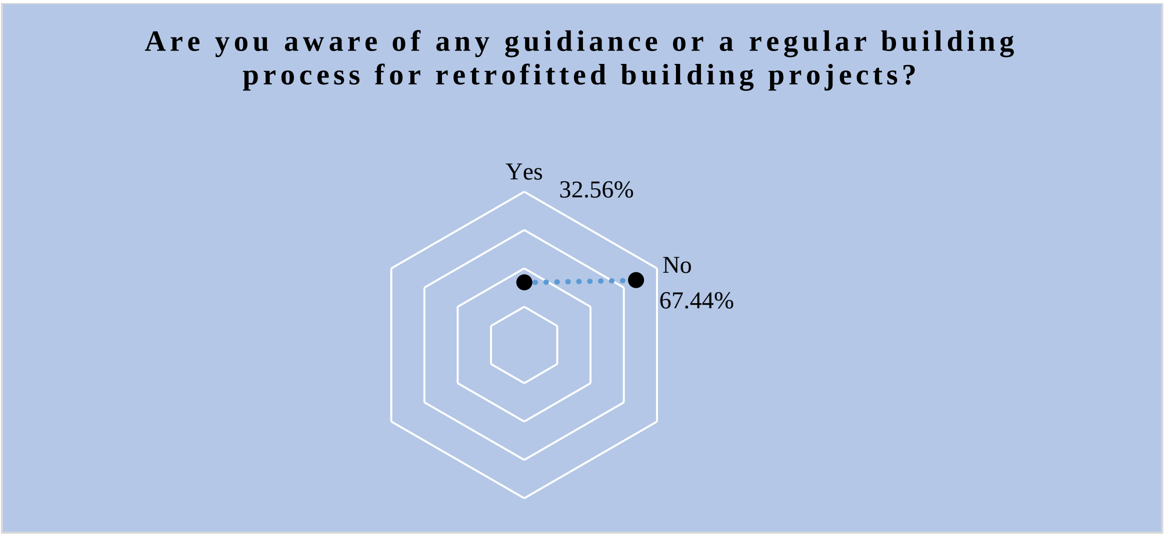


Figure 6. 13 Respondent distribution on awareness of guidance/process for the retrofit project

Figure 6.13 indicates that there is no particular building guidance or process in the industry as regards sustainable retrofitting. The result from the figure indicates that 67.44% of participants, which represents 58 out of 86, stated that they were not aware of any guidance available for delivering sustainable retrofit projects. Hence, this suggests the need for construction guidance or process for the uptake and delivery of sustainable retrofitted building projects. However, 32.56% of respondents, accounting for 28 in total, stated that they were aware. The option provided for them to report or name the guidance showed varied examples of guidance indicating the need for a general or standard process map/guidance for the uptake and delivery of retrofit projects. However, the recommended ones assisted in developing a retrofit building process for the industry.

The findings have demonstrated that the lack of a standard retrofit building process is one of the barriers to the uptake and delivery of sustainable retrofitted building projects. Hence, developing a uniform or standard retrofit building process for the construction industry in delivering retrofit building projects is one of the objectives of the current study. This is supported by a report by the Sustainable Traditional

Buildings Alliance (STBA) (2015) which stated that there is an increasing indication that the retrofit of traditional buildings (and indeed all buildings) over the past few years has not contributed to the expected reductions in energy use due to low interest from key stakeholders in embarking on the projects. They further stated that lack of building guidance has contributed to the low interest. They pointed out three disadvantages of not have sustainable retrofit guidance, which include: incorrect standards and assessment of traditional buildings; a single or narrow focus approach to both risks and retrofit measures; disjointed and poor quality building process.

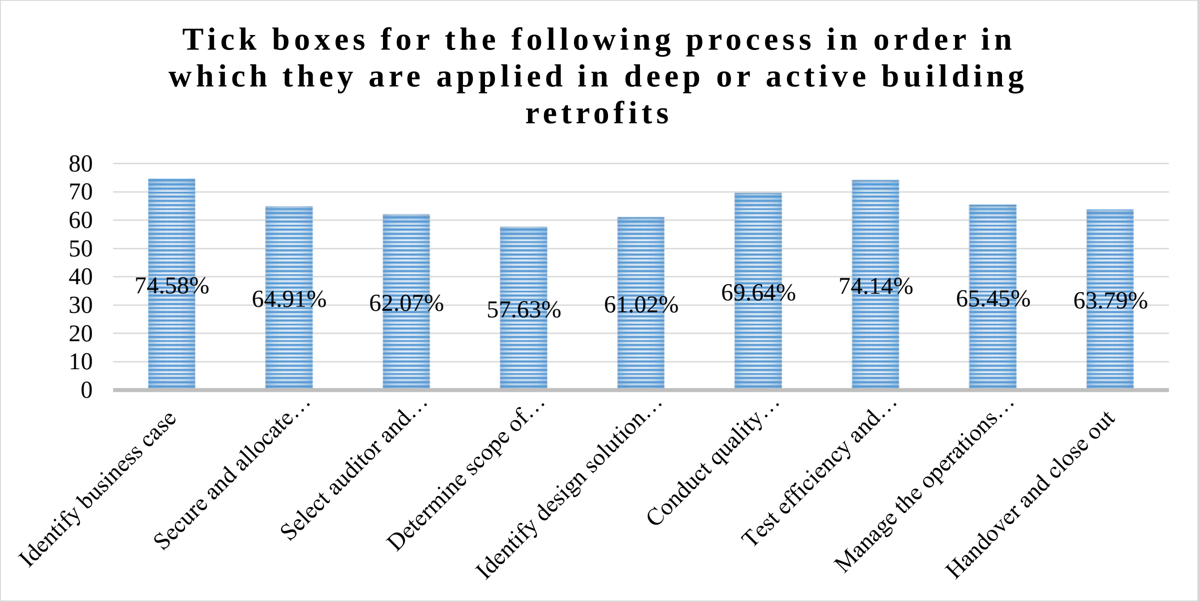


Figure 6. 14 Retrofit process order of application

Figure 6.14 has assisted the research in identifying a building process that can be developed and possibly adopted by the industry when it comes to embarking on and delivering sustainable retrofitted building projects. The respondents' answers indicate through the percentages available in Figure 6.14 the process that will be applied or followed when delivering a sustainable retrofitted building process. However, the respondents were given an option to state any process missing in the provided options and the following are the missing processes they mentioned: giving feedback to stakeholders and the wider market; selecting manufacturers of low-energy building materials; assessing lifestyle impacts; advocating higher standards of regulations and value engineering to test efficiency of the retrofitted building before handing over. These suggestions assisted the researcher in developing a retrofit building process.

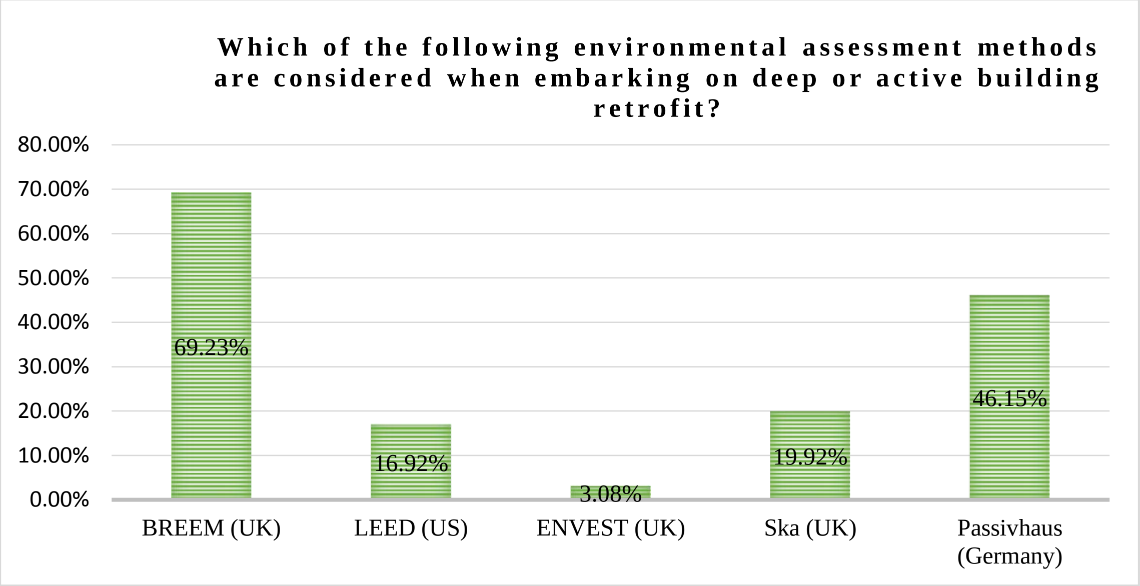


Figure 6. 15 Environmental assessment methods considered while delivering sustainable retrofit projects

Environmental assessment methods as discussed in Section 2.9.4 have been identified as relevant in general construction for environmental improvement. The importance of environmental assessment methods has been supported by Deakin and Reid (2014) and Dixon (2015) who in their studies affirmed that environmental assessment methods were designed to improve the environmental performance of a building project. However, the participants were asked to determine if the methods could be applied in sustainable retrofitted building projects. From Figure 6.15 the results indicated that BREEAM, a UK environmental assessment method, is relevant in sustainable retrofitted building project delivery.

Passivhaus is a German-originated environmental assessment method that is vital in the industry in delivering sustainable retrofit projects. The remaining environmental methods are not as popular or relevant. These tools can be used to measure the construction/fit out and retrofit of a residential or commercial property by judging some factors including health and wellbeing and energy and waste. This is supported by Dixon (2015) who stated that environmental assessment works by providing a building with a score based on its performance against eight sections. Those sections include: energy and water use; the health and well-being of inhabitants; pollution;

transportation issues; materials; waste and ecology; management processes and also matching them to established standards. Furthermore, the result will be relevant in developing a sustainable building process in this study.

6.4 Factor analysis

Factor analysis was carried out to determine the factors of barriers and enablers embarking, uptake and delivery of sustainable retrofitted building projects. The relative importance of drivers and enablers was measured through the questionnaire survey based on a five-point Likert scale ranging from 'strongly agree' (1) to 'strongly disagree' (5). Respondents were asked to indicate the relative importance of each barrier and driver to identify the significant ones limiting the uptake and delivery of sustainable retrofitted building projects. Component Factor Analysis (CFA) was employed to analyse the structure of interrelationships among the variables. The choice of factor analysis is supported by authors such as Qiang et al. (2015), who used it to ascertain factors governing construction project delivery.

Li et al. (2005) used factor analysis to access the critical success factors for PPP/PFI projects in the UK construction industry. Abd El-Karim *et al*. (2017) used CFA to assess the risk factors affecting construction projects. Babatunde (2015) used CFA in developing public-private partnership strategy for infrastructure delivery in Nigeria. Akadiri and Olomolaiye (2013) used factor analysis when assessing the relationship and reliability of the factors affecting designers' sustainability practices in the construction industry. Famakin *et al.* (2012) employed factor analysis when determining success factors for joint venture construction projects in Nigeria. Therefore, the choice of factor analysis technique was cognisant by these depths of usage by other researchers in construction management research and its importance as a standard technique used to determine the underlying relationships among variables.

6.4.1 Steps involved in factor analysis

Pallant (2016) listed three main steps in conducting factor analysis, namely:
(i) Assessment of the suitability of the data; (ii) factor extraction; and (iii) factor rotation and interpretation. These steps are briefly explained in the sections below.

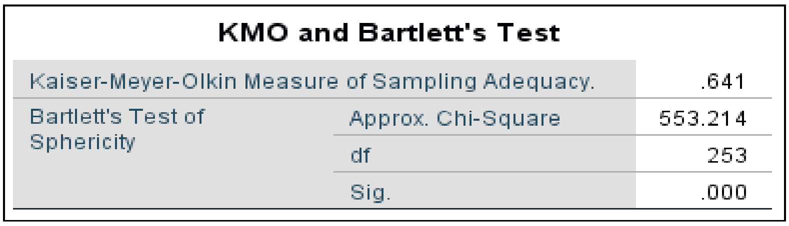
6.4.1.1 Assessment of the suitability of the data

The suitability of the data for factor analysis was carried out using the two suggestions by Pallant (2016): sample size and the strength of the relationship between the variables. In terms of the sample size, there has been controversy regarding sufficient sample sizes needed to conduct factor analysis (Norris et al., 2012). K'Akumu et al. (2013) argued that a satisfactory sample size was required to ensure the suitability and reliability of the data for factor analysis. There has been literature suggesting sample sizes to be employed in factor analysis. For example, de Winter *et al*. (2009) and Norris *et al.* (2012) indicated that factor analysis could be carried out with no fewer than 50 participants. Everitt (1975) recommends a minimum ratio of 10 responses for each variable. Tabachnick and Fidell (2013) proposed that 150–300 responses should be a sufficient sample for factor analysis. Various research studies have been carried out using different sample sizes for factor analysis; for example, Akintoye (2000) conducted factor analysis with a sample size of 84 when analysing the factors influencing project cost estimating practice.

Takim *et al.* (2004) conducted a factor analysis with a sample size of 93 when exploring measures of construction project success in Malaysia. Li *et al.* (2005) carried out a factor analysis with a sample size of 61 when assessing critical success factors for PPP/PFI projects in the UK construction industry. Awodele (2012) conducted a factor analysis with a sample size of 93 when developing a framework for managing risk in privately financed market projects in Nigeria. In relation to the arguments and suggestions based on sample size, the research adopted the recommendation by de Winter *et al.* (2009) and Norris *et al.* (2012) that proposed 50 as a minimum sample size in carrying out factor analysis.

Pallant (2016) raised the second issue in measuring the suitability of data for factor analysis, which is the strength of the relationship between the variables. Consequently, evaluating the appropriateness of data collected for factor analysis was conducted using Statistical Package for the Social Sciences (SPSS). Thus, supported by Norusis (1992) and Norris *et al.* (2012), they suggested that before carrying out the factor analysis, the data must be assessed for suitability for factor analysis using Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity. Hence, Table 6.5 and Table 6.6 highlight the results of Kaiser-Meyer Olkin (KMO) and Bartlett's test of sphericity on barriers and enablers respectively.

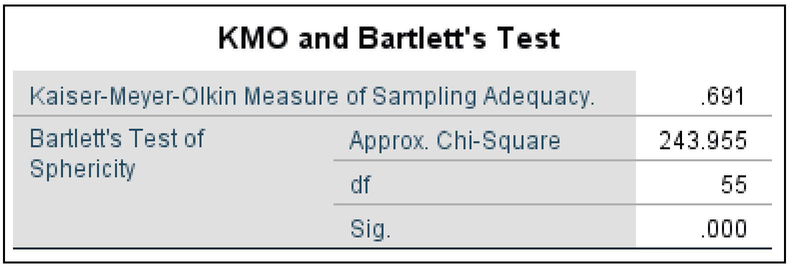
Table 6. 5 The results of Kaiser-Meyer-Olkin (KMO) and Bartlett’s test of sphericity on barriers



KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.641
Bartlett's Test of Sphericity	Approx. Chi-Square	553.214
	df	253
	Sig.	.000

Table 6. 6 The results of Kaiser-Meyer-Olkin (KMO) and Bartlett’s test of sphericity on enablers



KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.691
Bartlett's Test of Sphericity	Approx. Chi-Square	243.955
	df	55
	Sig.	.000

The Kaiser-Meyer-Olkin (KMO) test is a measure of how suitable data is for factor analysis. The test measures sampling adequacy for each variable in the model and the complete model. The statistic is a measure of the proportion of variance among variables. The lower the ratio, the more suitable the data is to factor analysis. According to Cerny and Kaiser (1977) and Norusis (1992), the significance of KMO should be less than the value of 0.05. Hence, Bartlett’s test of sphericity, which is used to validate assumption, should be significant (p <.05) for factor analysis to be considered suitable (Pallant, 2016).

The argument is supported by Norris *et al.* (2012) and Pallant (2016) who stated that the significance value should be 0.05 or less. Thus, from Table 6.5 and Table 6.6 the significance values for the barriers and enablers highlighted are 0.000 respectively. This suggests that the correlation is strong enough to be accurate and proper for conducting factor analysis. Additionally, sphericity for the enablers and barriers were found to be very significant (i.e. Bartlett’s test of sphericity = 1021, 5434 and 1166 respectively). Hence, the data were established as satisfactory and suitable for conducting factor analysis.

6.4.1.2 Factor extraction

Having confirmed that the data were suitable for factor analysis, the second step is factor extraction. This stage encompasses the identification of a relatively small number of factors that can be used to represent relationships among a set of several interconnected variables (Norris *et al*., 2012). Factor extraction postulates that observed measures are affected by common underlying factors and unique factors, and the correlation patterns need to be determined (Yong and Pearce, 2013). Yong and Pearce (2013) and Pallant (2010) stated that there is an array of extraction methods available in factor analysis. These include analysis of principal components; principal factors; image factoring; maximum likelihood factoring; alpha factoring; unweighted least squares and generalised least squares.

However, according to Pallant (2016), the most commonly used method is Principal Component Analysis (PCA). Therefore, this research used PCA to generate interpretable factors. This is supported by Fox and Skitmore (2007) and Norris *et al.* (2012) who stated that PCA sequentially extracts factors based on the maximum variance between the variables. Additionally, Pallant (2016) suggested that some techniques can be employed to assist in the decision regarding the number of factors to be retained. These techniques include Kaiser's criterion for principal component selection (i.e. factors with eigenvalues greater than one), scree plot and parallel analysis.

Consequently, this study employed the PCA method in combination with Kaiser's criterion or eigenvalue and the scree-plot decision criteria when the decision was made on the retained factors. The argument is supported by a similar study by K'Akumu *et al.* (2013) which affirms that eigenvalues are useful in factor analysis as a 'deciding criteria' with regard to the factors considered relevant in the analysis. From a calculation of the eigenvalues in a particular correlation matrix, Kaiser's criterion arbitrarily selects factors that are greater than 1 – i.e. this is the criterion used to decide which are the 'principal factors' to be used in an explanatory model. For example, the default position of deciding the number of factors to be considered in statistical analysis is the 'eigenvalue greater than 1.0 rule' (Norris *et al.*, 2012, Tabachnick and Fidell, 2013, K'Akumu *et al*., 2013, Pallant, 2016). Hence, this study rigorously followed the rule under Kaiser's criterion-retaining factors with an eigenvalue greater than 1.0 for further inquiry (see Figures 6.16 and 6.17 and

Appendices K and O for details). In the scree plot, the plots as generated by the SPSS software were reviewed to find a point at which the shape of the curve changes direction and becomes horizontal (see Figures 6.16 to 6.17 for details).

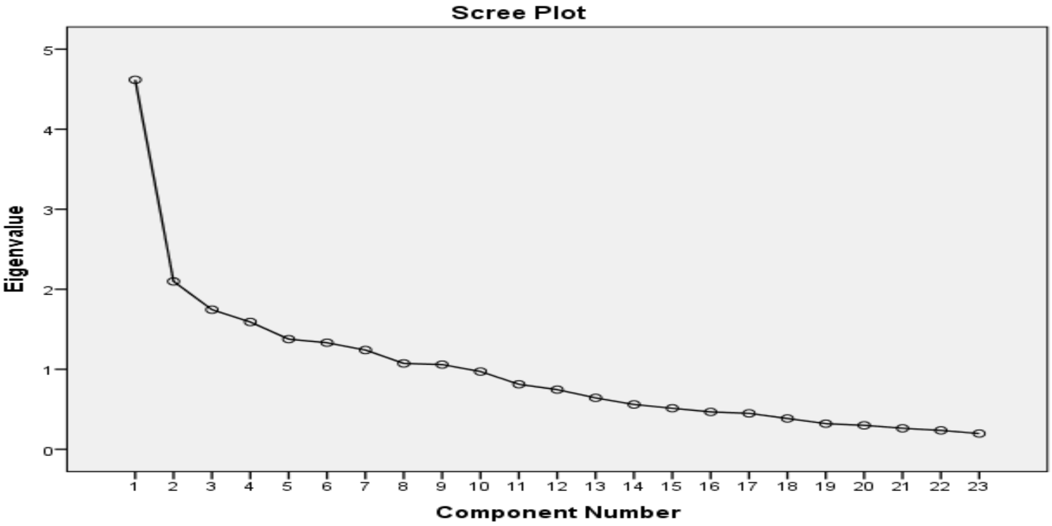


Figure 6. 16 Scree plot showing extracted factors on 27 identified barriers to sustainable retrofit projects

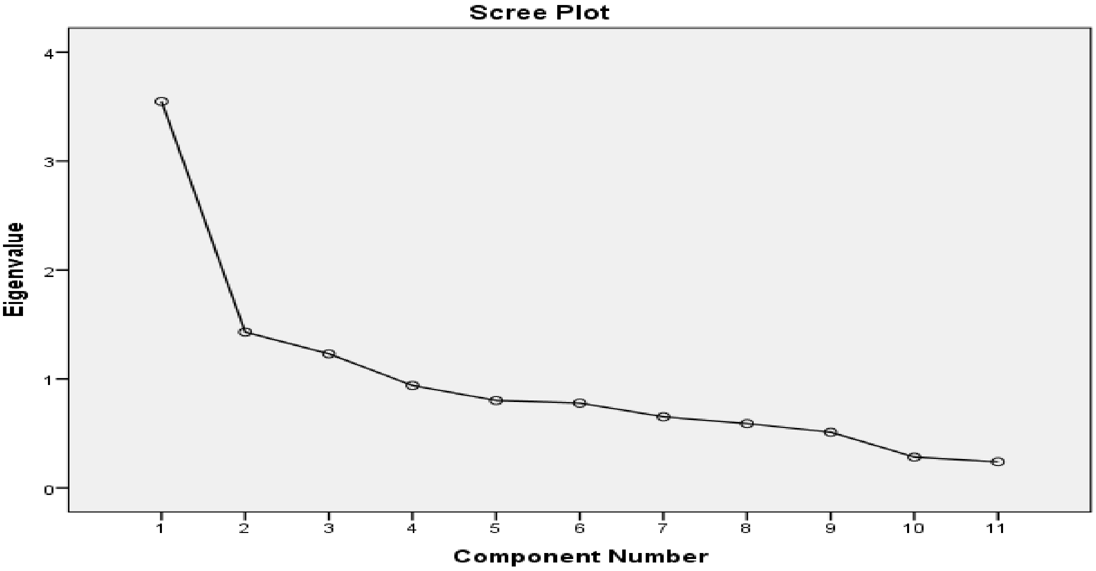


Figure 6. 17 Scree plot showing extracted factors on 17 identified enablers for sustainable retrofit projects

6.4.1.3 Factor rotation and interpretation

This is the third step, according to Pallant (2010), and once the numbers of factors have been determined the next step is is to interpret them. The factors were 'rotated'. Factors that are rotated are important for further interpretation to avoid ambiguity (Norris *et al.*, 2012). This does not change the underlying factors; instead, it presents the pattern of loadings in a manner that is easier to interpret (Pallant, 2016). The goal of rotation is to attain a simple optimal structure which attempts to have each variable load on as few factors as possible but maximises the number of high loadings on each variable (Norusis, 1992). Ultimately, the simple structure attempts to have each factor define a distinct cluster of interrelated variables so that interpretation is easier (Cattell, 1978). There are two types of rotation: orthogonal rotation and oblique.

Orthogonal rotation is when the factors are rotated 90°, and it is assumed that the factors are uncorrelated (Rummel, 1970). However, this is very unrealistic since factors are often correlated with each other to some degree (Kline, 2002). Two common orthogonal techniques are Quartimax and Varimax rotation (Tabachnick and Fidell, 2013). Quartimax involves the minimisation of the number of factors needed to explain each variable (Gorsuch, 1983). Varimax minimises the number of variables that have high loadings on each factor and works to make small loadings even smaller. Oblique rotation is when the factors are not rotated 90° from each other, and the factors are considered to be correlated. Oblique rotation is more complicated than orthogonal rotation since it can involve one of two coordinate systems: a system of primary axes or a method of reference axes (Rummel, 1970).

Additionally, oblique rotation produces a pattern matrix that contains the factor or item loadings and the factor correlation matrix that includes the correlations between the factors. The common oblique rotation techniques are Direct Oblimin and Promax. Direct Oblimin attempts to simplify the structure and the mathematics of the output, while Promax is expedient because of its speed in more massive datasets. Promax involves raising the loadings to a power of four that ultimately results in greater correlations among the factors and achieves a simple structure (Gorsuch, 1983). Additionally, Leech *et al.* (2005) and Tabachnick and Fidell (2007) stated that orthogonal rotation results in a solution that is easier to interpret and report, while oblique approaches allow the factors to be correlated, but they are more difficult to interpret, define and report. In consideration of the stated literature, this study employed the orthogonal approach.

In adopting the orthogonal approach, this study decided to use the Varimax method under the orthogonal approach. This method was chosen because Pallant (2016) argued that Varimax is the most commonly used orthogonal approach due to its ability to minimise the number of variables that have high loadings on each factor, thus resulting in distinct results that are easier to interpret. Therefore, principal factor extraction with Varimax rotation was conducted on the barriers and enablers to achieving sustainable retrofitted building projects. The results are shown in Tables 6.6 and 6.7 respectively (see Appendices C, E and G for details).

The loadings that result from carrying out the Varimax rotation are correlation coefficients. However, Brown (2009) argues that variables that have to load near 1 are unmistakably crucial in the interpretation of the factor, and variables that load near 0 are unimportant. Tabachnick and Fidell (1996) indicated that the value of the measure of sampling activities (MSAs) of all the identified factors is to be greater than 0.3. In the same vein, Leech *et al*. (2005) indicated that factor loadings of less than 0.3 are considered low. Kline (2002) explains that variables with a factor loading of 0.30 or higher can be regarded as significant. Having considered the arguments regarding MSAs from the literature, this study did not need to remove any variable because the factor component loadings are all greater than 0.3. For example, barriers to MSA loadings range from 0.323–0.678 (see Table 6.7) and enablers to MSAs loading range from 0.320-0.790 (see Table 6.8).

Principal Component Analysis (PCA) was conducted on 23 identified barriers to embarking upon and delivering sustainable retrofitted building projects. Table 6.6 shows the initial eigenvalues, and factor loading on the barriers (see Appendices B and C for details) and the first nine components had eigenvalues greater than 1. The result is further confirmed using the scree plot (see Figure 6.16) as suggested by Reyment and J¨oreskog (1993), Pallant (2010) and Norris *et al.* (2012) amongst others. Hence, the nine components were retained for further inquiry to satisfy Kaiser's criterion (i.e. eigenvalues greater than 1) and scree plot (see Figure 6.16 for details) criteria. Table 6.7 also contains nine factors with their eigenvalues; the percentage of the variance; the cumulative percentage of the variance in each factor and the factor loading. Table 6.6 reveals that the eigenvalues for the nine factors retained range from 1.059 to 4.618. The total variance explained by the first factor is 20.076% while the ninth factor explained a total variance of 4.605%. The total variance explained by the extracted nine factors accounted for 70.15% (see Appendix L for details).

Table 6. 7 Principal factor extraction of Varimax rotation and total variance explained on the barriers to delivery of retrofit projects

Reference Code	**Principal Factor**	**Factor Loading**	**Initial Eigenvalues**		
			Total	**% of Total Variance explained**	**Cumulative % of Variance explained**
Factor 1: Knowledge management issues					
F1/BR1	Lack of information on appropriate sustainable technology and materials	0.678	4.618	20.076	20.076
F1/BR2	Unclarity of information and information overload about sustainable retrofitting	0.579			
F1/BR3	Lack of capturing, documenting and reviewing mistakes and lessons learned in retrofit activities	0.570			
F1/BR9	Inadequate sustainable retrofit data	0.480			
Factor 2: Lack of political will					

F2/BR11 3	Lack of strong enforcement by government	0.565	2.098	9.122	29.198
F2/BR14	Lack of legislation on sustainable retrofitting	0.477			
F2/BR15	Lack of legislation for penalties	0.443			
Factor 3: Fund-related issues					
F3/BR11	Lack of proper government funding or grant	0.629	1.745	7.587	36.785
F3/BR12	Inadequate engagement between lenders and finance providers	0.621			
Factor 4: Poor awareness issues					
F4/BR5	Awareness gaps in sustainable retrofitting	0.495	1.591	6.917	43.702
F4/BR19	Lack of clarity, long-term plans and a road map by the government	0.323			
Factor 5: Decision issues amongst key stakeholders					
F5/BR4	Investor and user dilemma (usually landlord and tenant)	.573	1.377	5.986	49.688
F5/BR21	Lack of appropriate decision-making due to stakeholders' different opinions	0.478			

F5/BR22	The low rate of return on investment of low-carbon technologies	0.330			
Factor 6: Lack of expertise and required technologies					
F6/BR8	Lack of skilled workforce	0.615	1.332	5.791	55.479
F6/BR7	Lack of suitable materials	0.558			
Factor 7: Cost-related issues					
F7/BR20	Perceived as an expensive project to embark	0.593	1.241	5.394	60.873
F7/BR6	The hidden cost of retrofits	0.559			
Factor 8: Collaboration issues					
F8/BR23	Lack of collaboration amongst construction key stakeholders	0.595	1.073	4.666	65.539
F8/BR10	Tenant/property owner disagreements over rent increase after sustainable retrofits	0.489			
F8/BR17	High maintenance cost of low carbon technologies/materials	0.436			
Factor 9: Change resistance issues					
F9/BR16	Diminished aesthetics	0.551	1.059	4.605	70.144
F9/BR18	Resistance to change from	0.448			

	traditional refurbishment				
Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy		0.641			
Bartlett's test of sphericity: Significance		0.000			
Cronbach's alpha		.787			

Extraction method: Principal Component Analysis
Rotation method: Varimax with Kaiser Normalisation
Rotation converged in 27 iterations

6.5 Discussions on factor analysis results

Factor analysis results for barriers and enablers of the sustainable retrofitted building project are discussed in detail in the ensuing Sections 6.5.1 and 6.5.2.

6.5.1 Barriers to the uptake and delivery of sustainable retrofitted building projects

Principal Component Analysis (PCA) was conducted on 23 identified barriers to embarking upon and delivering sustainable retrofitted building projects. The correlation matrix of the 23 barrier items from the survey data was calculated. The value of test statistics for sphericity was Bartlett's test of sphericity (243.4103) (see Table 6.7) with a mall significant level (P-value = 0.000) (see Table 6.9), indicating that the population correlation matrix is not an identity matrix (see Appendices K, L, M and N for further details). The value of the KMO statistic is 0.641, which according to Kaiser (Norusis, 1992) is satisfactory for factor analysis. Table 6.7 indicates the initial eigenvalues and factor loading on the 23 barriers (see Appendices B and C for details). Hence, the PCA produced a nine-factor grouping solution based on Varimax rotation as shown in Table 6.7, and the rotation matrix converged in 27 iterations.

The nine groupings range from 1.059 to 4.618 with eigenvalues greater than 1.000 explaining 70.15% of the variance as highlighted in Table 6.8 while the remaining barriers together account for 29.85% of the variance. Correspondingly, the first nine-factor components that had eigenvalues greater than one as earlier stated were further established using scree plot (see Figure 6.16), as suggested by previous researchers (e.g. Kim and Mueller, 1978, Kline, 2002). The total variance explained by the first factor is 20.076% while the ninth factor explained a total variance of 4.605%. However, it is pertinent to state that the nine components were retained for further inquiry to satisfy Kaiser's criterion (i.e. eigenvalues greater than 1) and scree plot (see Figure 6.16 for details) criteria.

It is relevant to state that the factors were named according to the loading or grouping of the variables. Yong and Pearce (2013) corroborated the result and argued that naming of factors is more of an 'art' as there are no rules for naming factors, except to give names that best represent the variables within the grouped factors. Hence, the following names were allocated to each of the nine factors in the ensuing section that have also been reported in Table 6.7. Furthermore, Table 6.7 also highlights the cumulative percentage of the variance in each factor and the factor loading.

6.5.1.1 Nine component factor groupings for 23 barriers with their names

Factor grouping 1 denotes *knowledge management*

Factor grouping 2 denotes *weak legislation, regulations and political will*

Factor grouping 3 denotes *fund-related*

Factor grouping 4 denotes *poor awareness*

Factor grouping 5 denotes *decision issues amongst key stakeholders*

Factor grouping 6 denotes *lack of expertise and required technologies*

Factor grouping 7 denotes *cost-related*

Factor grouping 8 denotes *collaboration*

Factor grouping 9 denotes *change resistance*

Factor grouping 1: Knowledge management (KM)

This factor represents 20.07% (Table 6.8) of total variance amongst or between the barriers to delivering sustainable retrofit projects. The barrier factor constituents under *knowledge management* issues include:

- Lack of information on appropriate sustainable technologies and materials
- Lack of information clarity in sustainable retrofit issues

- Lack of capturing, documenting and reviewing mistakes and lessons learned in retrofit activities

- Inadequate sustainable retrofit data

The factor loading groupings for the components are 0.678, 0.579, 0.570 and 0.480 (see Table 6.7). Amongst the components rating, it can be deduced that *lack of information on appropriate sustainable technologies and materials* has the highest total variability between the barriers of retrofit analysis. This is followed by *lack of information clarity, information overload, lack of capturing, documenting and reviewing mistakes and lessons learned in retrofit activities,* and the lowest factor loading on this grouping is *inadequate sustainable retrofit data*. It is evident that the lack of managing projects in delivering sustainable retrofitted building projects remains one of the most significant challenges amongst the key stakeholders. The result of the KM factor can be related to Khalfan et al. (2002), Shelbourn et al. (2006), Hakkinen and Belloni (2011) and Maduka et al. (2015e) who have all acknowledged in their studies the need for the industry to manage project knowledge activities in the day-to-day running of construction projects particularly for sustainable retrofitted building projects.

Factor grouping 2: Lack of political will

Lack of political will represents 9.12% (see Table 6.7) of the total variance for barriers of sustainable retrofitted building projects. The three components that fall under this grouping include:

- Lack of strong enforcement by government

- Lack of legislation on sustainable retrofitting

- Lack of legislation for penalties

The factor loadings for the three components of barriers are 0.565, 0.447 and 0.443 (see Table 6.7) respectively. However, the *lack of strong enforcement by the government* has the highest loading followed by *lack of legislation on sustainable retrofitting*, and the lowest factor loading is *lack of legislation for penalties*. Wilson and Tagaza (2004), Zhang et al. (2010), Winston (2010) and Azizi et al. (2011) all acknowledge that lack of political will, which includes inadequate legislation, enforcement and penalties, has derailed a reasonable uptake of sustainable retrofit projects in the construction industry. They agreed that there is a need for the government to be proactive in its responsibilities to achieve the government's target in emission reduction of greenhouse gas.

Factor grouping 3: Lack of funding/grants

Lack of funding/grants remains one of the most significant challenges of delivering sustainable retrofitted building projects. It has total variances of 7.58% (Table 6.7) of the barrier factor. The two components that fall under *lack of funding/grants*-related issues are:

- Lack of proper government funding or grants
- Inadequate engagement between lenders and finance providers

Between the two components, *the lack of government funding* factor loading is 0.629 (see Table 6.7), which has a higher factor loading than *inadequate engagement between lenders and finance providers* which has a lower factor loading of 0.620 (see Table 6.7). *Fund-related issues* remain one of the major challenges to embarking on and delivering sustainable retrofitted building projects. This is supported by different studies that have suggested the need for improved government grants and funding to encourage the key stakeholder to embark on retrofit projects (Wilson and Tagaza, 2004, Pitt *et al.*, 2009, Zhang *et al.*, 2010). Further details on the *lack of funding/grants* factor on barriers of sustainable retrofit have been discussed in Section 2.11.

Factor grouping 4: Poor awareness

This factor accounts for 6.91% (see Table 6.7) of the total variance of barrier factors. The factor consists of two components that include:

- Awareness gaps in sustainable retrofitting
- Lack of clarity, long-term plans and a roadmap by the government

It is imperative that the key stakeholders improve on the awareness creation of significant benefits of retrofit buildings in order to increase the uptake of sustainable retrofit projects. *Awareness gaps of sustainable retrofitting* and *lack of clarity* have a factor loading of 0.495 and 0.323 respectively. This poor awareness has also been identified by Pitt *et al*. (2009), Chan et al. (2009) and Azizi *et al*. (2011) who, in their studies, agreed that this is one of the significant challenges in the delivery of sustainable building projects.

Factor grouping 5: Decision issues amongst key stakeholders

This factor accounts for 5.98% of total variance and represents three components, which include:

- Investor and user dilemma (usually property owner/landlord and tenant)
- Lack of appropriate decision-making due to stakeholders' different opinions
  - The low rate of return on investment of low-carbon technologies

However, the factor loading for *investor and user dilemma*, *lack of appropriate decision making* and *low rate of return on investment* are 0.573, 0.478 and 0.330 (see Table 6.7) respectively. Investor and user dilemma has the highest factor loading while a low rate of return on investments has the lowest factor loading. The need for a decision support framework is necessary to address the *decision support issues* with the key stakeholders.

Factor grouping 6: Lack of expertise and required technologies

Lack of expertise and required technologies remain a challenge to embarking on and delivering sustainable retrofitted building projects. This factor represents 5.79% (see Table 6.7) of the total factor variances in the factor grouping of barriers to the delivery of sustainable retrofit projects. The two-factor components involved include:

- Lack of skilled workforce
- Lack of suitable materials

The components' factor loadings are 0.615 and 0.558 respectively. *Lack of skilled workforce* has the highest factor grouping loading while the *lack of suitable materials* has a low factor loading. Lack of expertise has been highlighted in Section 2.12 as a barrier to delivering sustainable retrofitted building projects. Section 2.12 has highlighted *lack of expertise* as a limiting factor in the uptake and delivery of retrofit projects. Lack of expertise has been acknowledged by Jankel (2018) as a barrier to retrofit project delivery and suggested the need for governments and private-sector organisations to effectively plan for skills development. They also emphasised the need to explore opportunities in developing technologies that are required in delivering sustainable retrofitted building projects.

Factor grouping 7: Cost-related

Cost-related issues have a total factor variance of 5.39% (see Table 6.7), and there are two components under the group loadings which include the following:

- Perceived as an expensive project to embark upon
- Hidden cost of retrofits

However, the factor loadings stated above represent 0.593 and 0.559 (see Table 6.7) respectively. Meanwhile, *perceived as an expensive project* has a higher factor loading than *hidden cost*. Cost-related issues have been identified as a barrier to the uptake and delivery of sustainable retrofit building projects (Williams and Dair, 2007).

More details can be seen in Section 2.12 which discusses cost perception as a barrier to the delivery of retrofit projects.

Factor grouping 8: Collaboration issues

Collaboration issues account for 4.66% of total variances in the sustainable retrofit barrier analysis. The components under this factor-loading grouping include:

- Lack of collaboration amongst construction key stakeholders
- Tenant/property owner disagreements over rent increase after sustainable retrofits
- High maintenance cost of low-carbon technologies/materials

A high factor group loading of 0.595 (see Table 6.7) was associated with *lack of collaboration amongst key stakeholders* while *tenant/property owners* had a loading factor of 0.489 and lastly *high maintenance cost* had the lowest factor loading of 0.436. Lack of collaboration amongst construction key stakeholders remains a barrier in the industry as it relates to sustainable retrofit. This is supported by Winston (2010) and Pitt *et al*. (2009) in their studies on barriers and challenges of achieving sustainable construction, especially retrofit projects. Further details are seen in Section 2.12.

Factor grouping 9: Change resistance

Change resistance issues account for 0.460% of the total variances between barriers of sustainable retrofit projects. It has two-factor components that are listed below.

- Diminished aesthetics
- Resistance to change from traditional refurbishment

The two components have a factor loading of 0.551 and 0.448 respectively. The factor loading depicts that *resistance to change* has a higher loading than *diminished aesthetics*. *Change resistance* has also been identified as a barrier to the uptake and delivery of sustainable retrofit projects in the study of Winston (2010) which stated that the negative attitude of building owners in the demolition during retrofit is due to social attachment and diminished aesthetics of the existing building.

Furthermore, a reliability test was conducted to check the internal consistency and homogeneity of the measured variables. The result revealed that 0.787 is the Cronbach alpha statistic which is above 0.7, the minimum value recommended for acknowledging the internal consistency of the measured variables (BrckaLorenz *et al*., 2013). Hence, this study concludes that the internal consistency and homogeneity of the 23 barrier items were measured.

6.5.2 Enablers or drivers to the uptake and delivery of sustainable retrofitted building projects

Principal Component Analysis (PCA) was conducted on 11 identified enablers of the uptake of sustainable retrofitted building projects. The correlation matrix of the 9-enabler variables from the survey data was calculated. The value of test statistics for sphericity was substantial (Bartlett's test of sphericity = 553.214) (see Table 6.8) with a significant level (P-value = 0.000) (see Table 6.8) indicating that the population correlation matrix is not an identity matrix (see Appendix Q for further details). The value of the KMO statistic is 0.691, which according to Kaiser (Norusis, 1992) is satisfactory for factor analysis.

The principal component analysis was carried out on 11 barriers which produced three enabling-factor solutions with 17 iterations (also see Table 6.8) with eigenvalues greater than 1.000 as indicated in Table 6.8 and also highlighted on the scree plot (see Figure 6.17). The three-factor groupings ranged from 1.230 to 3.547

explaining 57.15% of the variance as highlighted in Table 6.8. While the remaining factors or barriers together account 42.93% of the variance. The factor grouping was based on Varimax rotation as shown in Table 6.8, and the three components of this factor grouping have been retained and named for further investigation in the ensuing sections. Furthermore, Table 6.8 also displays the percentage of the variance, the cumulative percentage of the variance in each factor and the factor loading.

6.5.2.1 Three component factor groupings for 11 enablers

Factor 1 grouping denotes *social*

Factor 2 grouping denotes *economic*

Factor 3 grouping denotes *environmental*

Factor 1 grouping: social

Social factor represents 32.24% (see Table 6.8) of the total variances of enablers of sustainable retrofitted building projects. The components in this grouping are vital in the uptake and delivery of sustainable retrofit projects, particularly the client’s awareness. However, there are four components in this principal factor, and they include:

- Client awareness
- Increased building value
- Better health improvement for building occupants
- Sustainability brand reputation improvement

The highest factor loading in this group is associated with *client awareness*, which has 0.662 significance. *Increased building value* follows this with 0.617, *better health improvement* with 0.538, and sustainability brand reputation with 0.372. *Client awareness* remains a significant factor that will drive the interest of the key stakeholders to embark upon and deliver sustainable retrofitted building projects. A retrofitted building, in turn, comes with good health because emissions of greenhouse gas are reduced. *Social factor* remains an enabler to the uptake and delivery of sustainable retrofitted projects. This has been supported by studies that acknowledged *social factor* as an enabler to the delivery of retrofit projects and these include: *client awareness* (Azizi *et al*., 2011); *increased building value* (Chan *et al.*, 2009); *better health improvement* (Wilson and Tagaza, 2004) and *sustainability brand improvement* (Zhang et al., 2010).

Factor 2 grouping: economic

Economic factor remains one of the primary drivers or enablers to embark on sustainable retrofit projects. The principal economic factor is 12.99% (see Table 6.8) of the total variance in the factor analysis of enablers of sustainable retrofit projects. However, there are four components associated with this principal factor, and they include:

- Energy cost reduction
- Lower operational cost and maintenance
- Financial incentives
- Higher profit or return on investment in the long term

The four components have different factor loading groupings. From the groupings, it is revealed that *energy cost reduction* with 0.790 significance, *lower operational cost* with 0.701, and *financial incentives* of 0.652 have the highest factor loadings and *higher profit or return on investment* has the lowest factor loading of 0.481. It has been widely documented that financial incentives remain one of the important enablers of sustainable retrofitted building projects. *Economic factor* is one of the critical enablers to the uptake and delivery of sustainable retrofitted building projects. Studies identified *energy cost reduction* (Association for the Conservation of Energy, 2002), *lower operational cost* (Chant *et al*., 2009), *financial incentives* (Pitt *et al*., 2009) and *higher profit and return on investment* (Pitt *et al*., 2007) as enablers or drivers to the uptake and delivery of retrofit projects.

Factor 3 grouping: Environmental

Environmental factor remains one of the factors that drive the uptake and delivery of sustainable retrofit projects. The principal environmental factor represents 11.18% (Table 6.8) of the total variance in the factor analysis for the enablers of retrofit projects with three principal factor components associated with it. These components are as follows:

- Contributing to greenhouse emission reduction targets
- The positive public image associated with environmentally responsible practices
- Building regulation code

Contributing to greenhouse emission reduction targets has a significant value of 0.614 (see Table 6.8), and this recorded the highest factor loading under this grouping. The *positive public image associated with environmentally responsible practices* has a lower factor loading of 0.333 while *building regulation code* has the lowest factor loading of 0.320. *Environmental factor* indices remain an enabler to the uptake of sustainable retrofits (DCLG, 2006b, Chan et al., 2009). Table 6.8 highlights the principal factor loading, factor loading and initial eigenvalues.

Table 6. 8 Principal factor extraction of Varimax rotation and total variance explained on enablers for a sustainable retrofit project

Reference Code	**Principal Factor**	**Factor Loading**	**Initial Eigenvalues**		
			Total	**% of Total Variance explained**	**Cumulative % of Variance explained**
Factor 1: Social					
F1/EB5	Client awareness	0.662	3.547	32.249	32.249
F1/EB11	Increased building value	0.617			
F1/EB7	Better health improvement for building occupants	0.538			
F1/EB2	Sustainability brand reputation improvement	0.372			
Factor 2: Economic					
F2/EB4	Energy cost reductions	0.790	1.430	12.999	45.248

F2/EB3	Lower operational cost and maintenance	0.701			
F2/EB8	Financial incentives	0.652			
F2/EB1	Higher profit or return on investment in the long term	0.481			
Factor 3: Environmental					
F3/EB09	Contributing to greenhouse emission reduction targets	0.614	1.230	11.82	56.431
F3/EB10	The positive public image associated with environmentally responsible practices	0.333			
F3/EB11	Building regulation and code	0.320			
Kaiser-Meyer-Olkin (KMO) measure of sampling adequac		0.691			
Bartlett's Test of Sphericity: Significance		0.000			
Cronbach's alpha		0.763			

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization
Rotation converged in 17 iterations

Furthermore, a reliability test was conducted to check the internal consistency and homogeneity of the measured variables. The result reveals that 0.763 is the Cronbach alpha (see Table 6.8), which is above 0.7, the minimum value needed to acknowledge the internal consistency of the measured variables. Hence, this study concludes that there is internal consistency and homogeneity of the 11 items measured (BrckaLorenz et al., 2013).

6. 6 Data analysis based on the need to manage knowledge in the delivery of sustainable retrofitted building projects

Table 6. 9 Respondents' feedback on the rating of organisations on capturing and documenting information about experiences (good or bad) and lessons learned during and after retrofit projects

Options	Frequency	Percentage	Valid percentage	Cumulative percentage
Yes	27	31.40	31.40	31.40
No	59	68.60	68.6	100.00
Total	86	100.00	100.00	

Table 6.9 is part of the knowledge management questions, which is one of the primary reasons for this research as documented in Chapter 1. It was widely documented that lack of knowledge management in the industry impedes the uptake of sustainable retrofitted building projects (Shelbourn *et al.*, 2006, Maduka *et al.*, 2015a, Maduka *et al.*, 2015b). For the participants to understand the questions, knowledge management principles or approaches that have been extensively discussed in Section 3.4 were used to ask the questions to avoid the ambiguity of knowledge management. Table 6.9 further indicates that the construction industry still lacks the application of knowledge management approaches in delivering sustainable retrofitted building projects. Hence, 68.60% stated that they do not capture or document experiences and lessons learned during and after sustainable retrofitted building project activities, while 31.40% indicated that they document retrofit activities.

The finding shows that the adoption of knowledge management is still very poor in the industry, and this will continually impede the uptake and delivery of sustainable retrofitted building projects and promote poor decision-making between key stakeholders. The industry needs to embrace KM in construction for competitive advantage and optimal project delivery. Lack of interest in knowledge management by key stakeholders poses a threat to make an informed decision. Hence, the key stakeholders keep reinventing the wheel in retrofit project delivery. It is pertinent to note that further investigation was carried out through semi-structured interviews in Chapter 7 to have in-depth insight into knowledge management issues in the uptake and delivery of retrofit building projects. This section has answered Research Objective 7.

6.7 Data analysis based on decision-making issues in the uptake and delivery of sustainable retrofitted building projects

Table 6. 10 Respondents' feedback on rating the use of RIBA or process protocol or any other decision framework/structured model for making decisions when retrofitting

Options	Frequency	Percentage	Valid percentage	Cumulative percentage
Yes	15	17.4	17.4	17.4
No	71	82.6	82.6	100.00
Total	86	100.00	100.00	

Table 6.10 depicts N to be the number of the total respondents, and in this case all the 86 respondents were represented in this question. There is a need to verify the use of RIBA/process because there is a lack of a standard sustainable retrofit building process in the construction industry. Table 6.10 highlights that 71 respondents, representing 82.56% out of the 86 total respondents, stated that they do not use RIBA's plan of work for decision-making in sustainable retrofit projects while 15 respondents representing 17.44% reported that they use it for retrofit projects. The result suggested that there is a need for a plan of work or retrofit process that would assist the key stakeholders in making informed decisions in delivering sustainable retrofitted building projects. RIBA's plan of work serves as a project process or guideline to the delivery of conventional building construction and not for sustainable retrofit building projects.

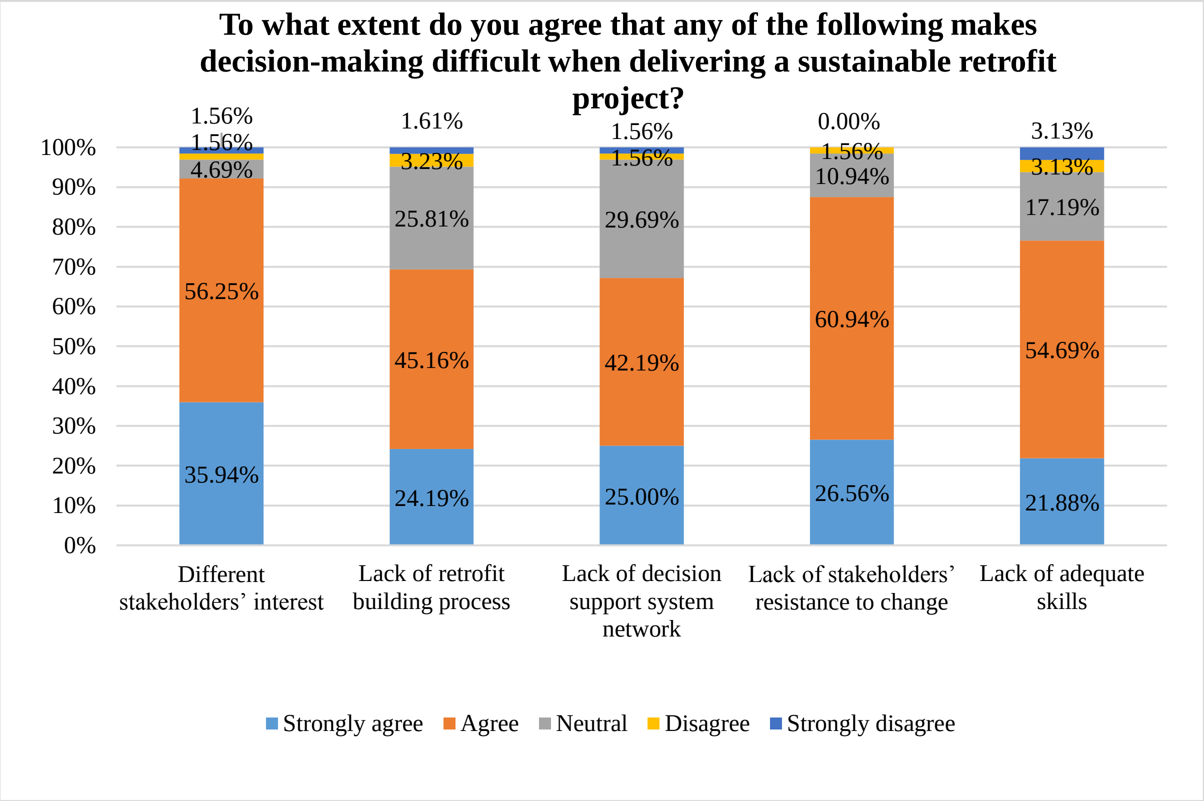


Figure 6. 18 Multi-item statements to measure options in making the decision difficult in a retrofit project

Inappropriate decision-making due to lack of knowledge management has been identified as one of the barriers to delivering or achieving the uptake of sustainable retrofitted building projects. Further discussion on decision-making occurs in Section 2.12.6. To identify the challenges of making decisions in delivering sustainable retrofitted building projects, Figure 6.18 highlights the feedback of the respondents which showcases the fact that *different stakeholders' interest* has strongly agree with 35.94%, agree 56.26%, neutral 4.49%; *lack of retrofit building process* has strongly agree 24.19%, agree 45.16%, neutral 25.81%; *lack of decision support network* has strongly agree 25.00%, agree 42.19%, neutral 29.69; *lack stakeholder's resistance to change* has strongly agree 26.56%, agree 60.94% neutral 10.94%; and *lack of adequate skills* has strongly agree 21.88%, agree 54.69% and neutral 17.19%.

From Figure 6.18 it is evident that there is a need for a standard retrofit building process in other to assist in guiding the key stakeholders in making decisions in the uptake and delivery of sustainable retrofit projects. In addition, there is a need for developing a decision support framework with knowledge management principles to help key stakeholders make an informed decision because a lack of decision-making tools has been highlighted as one of the problematic decisions that stakeholders face when delivering sustainable retrofit projects.

Figure 6.18 also illustrates the need for knowledge management in making decisions easier in delivering retrofit projects. From the result, one can deduce that capturing or documenting mistakes made and reviewing good and bad experiences during retrofit projects are approaches to knowledge management (Maduka *et al.*, 2015c). It again points to the importance of the construction industry to adopt knowledge management approaches in embarking on and delivering sustainable retrofits projects. Figure 6.18 highlights that a more systematic model or framework ranks high as an enabler to easy decision-making in delivering retrofit projects.

Correlation analyses were further conducted with Statistical Package for the Social Sciences (SPSS) in Section 6.7 to explore and ascertain the strength of directions and relationship of the variables in Figure 6.18 and 6.19.

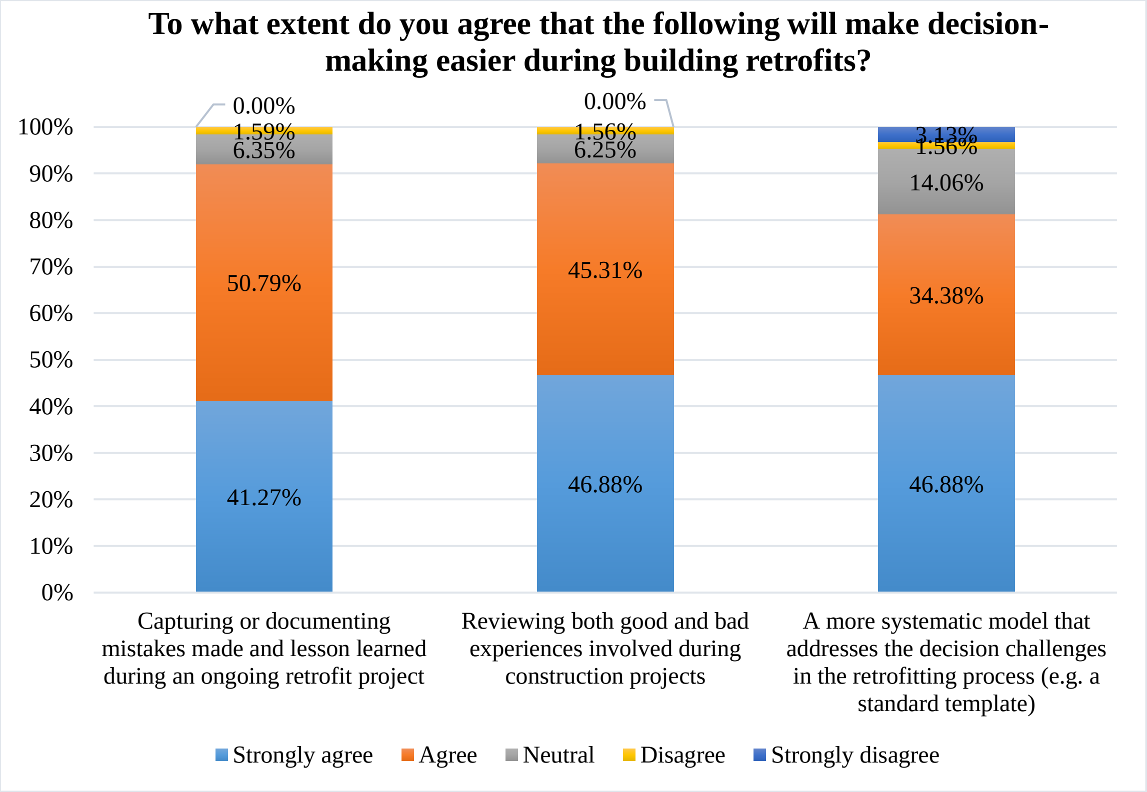


Figure 6. 19 Multi-item statements to measure options to easier decision-making in retrofit projects

6.8 Pearson Correlation

To indicate the strength and direction of the relationship of Figures (6.22) and (6.23), a Pearson (r) correlation was conducted. The choice of Pearson correlation agrees with some studies in the construction industry. These studies include: Gonz´alez-Dom´ınguez and Mart´ın (2017) who conducted a research using Pearson correlation on fast parallel construction of correlation similarity matrices for gene co-expression networks on multicore clusters; Kozlovskaa et al. (2016) conducted a survey of construction management documentation usage in planning and construction of building project; Liphadzi *et al.* (2015) carried out a study on the relationship between leadership styles and project success in the South African construction industry and Bakhshi and Touran (2012) carried out research to find out a method for calculating cost correlation between construction projects in a portfolio. However, before performing the Pearson correlation, it has been suggested that a scatter plot should be generated. The scatter plot helps to check for violation of assumptions of linearity and homoscedasticity. The inspection of the scatterplot also reveals the nature of the relationship between the sets of variables (see Figures 6.22 and 6.23).

6.8.1 Necessary checks in interpreting Scatter plot

1. *Checking for outliers*: The outlier checks for a data point that emanates from a different model compared to the rest of the data. It can also be defined as data points that are out on their own, either very high or very low or away from the primary cluster of points (Norris *et al*. 2012). It is argued that outliers could have a negative effect on data analysis hence it is worth investigating using scatter plot (Pallant, 2016). This research examined for outliers in Figures 6.20 and 6.21, which indicated that there is no outlier in the scatter plot.

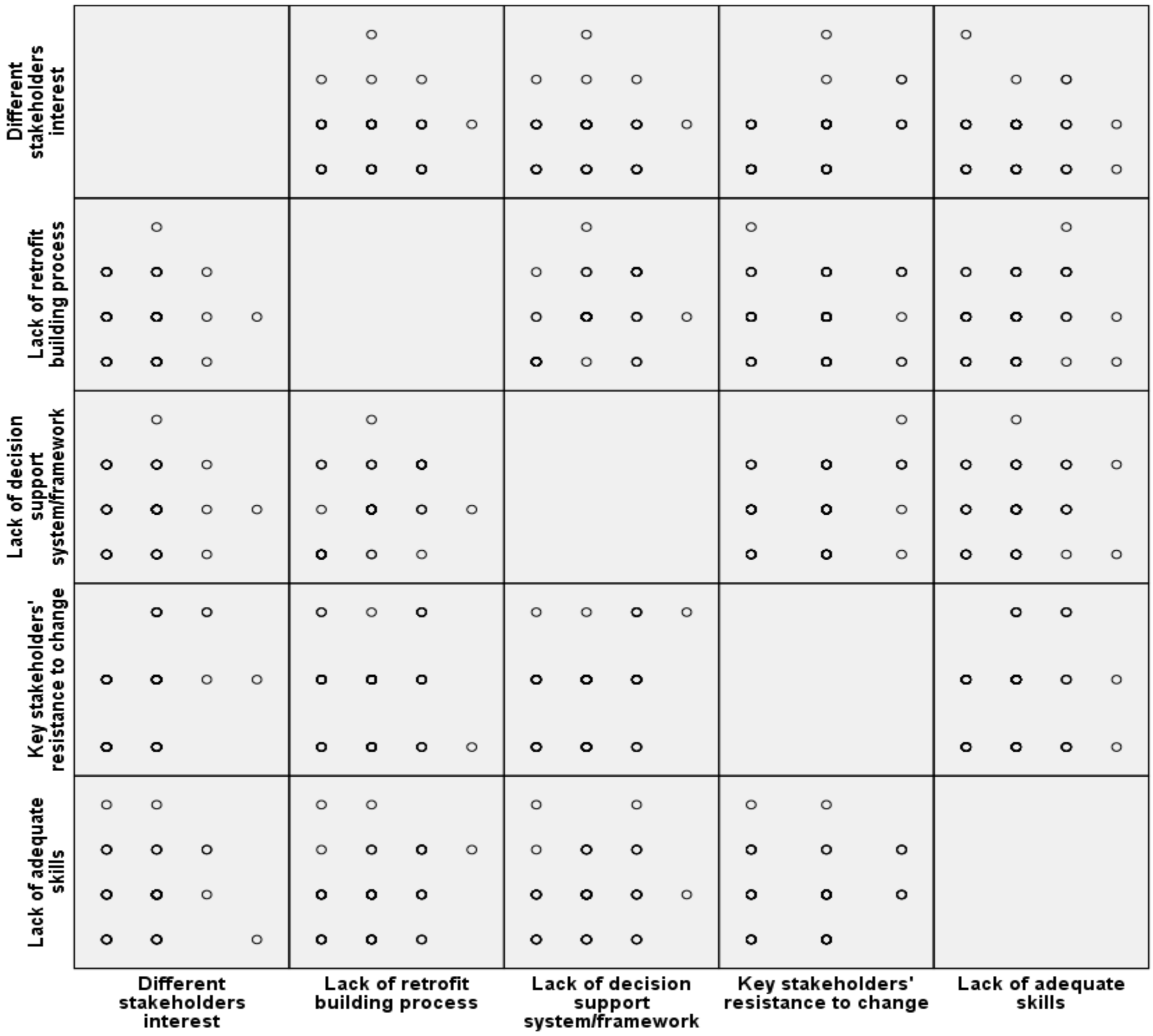


Figure 6. 20 Scatter plot to determine if the variables for possible options in making the decision difficult met the criteria needed to conduct a Pearson correlation

2. *Inspect the distribution of data points:* checking the distribution of data points in Figures 6.20 and 6.21 criteria A to D (discussed below) determines if the distribution of the variables met the criteria or not. A) Whether the data points spread all over the place and if it did spread all over the place it shows very low correlation (Norris et al., 2012, Pallant, 2016). Checking Figures 6.20 and 6.21, one can deduce that the points did not spread all over, the plot instead was arranged, and that means correlation can be carried out on the variables. B) Are the points neatly arranged in a narrow cigar shape, horizontal or straight line, and if so then it suggests a very strong correlation (Howell, 2002, Norris *et al*., 2012, Pallant, 2016). Checking the

scatter plot in Figures 6.19 and 6.20 it is evident that the data points did not spread all over, the place and the points are neatly arranged in a narrow cigar shape, and a horizontal line can be drawn indicating very high correlation. C) Can a straight line be drawn through the central cluster of points or would a curved line better represent the points? If it reveals a curved line, then Pearson correlation is not recommended because it assumes a linear relationship (Norris *et al.,* 2012, Pallant, 2016). Criteria C was achieved looking at Figures 6.20 and 6.21 because a straight line can be drawn through the central cluster that means there is no linear relationship; hence, Pearson correlation is recommended. D) What is the shape of the cluster? Is it even from one end to the other? On the other hand, does it start narrow and then get flatter? If this appears in shape, then the violation of the assumption of homoscedasticity is evident (Norris *et al.*, 2012, Pallant, 2016). Figures 6.20 and 6.21 reveal that a straight line or cigar shape can be drawn hence there is no violation of homoscedasticity meaning the Pearson correlation is in order.

3. *Determine the direction of the variables:* scatter plots help to indicate the positive or negative relationship between the variables (Nicol and Pexman, 2010). If a line were drawn through the points, then what is the direction, does it pointed to the left or to the right? Upwards or downwards? An upward trend indicates positive directions while a downward trend suggests a negative correlation (StatsDirect, 2008). A negative pattern runs from the upper left to the lower right while a positive pattern runs from the lower left to the top right (Hollander and Wolfe, 1999, Howell, 2002). From Appendices (S) and (T) it is evident that the direction of the lines run from left to right indicating an upward trend. Therefore, it has positive correlations.

Furthermore, Figures 6.20, 6.21, Appendices (S) and (T) highlight from the above discussions that the distribution of the scores met all the criteria needed to proceed to the Pearson correlation. In addition, the distribution of scores in the scatter plots depicts a relationship between the variables that is linear, and the scores are evenly distributed, hence, the researcher proceeds to interpret the correlation output.

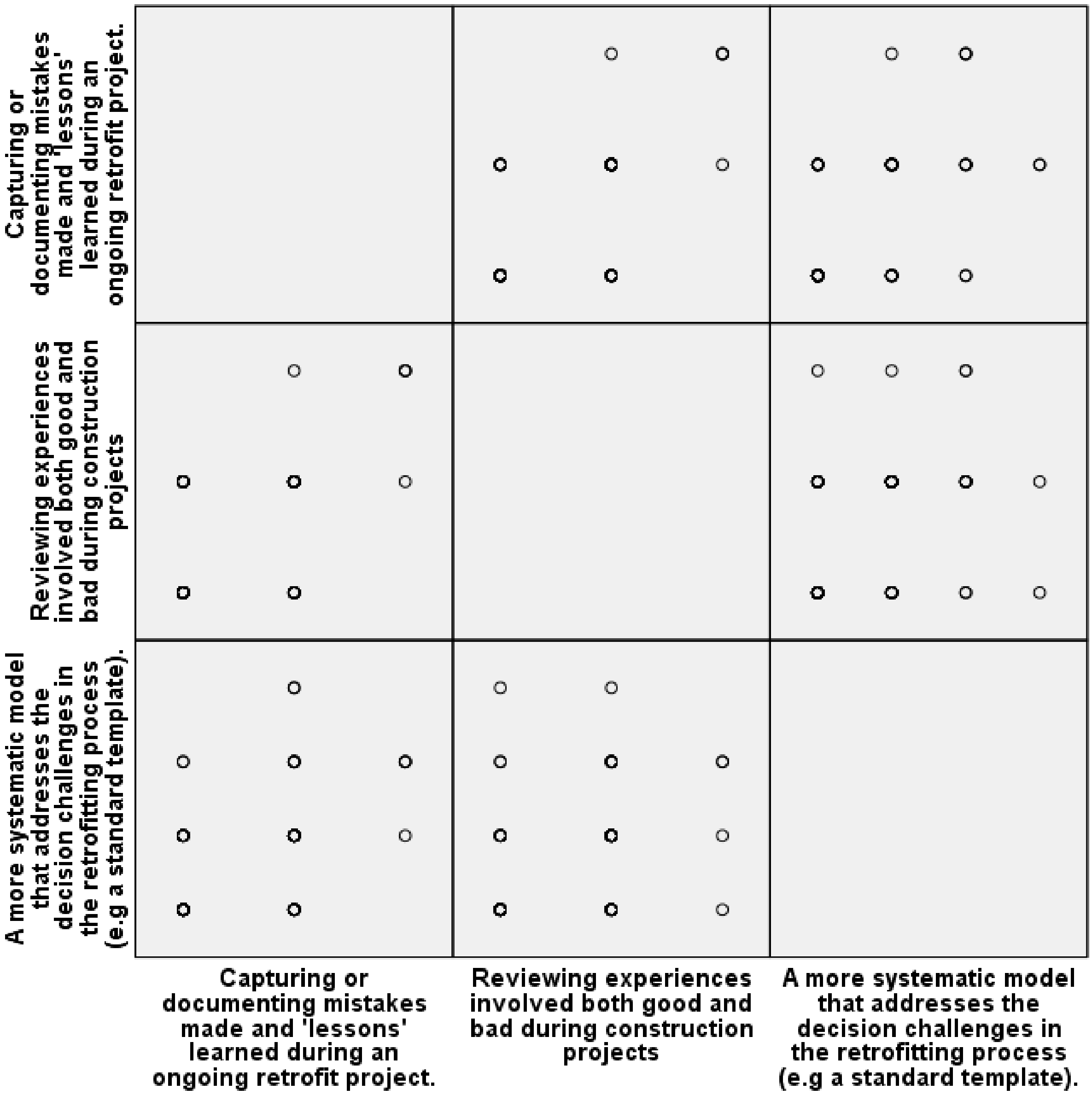


Figure 6. 21 Scatter plot to determine if the variables for possible options in making the decision easy met the criteria needed to conduct a Pearson correlation

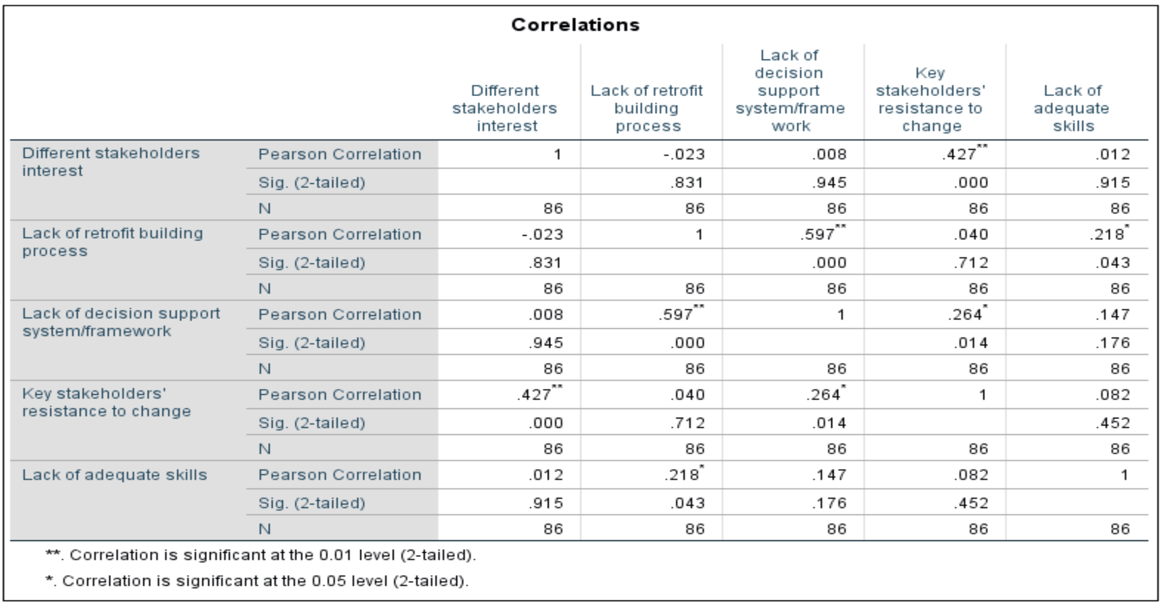
6.8.2 Interpreting output from correlation

Nicol and Pexman (2010), Norris *et al*. (2012) and Pallant (2016) publications in the interpretation of Pearson correlation output suggest that researchers should check for the information in the sample, determine the direction of the relationship and the strength of the relationship and access the significant level before proceeding for Pearson correlation.

1.*Sample information checks:* It is essential to check firstly the N which means the number of cases to ascertain if it is correct (Howell, 2002). This also suggests that high scores on one are associated with low scores on the other. Tables (6.12) and (6.14) show that there are 86 cases that had scores so no missing case.

2. *Check to determine relationship direction:* It is essential to check the course of the relationship to know whether it is positive or negative. If values generated have a minus sign, then it is a negative correlation; this implies that as one variable increases in value, the second variable decreases in value (Moore, 2004). Then if the values are positive, it means a positive correlation, which indicates that as one variable increases in value, the second variable also increases in value (StatsDirect, 2008). Pearson's correlation was carried out to look for relationships between the variables in Tables 6.11 and 6.13, and the output of the correlations depicts significant evidence of positive correlation because the values are all positive.

Table 6. 11 Correlation between the options that make decision-making difficult



Correlations

		Different stakeholders interest	Lack of retrofit building process	Lack of decision support system/frame work	Key stakeholders' resistance to change	Lack of adequate skills
Different stakeholders interest	Pearson Correlation	1	-.023	.008	.427**	.012
	Sig. (2-tailed)		.831	.945	.000	.915
	N	86	86	86	86	86
Lack of retrofit building process	Pearson Correlation	-.023	1	.597**	.040	.218*
	Sig. (2-tailed)	.831		.000	.712	.043
	N	86	86	86	86	86
Lack of decision support system/framework	Pearson Correlation	.008	.597**	1	.264*	.147
	Sig. (2-tailed)	.945	.000		.014	.176
	N	86	86	86	86	86
Key stakeholders' resistance to change	Pearson Correlation	.427**	.040	.264*	1	.082
	Sig. (2-tailed)	.000	.712	.014		.452
	N	86	86	86	86	86
Lack of adequate skills	Pearson Correlation	.012	.218*	.147	.082	1
	Sig. (2-tailed)	.915	.043	.176	.452	
	N	86	86	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3. *Check the strength of the relationship:* this helps to check the output value of the correlation coefficient. The output value as indicated in Table 6.12 highlights different levels of the range (coefficient values and association). For example, it ranges from -1 to 1 which specifies the strength of the relationship between measured variables. When Pearson r is closer to 1, this means that there is a strong relationship between the variables. Hence, changes in one variable are strongly correlated with changes in the second variable (Nicol and Pexman, 2010). When Pearson r is close to zero, this means that there is a weak relationship between the two variables. This means that changes in one variable are not correlated with changes in the second

variable (Cohen, 1988). Tables 6.11 and 6.13 reveal that there is significant evidence in most of the correlations because the values are within the strong category while very few are within the moderate association.

Table 6. 12 Correlation coefficient value and association

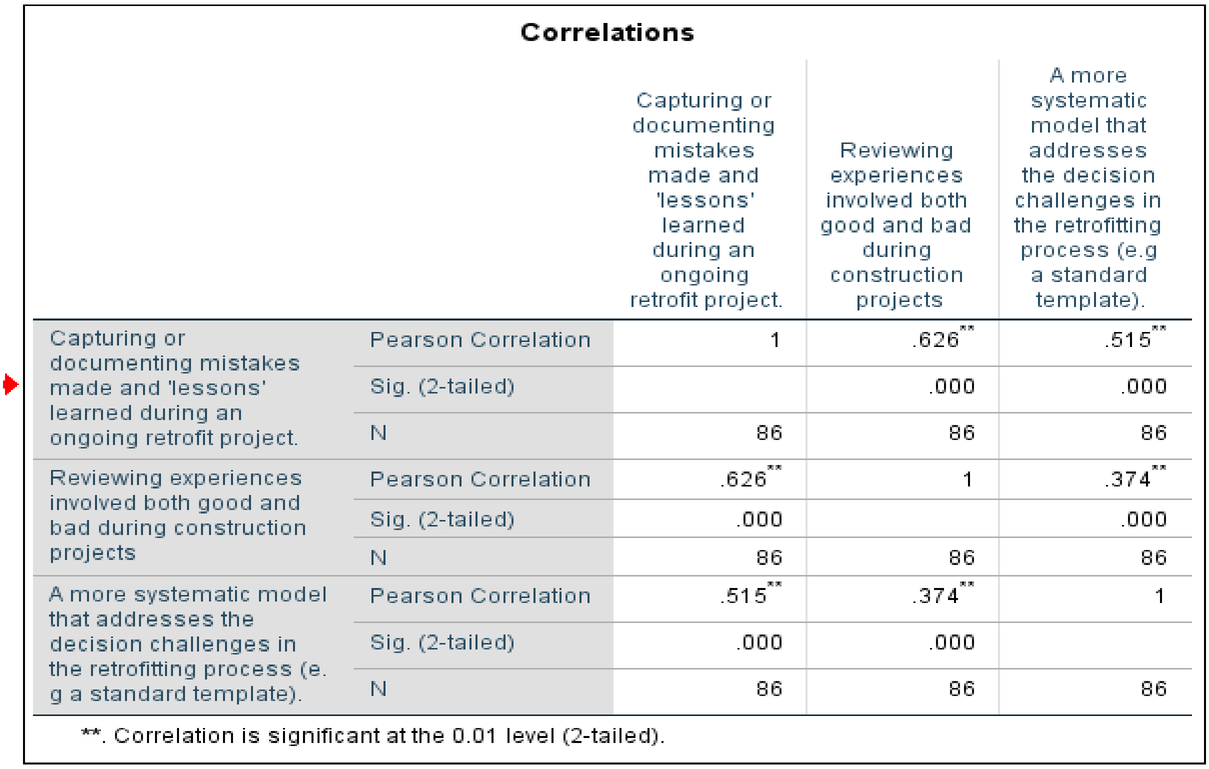
Correlation coefficient value	**Association**
-0.3 to +0.3	Weak
-0.5 to -0.3 or 0.3 to 0.5	Moderate
-0.9 to -0.5 or 0.5 to 0.9	Strong
-1.0 to -0.9 or 0.9 to 1.0	Very strong

Source: Cohen (1992)

4. *Check significant level (listed as Sig.2 tailed*): This is the last point to consider in interpreting the Pearson correlation result. It was argued that the level of statistical significance does not determine how strongly the variables are associated; instead, it stipulates the confidence level of the data obtained (Pallant, 2016). If the Sig (2-Tailed) P-value is greater than .01 or .05, it concludes that there is no statistically significant correlation between two or more variables (Cohen, 1992). That means that increases or decreases in one variable do not significantly relate to increases or decreases in the second variable. Then if the Sig (2-Tailed) value is less than or equal to .01 or .05, it infers that there are statistically significant correlations amongst the variables (Howell, 2002). That means, increases or decreases in one variable do significantly relate to increases or decreases in the second variable. Looking at Tables 6.11 and 6.13 *Sig. 2 tailed* ascertain the satisfactory level of confidence in the result obtained because most of the variables' significant level or P values are within or less than the level of 0.50 and 0.10 respectively. Hence, the researcher concludes that there is a statistically significant correlation between the set of variables measured.

It is also relevant to indicate that the diagonal *ones/1s* in Tables 6.11 and 6.13 further indicate perfect correlations between the measured variables. The matrix is symmetrical on either side of the diagonal oblique meaning that all correlations are given twice.

Table 6. 13 Correlation between the options that make decision-making easy



Correlations

		Capturing or documenting mistakes made and 'lessons' learned during an ongoing retrofit project.	Reviewing experiences involved both good and bad during construction projects	A more systematic model that addresses the decision challenges in the retrofitting process (e.g a standard template).
Capturing or documenting mistakes made and 'lessons' learned during an ongoing retrofit project.	Pearson Correlation	1	.626**	.515**
	Sig. (2-tailed)		.000	.000
	N	86	86	86
Reviewing experiences involved both good and bad during construction projects	Pearson Correlation	.626**	1	.374**
	Sig. (2-tailed)	.000		.000
	N	86	86	86
A more systematic model that addresses the decision challenges in the retrofitting process (e. g a standard template).	Pearson Correlation	.515**	.374**	1
	Sig. (2-tailed)	.000	.000	
	N	86	86	86

**. Correlation is significant at the 0.01 level (2-tailed).

6.9 Chapter Summary

This chapter has presented the study results on the statistical analysis of the industry survey. This exploratory research employed an industry-wide survey as its research strategy, which was accomplished mainly based on an internet-based questionnaire and a set of descriptive and inferential statistical analyses of the collected data. The presentation of the result aimed at ascertaining current practices in the delivery of sustainable retrofitted building projects mainly to determine the level of knowledge management in construction activities, particularly retrofit projects. The survey findings presented in this chapter revealed that indeed key stakeholders have a poor attitude or interest in managing knowledge in delivering retrofit projects. Hence, uninformed decisions are made by the key stakeholders, which in turn limits the uptake and delivery of retrofit projects. It has been revealed in extant literature in construction management that applying knowledge management principles and procedures will assist the stakeholders in the industry to make an informed decision on the uptake and delivery of sustainable retrofit projects. The survey questionnaires were distributed to 217 construction organisations across the United Kingdom and received an overall response rate of about 40%. The respondents were mainly involved in sustainable building retrofits and new build. The organisations of the respondents ranged from large construction companies to medium and small ones. Hence, the data were well distributed.

The research employed various statistical tests to analyse survey data as aforementioned, and these include descriptive frequencies, reliability tests, Pearson correlation and factor analysis. It is important to state that there was a substantial corroboration between the study results and the literature review findings. A summary of the survey findings is as follows:

a. The findings reveal that the respondents and the organisation they work for are involved more in sustainable retrofitted building projects hence the reliability and validity of the industry survey is established.
b. The data represented respondents from large construction organisations to medium and small-scale construction organisations.
c. The testing of the results established the reliability (internal consistency within the respondents) in the collected data as regards the reliability test conducted for the environmental benefits (economic, social and environmental) of sustainable retrofitted building projects.
d. The results revealed that the construction industry, particularly the key stakeholders, are not committed to the values and promotion of sustainable principles and practices when embarking on and delivering sustainable retrofitted building projects.
e. There is a lack of retrofit guidance and processes in the industry as regards embarking, uptake and delivery of sustainable retrofitted building projects. The results indicate the need for a retrofit process that can guide key stakeholders on the step-by-step or systematic processes needed to embark on sustainable retrofit projects.
f. The study established that the industry recognises environmental assessment methods (particularly BREEAM and Passivhaus methods) and some construction organisations apply them in the delivery of retrofit building projects.
g. The results revealed that the industry is favoured to whole house retrofit because they believe passive retrofit has very little contribution to the greenhouse gas emission reduction.
h. The findings revealed the order of priority that can be adopted in developing a sustainable retrofit building process.

i. The results generated and classified through factor analysis nine principal barrier factors, their components, three principal enabling factors, and their components. These factors influence the uptake and delivery of sustainable retrofitted building projects.

j. The result answered some research questions which included, amongst others: who the key stakeholders are in retrofit projects; evidence of poor management of project knowledge in the industry, particularly in the uptake and delivery of retrofit projects (see Section 6.6) and decision criteria/options that can either make retrofit decisions easy or difficult in the delivery of retrofit projects (see Section 6.7).

However, the ensuing chapter will further present and analyse the qualitative research conducted as part of this study. It will also investigate some of the findings documented in this chapter to fully answer the research questions and deliver research objectives. Some of the issues that were investigated further include: establishing critical barriers and enablers to the uptake of sustainable retrofit projects; establishing what knowledge and knowledge management mean to the stakeholders and answering knowledge questions regarding the uptake and delivery of retrofit projects and decision-making issues in the uptake and delivery of retrofit projects.

CHAPTER SEVEN: CASE STUDIES: DATA ANALYSIS, PRESENTATION AND DISCUSSION

7.1 Introduction

This chapter emphasises the key findings obtained from the multiple case studies with the 12 selected industry practitioners/key stakeholders. The chapter also highlights the case organisations and their brief backgrounds and that of the interviewees and rationales for their selection. Section 7.2 discusses the aim and objectives, invitation process, conduction of interviews and transcriptions, the trustworthiness of the research findings, the rationale for NVivo11 choice for data management, the rationale for selecting qualitative content analysis and presentation of the key findings. The chapter concludes in Section 7.8 with a summary of the entire content.

7.2 Aim and objectives of the case study

Section 5.2.2 introduced the approach adopted for carrying out the multiple-case studies and described how the aim and objectives of the multiple-case studies were identified. The main aim(s) of the case study are:

- To investigate the current practices as it relates to the uptake and delivery of sustainable retrofitted building projects;
- To ascertain the critical barriers and enablers to the uptake and delivery of sustainable retrofitted building projects;
- To ascertain the level of knowledge management penetration in the delivery of sustainable retrofit projects;
- To answer the remaining research questions;
- To address emerging issues from the industry surveys; and
- To close the gap of limitations from industry survey, for example, investigating in-depth the barriers and critical factors in the uptake of retrofit projects and in-depth investigation of knowledge issues.

7.3 Methods for carrying out the multiple-case studies

This section introduces the specific method for conducting multiple-case studies. Section 5.6.1 discussed the general methods for carrying out the multiple-case studies. The method used to investigate the issues in the study was the semi-structured interview, as discussed in Sections 5.2.3 and 5.4.3.

7.3.1 Rationale for selecting the multiple-case study organisations

Section 5.2.3 addressed the rationale for choosing construction organisations to conduct the multiple-case studies. The rationale for selecting the target organisations included three criteria:

- The construction organisations participated in the survey and communicated their interests in the follow-up study;
- Organisations are involved in sustainable retrofit projects and have had years of experience in the delivering of sustainable retrofit projects; and
- Organisations are large, medium and small thereby availing the researcher opportunity to have a comprehensive perspective.

7.3.2 Background information about the case study organisations

Twelve organisations were selected for the in-depth investigation regarding multiple-case studies. This section provides background information about each organisation.

Company 1: the company is a UK executive non-departmental public body that focusses on funding sustainable buildings and other construction projects. A non-departmental public organisation is operating at arm's length from the government and reports to the department of business UK. The UK government funds it. The company was established in 2004 before becoming an independent body in July 2007 after the organisation's reorganisation. The company has more than 250 employees and an annual turnover of about £560M. The organisation has engaged in collaborative research and development with construction organisations and engaged in small business research initiative. It has a construction section that involves supporting small- and medium-scale construction organisations in developing initiatives that will assist in achieving the reduction of greenhouse gas emission by 2050. Sustainable retrofitting and new build projects and collaboration with the industry have been some of their major targets as regards service delivery. The head technologist of this organisation was the interviewee whose background in PhD was investigating the energy performance of buildings, with professional work experience of over eight years in the construction industry.

Company 2: this is an applied building and energy research group located in the UK. It is an establishment of one of the leading UK universities with a staff of more than 5,000 and over £200M yearly turnover. Their focus is ascertaining an evidence base to have good knowledge and understanding to address issues of energy consumption in buildings. The company has been involved in a lot of funded research in relation to the delivery of sustainable retrofit projects. The establishment covers a whole range of disciplines that include the performance of buildings, construction management, and architectural design, amongst others. Some of the main aims of the establishment are: 1. To support the delivery of energy efficient buildings; 2. Collect evidence of fabric and system performance in an existing building; 3. Examine the influence of individual in the adoption of energy building improvements and energy use demand; and 4. Delivering sustainable retrofitted building and working with key stakeholders to develop practical solutions and options to improve building energy retrofit performance. The company has been involved in the retrofitting of a number of existing buildings. Its team of researchers are drawn from different disciplines particularly engineering, computing, and construction with the target of delivering the company aim(s). The interviewee from the company is a professor of construction management, who plays key role in the establishment. The interviewee became involved in both new and retrofit research projects in 2002. In 2008, the professor got fully involved in the sustainability of new and retrofitted buildings. He has over 20 years of research and development experience.

Company 3: the interviewee is a specialist energy and sustainability consultant who has worked in the building and housing industry for more than 34 years. The company is entirely a consulting construction organisation with more than 10 employees and an annual turnover of more than £500k. The interviewee is the director of the company with a vast knowledge of retrofit building projects. The company is involved in the design of energy-efficient buildings and delivery of retrofit projects.

Company 4: this company was established over seven years ago, and it is traditionally a design and technology construction company. Mainly a consultancy company. They have been involved in many retrofit projects and Passivhaus housing projects. They have been involved in the delivery of about 13 retrofit projects and 20 Passivhaus. The company has more than 20 employees with an annual turnover of approximately £1.5M. The interviewee that represented the company is a strategy and development manager, whose background is management and strategy consulting. They render paid services to both private and public clients.

Company 5: this consultancy company has been involved in retrofit projects. Their consultancy is based particularly in social housing. The company involves in the delivery of both new and retrofitted building in the UK. It has both public and private clients with 10 employees and an annual turnover of about 800k. The interviewee has more than eight years of professional experience in the industry and is a senior sustainability consultant manager with the company. The company has delivered approximately 12 retrofitted building projects.

Company 6: the company is one of the leading UK universities that founded the company. It is an energy research centre with more than 5,000 employees and an annual turnover of more than £350m. The establishment also renders services in consultancy, which delivers services in architectural design, quantity surveying, contracting, and construction. The company's clients are both private and public. The interviewee is a research fellow, who has been involved in the construction industry for more than 15 years. He has also been involved in delivering some sustainable retrofit building projects.

Company 7: this is a construction organisation that involves business development. It specialises in advertising and selling low carbon materials for the delivery of new and retrofit projects. The company sells for one of the biggest UK construction manufacturers. It also gets involved in research and development. With a turnover of more £2.5m and more than five members of staff, the company has been able to supply low carbon materials to over 50 clients that retrofitted both residential and public buildings. The interviewee is a business development manager with more than 33 years of experience in the building industry.

Company 8: this building performance engineering company engages in consultancy and technical services (including quantity surveyor) as regards to energy improvement in buildings. They have been in sustainable retrofitted building projects and have delivered about 25 sustainable retrofitted building projects. Their annual turnover is estimated to be more than £500,000 with eight employees. The interviewee has more than 10 years of industry experience. The interviewee is a chartered engineer and a managing director of the company. He renders professional services to both public and private clients.

Company 9: this is a small/medium scale construction company that has existed for more than six years and is privately owned. It is one of the UK's major suppliers for a big manufacturing company. The company supplies low carbon materials for construction projects. Its annual turnover is more than £500,000 with at least five staff. The company delivers construction projects for primary schools, colleges, universities, and other commercial contracts. It also supplies residential/private stakeholders.

Company 10: the construction organisation is one of the biggest UK contractor organisation that subcontracts to other smaller contractors to deliver construction projects. The company founded more than 100 years ago. They provide different gigantic construction projects including retrofit projects across the UK. They have an annual turnover of more than £250m with over 4,000 staff. There engage both public and private clients. The interviewee is a sustainability research and development manager with an architectural background with a professional experience spanning more than 15 years.

Company 11: it is a small-scale consultancy construction organisation delivering services around sustainability and energy efficiency in buildings. A small-scale consultancy construction organisation. They have more than five staff with an annual turnover of more than £200,000. They have been involved in a lot of retrofit projects. The interviewee is the director and owner of the company with over 13 years of industry experience. Although his background is in human resources and organisational design, he has been involved in the delivery of about 35 retrofit projects in the UK.

Company 12: this technology system integrator company is involved in the manufacturer of sustainable building construction materials particularly low carbon materials. It has been involved in retrofit projects for over 10 years. The company has more than 20 staff with an annual turnover of about £2.5m. Its clients are both public and private. The interviewee is the Chief Executive Officer (CEO) of the company with an IT background for more than 16 years, but with 10 years' construction industry experience. The interviewee is involved in saving energy in buildings through technology and delivers services to manufacturers of low carbon materials for new build and sustainable retrofit projects. Tables 7.1 and 7.2 highlight the backgrounds of interviewees and their construction companies.

Table 7. 1 Background information for the multiple-case organisations

Case study organisations	**The annual turnover of £**	**Number of employees**	**Construction Discipline**	**Do you retrofit buildings?**	**Regular clients**
Company 1	≥560M	≥250	Executive non-departmental public body specialises in funding sustainable buildings	Yes	Private and public
Company 2	≥200M	≥5000	Research and development	Yes	Private and public
Company 3	≥500,000	≥ 10	consultancy specialises in architectural designs and construction	Yes	Private and public
Company 4	≥1.5M	≥ 20	Passive home builders/consultancy	Yes	Private and public
Company 5	≥800,000	≥10	Consultancy social housing	Yes	Private and public
Company 6	≥350M	≥5800	Energy Research and development and training	Yes	Private and public

Company 7	≥2.5M	≥5	Construction business development centre	Yes	Private and public
Company 8	≥500,000	≥8	Contractor and Building performance engineering company	Yes	Private and public
Company 9	≥500,000	≥5	Consultancy and suppliers	Yes	Private and public
Company 10	≥250M	≥4000	Contractor and engineering	Yes	Private and public
Company 11	≥250,000	≥5	Consultancy, contractor	Yes	Private and public
Company 12	≥2.5M	≥20	Technology systems integrator and construction	Yes	Private and public

Table 7. 2 Information of interviewees

Case study organisations	**Interviewee serial numbers**	**Interviewee position/profession**	**Yrs. of experience**
Company 1	Interviewee 1	Lead technologist.	8
Company 2	Interviewee 2	Professor of construction management.	20
Company 3	Interviewee 3	Director	34
Company 4	Interviewee 4	Director	5
Company 5	Interviewee 5	Senior Sustainability Consultant	8
Company 6	Interviewee 6	Building Services Engineer	15
Company 7	Interviewee 7	CEO business marketer/developer	32
Company 8	Interviewee 8	Managing director	10
Company 9	Interviewee 9	Technical sales manager	16
Company 10	Interviewee 10	Technical sales manager	15
Company 11	Interviewee 11	The sustainability research and dev. Manager.	12
Company 12	Interviewee 12	Chief executive officer (CEO)	16

7.3.3 Invitation process and preparation

The invitation process of the interviewees from different organisations has been discussed in detail in Section 5.4.3. However, the participants came from 12 construction organisations. Their selection was due to the continual contact with individuals who declared an interest in the interview through the survey. Only seven respondents from the questionnaire declared an interest in the interview. To increase the participation rate for rich data, the researcher contacted more survey respondents involved in sustainable retrofit projects and engaged them as part of the interview process. The potential participants were asked for participation and reminded about the background of the research background via email and telephone, the aim(s) of the research, research questions, expected contribution, the benefit of the study ethics involved, the method used, and the target audience. Subsequently, the researcher approached them to schedule appointments for interviews. The engagement was successful as five more questionnaire respondents declared an interest to be part of the interview, acheiving 12 participants across 12 construction organisations. The reasons for selecting the interview participants is based on the intention to integrate many different views and perspectives (Alvesson and Ashcraft, 2012).

7.3.4 Conducting interview and transcription

Out of the 12 interviews conducted, two were face-to-face interviews, two were conducted via telephone recordings, while eight were conducted using Skype video. All the methods used to perform the interviews were at the instances of the companies/interviewees. The interviewees spoke fluent English; hence, the interview was conducted in the English language and was audio-recorded and transcribed word-for-word in the English language. The researcher transcribed the interview responses, which was time-consuming, but necessary, because it gave the researcher the opportunity to document ideas that cropped up in the course of the transcription. The style of the transcription uses word-for-word transcription; however, without noting ‘erm, ‘ah’, ‘oh’, ‘o yea’, and such like. Furthermore, noises, pauses, emotional expressions, and emphases in notation were not included in the transcription. The researcher employed this transcription style for practical reasons to avoid complication and slowing down the process.

After the transcription, emails were sent to the 12 participants with a transcript document attached to ensure that the transcriptions were reflected correctly and appropriately. It took two weeks for all the participants to reply to emails. However, none of the participants requested changes from the transcription that indicated that their views were appropriately reflected.

7.4 Analysis of the multiple-case studies results and presentation of key findings

The data analysis was achieved using thematic/qualitative content analysis (QCA) and NVivo as discussed in Section 5.10.

In presenting findings for further analysis, Miles *et al.* (2014) state that reporting qualitative data might be one of the most fertile fields of the reporter. They conclude that there are no standardised formats or ways for data to be analysed, suggesting that interpretation and reporting varies. However, Grbich (2013) holds a different position on data presentation and data reporting. Grbich (2013) states that theory minimisation in qualitative data reporting lies in the postmodern tradition, where minimal interpretation is made, but the maximal display of data is preferred. Thus, the reader can get close to the interviewees or participants' experiences and make their own interpretative decisions and inferences based on their understanding. Grbich, (2013) states that, *'extensive display of data rather than elaborate theorising is seen as the best way to bring your reader close to the experiences you wish to transmit'* (p.294). This is similar to O'Leary (2010), who states that the *'power of qualitative data is in the actual words and images themselves hence, words and stories of the participants/interviewees presented are the most compelling*' (p.271).

Having considered the literature of data presentation, interpretation, and reporting, this study adopts the statements of Grbich (2013) and O'Leary (2010), which in summary, suggest theory minimisation, but the maximal display of interviewees' experiences and responses. The ensuing section presents key findings on critical barriers and drivers to sustainable retrofit projects.

7.4.1 Critical barriers and enablers (on the opposite) to sustainable retrofit projects

The researcher explored the barriers and enabling factors established through the survey findings to establish, through multiple-case studies, the critical barriers and enablers to embarking on and delivering sustainable retrofitted building projects. As stated earlier, the opposite of barriers are enablers. Hence, the following presents the critical barriers and enablers of embarking on and delivering sustainable retrofitted building projects.

7.4.1.1 Lack of knowledge and knowledge management

The issue of the lack of knowledge management (KM) in construction activities has been a recurring issue in the construction industry, particularly in the uptake and delivery of sustainable retrofitted building projects. The issue of the lack of KM was discussed in Sections 2.12.5 and 3.6 in detail and it has been documented by different studies (Landman, 1999; Shelbourn *et al.*, 2006; Wood, 2007; Chan *et al.*, 2009; Hakkinen and Belloni, 2011; Maduka *et al.*, 2015a; Maduka *et al.*, 2015b). A lack of managing project knowledge relating to the uptake and delivery of sustainable retrofits remains a critical barrier factor to the uptake and delivery of sustainable retrofit projects. The interviewees indeed agreed that a lack of knowledge in the industry is a critical barrier that exists in the uptake and delivery of sustainable retrofitted building projects. Williams and Dair (2007) and Dowson *et al*. (2012) agree, in their studies, that lack of knowledge remains a major challenge that is inter-related to several barriers to embark on and deliver retrofit projects. Rydin *et al.* (2006) affirm that while designers demonstrate confidence in their ability to access and use knowledge in general, this confidence staggers when specific issue of sustainable retrofit issues are addressed.

Most of the interviewees agreed that the lack of KM remains a big challenge to the uptake and delivery of retrofit projects. This is similar to Persson and Gronkvist (2015) study discovered that the most significant barrier in the industry is a lack of knowledge. Persson and Gronkvist (2015) went further to state that a house is a complex product, but the buyer and seller are often ignorant, causing inappropriate decisions. Therefore, a broad knowledge within the building sector is favourable to the uptake and delivery of retrofit projects. Unfortunately, the opposite is reported.

The interviewees aligned, amongst other things, that training is one of the gaps that exist in knowledge of retrofit projects; hence, it was suggested that some training organisations get more involved in training industry workers in relation to retrofit project delivery. Below are some of the excerpts from the interviews on knowledge issues.

Interviewees' supporting quotes on lack of knowledge management

'Yeah. It's a bad industry for knowledge management because we don't have a central delivery path. You know, if you think about something like aerospace, they have a very large number of component manufacturers and factories globally, but all those components get channelled through a very small number of companies at the top, which ultimately are making the planes. You know, your Airbuses, like Boeing and so on. Therefore, there are a very small number of people who need to hold the knowledge and the decision making for that to cascade down through the supply chains. In addition, the supply chains are usually… They have long-term relationships with these customers built up over many decades, and so they understand the customer, and the customer talks to the supplier, and they get into a position where they each have very good knowledge sharing between them. The construction industry does not have that. We miss out on this because any knowledge that's created on one project… Yes, that knowledge stays with the individuals, but it never turns into something bigger than that'. – (NM8)

'Often you could have a very small scale retrofit, like a residential customer doing something themselves and in that situation, there might be a lack of knowledge about what they are doing because they are just doing things themselves which they are not trained for hence lack of knowledge. There is automatically a skill sometimes… not a shortage, but a lack of knowledge about what the terminology might be or how things are done can affect the uptake of the project'. – (NM1)

'*Lack of training and knowledge is a big one. I mean, the average bricklayer, the average plasterer, the average window fitter does not really know much about all these starry-eyed ambitions as regards retrofit that more educated architects and planners and engineers are familiar with. Therefore, the people who design the buildings are familiar with the kinds of challenges that you talk about, but the people who build it, who are the most important people, by the way, do not have enough* *knowledge to achieve the best finish. Simply put, training and managing retrofit knowledge are essential towards achieving a reduction in greenhouse gas emissions'. – (*NM2)

'A key problem with any retrofit is lack of knowledge. There is a lack of knowledge of not knowing the construction details and having enough information on the details. In addition, there is a lack of knowledge regarding interfacing our product with existing buildings. Moreover, that means it normally requires a visit by us to the building site to document construction activities, which would not cost much yet we won't do it'. – (NM3)

'Yes lack of knowledge and appropriate managing of it is a big issue…Well I think for everyone in the industry; I think the installers don't have appropriate training, the designers don't have appropriate training and one of the things I've learned over the last few years is: retrofit is just so completely different from new build, because you've got an existing building, you've got old construction, you've got people in place with all their things; it's just not like new build, and we need new materials and products and processes and we've been doing a lot of work with a thing called the retrofit academy, which is a body which is a training organisation that is training a group of people we call 'retrofit coordinators' and they are sorts of expert retrofit project managers, whose job is to run the whole project from one end to the other and we're trying to get as many people through this retrofit coordinator training as possible. It started at a thing called the Centre for Refurbishment Excellence, or CORE, which was in Stoke on Trent, but that, unfortunately, went broke and closed down at the end of 2015 so we've revived the training through the retrofit academy, and we're currently running quite a few programmes actually, so… That's a start, but we have to do industry-wide training, really, really because training within the industry professionals and sometimes clients is very important because that it where knowledge is acquired'. – (NM4)

'I do not think the targets will be achieved by retrofit and the reason is: retrofit projects are very difficult, and we have knowledge gaps in carrying out projects most times. Working with an existing building is very difficult, and sometimes, modern engineering material and modern solutions cannot very easily be rather applied to, for instance, a 300-year-old cottage building. Solid walls, for instance, just to give

an example, are notoriously difficult to treat, so to go back to your question, no, I do not think the retrofit project will be achieved without proper knowledge, but there is a lot of good will, and there is a lot of good work being done. We are looking at very old buildings in Yorkshire that are being retrofitted, using a passive house design package, so very few enlightened, intelligent, motivated developers and professionals are doing it, but not everybody does it, and the reason why everybody is not doing it is because it's difficult and the knowledge in the form of training is not there'. – (NM5)

'It depends upon the type of renovation, doesn't it? If it is one that… the Building Manager System (BMS) is doing. Those are very complicated and to be honest, rather than it be helpful, they are more of a pain and could be more energy intensive because the users don't know how to manage it, so there is not a proper knowledge management, no proper line of educating the end users, but then if it's a technology that is "fit and forget", they don't have to do anything, but we haven't got to that'. – (NM6)

'Some people do not have very strong environmental beliefs, and some people just do not know what they are supposed to do because knowledge is poor in the built environment. I mean, heating controls are notoriously difficult to understand, and even if you are shown how to use your heating controls, you may still not use them properly. In essence, to acquire knowledge, there should be proper training and handover after sustainable retrofitted building project is completed. This will help the end users apply the knowledge the acquired knowledge'. – (NM10)

'Well, the thing is, because I normally source innovations and I try to avoid things that have an element of confusion; I prefer things that… Like insulation; you put it in, it protects the thing, or you put something on the boiler, and after that, you do not have to do anything; you don't have to monitor it. Such things tend to work better if the knowledge you have is properly managed or rather applied to write things down to serve as a reminder rather training all the time'. – *(*NM12)

7.4.1.2 Lack of awareness and promotion

The interviewees identified awareness and promotion to be the critical barrier and enabler to embarking on and the delivery of retrofit projects. The interviewees expressed displeasure that not enough awareness has not been created about sustainable retrofit projects. The issue of this lack of awareness was highlighted in Section 2.12. In addition, it has been acknowledged to be one of the major issues in lack of interest by key stakeholders in embarking on retrofit projects (Chan *et al*., 2009; Pitt *et al*., 2009; Azizi *et al*., 2011; Hakkinen and Belloni, 2011; Davoudpour *et al*., 2012; Klöckner and Nayum, 2016). The interviewees stated that the lack of promotion of retrofits benefits remains one of the major barriers to the uptake of retrofit projects. They stressed that some stakeholders have the funds to embark on sustainable retrofit projects, but unfortunately, they do not see the need to retrofit because of lack of awareness and promotion of benefits associated with retrofitted buildings.

There is growing evidence that awareness has a critical role to play in driving key stakeholders' interests to embark on retrofit projects. In finding a solution to awareness creation, Darko *et al.* (2017) and Wong and Abe (2014) suggest that it is vital to increase the knowledge and environmental awareness of all stakeholders, particularly to disseminate retrofit benefits to increase the demand side, i.e. clients, tenants, investments, and financial institutions. The study findings suggest that information is vital for the acquisition of relevant knowledge; it is also a means of creating public awareness and acceptance. The need for awareness and promotion of sustainable retrofit projects remains vital in their uptake and delivery. Below are some of the excerpts from the interviews regarding the issue of the lack of awareness and promotion.

Interviewees' supporting quotes on lack of awareness and promotion

'There is a lot of association of a comfortable domestic lifestyle with the deep retrofit, but it's only really done though exemplars like Super Homes. We have not really at any scale persuaded people that they ought to do this, and so we have a situation where we are trying to… As an industry, we are trying to persuade people that they not only do not want to do, but they don't know why they would want to do it, and it's very expensive as well, so it seems a losing battle. Therefore, it really

amounts to the fact that we need promotion. For me, the biggest barrier is not promoting the need to do retrofit as an environmental issue as much as anything else, but also because in an era of rising fuel prices, households are going to struggle if they don't do the retrofit'. – (NM3)

'For people who want to build extensions or retrofit their homes in the UK, there isn't anybody telling them about the quantifiable, measurability, clarity of energy benefits of that retrofit. So the issue of awareness and promotion cannot be overemphasised in encouraging stakeholders to embark on retrofit projects'. – (NM7)

'There's the climate change issue, which is: it's really hard to persuade people to take… And it's quite interesting because my wife's doing a psychology degree at the moment and has been studying a module about why it is that lots of people agree that there's an environmental problem and that climate change is real and that it's a threat, but don't do anything in their lives to change it; they just behave in the same way that they ever do. They think that may be if they recycle their rubbish, they have done their bit, you know. Therefore, there is disjoint between people's knowledge and understanding, and people's actions and behaviour and that is a barrier. That is why promotion is very important to achieving greenhouse gas reduction through retrofit. Nevertheless, climate change ought to be a driver, and for some people, of course, it is; they change their lifestyle'. – (NM2)

'But, in all seriousness, there is a huge amount of awareness of the work that needs to be done. The retrofit challenge actually Specialist Independent Building Services (SIBS) and the Chartered Institute of Building Services Engineers (CIBSE) put together a conference and then a proposal called the retrofit challenge. You know, we have to retrofit a building an hour in this country. However, the measures that we use is primarily, from a technical point of view, added insulation and better H-vac systems. We use those measures. The social scientist colleagues of mine try to influence human behaviour as well, but that is all to do with the building and convincing house owners. There is a need to create awareness about the positive outcome of a retrofitted building and take it to the grassroots to convince them'. – (NM1)

'People need to be aware of the benefits of sustainable retrofitting. We need to love people to be aware that modern engineering materials exist to give them a much better building fabric design. Perhaps it goes back to education and awareness. Perhaps we have a whole array of television shows like Grand Designs and all these television shows that primarily talk about 'beauty'. The same thing could be done by the BBC, by ITV, by broadcasters, to raise awareness on the general public to care about the energy and environmental performance of a retrofitted building as much as they care about the beauty as well'. – (NM4)

'Promotion of retrofit is essential you know, for example, turning very old buildings into beautiful majestic homes via retrofits in television adverts will over time create the awareness needed to achieve a reasonable uptake of the retrofit project by the stakeholders especially the key stakeholders'. – (NM5)

'Yeah, no I use four things called the 'four As', which is awareness, attractiveness, affordability and availability. So any one of those that does not happen, as in if they do not know… That is the biggest barrier and if they happen the greatest drivers; if people are not aware of the need to retrofit, they will not get the idea to retrofit. Moreover, to overcome that, then we will do more promotion and create awareness. We can even print handbills distribute to homes it will go a long way really'. – (NM6)

'Yeah, I think it is the ability to raise greater awareness. It is pertinent to inform people of the benefits that our system offers over and above other systems, whether it is financial benefits or health benefits or environmental benefits. The voices of the stakeholder and construction practitioners must be heard and felt across the UK to create the awareness'. – (NM8)

'There is no promotion on what the benefits are on the wider population. So we do not get any of that, and that is a big barrier and on the opposite a big driver' the government, architects, project managers etc. should create awareness and promote the benefits'. – (NM9)

'I think if people were much more aware of what is possible, they would get more involved in it even if the funding is not there because of the awareness the hunger and demand to get their buildings retrofitted will be on the increase. I think perhaps, the trick that has been missed is that we do not try too hard to help people that are doing a renovation to do more of the things that we are trying to get them to do

because there is no general promotion. The industry itself isn't asking people to do more, so it's a combination of all of those things that inhibit the uptake of retrofit'. – (NM11)

'*Another way of influencing the uptake of retrofit would be for the retrofit industry in collaboration with the government to get better at marketing what it does and making it attractive to customers. This can be achieved through TV and radio adverts, billboard, handbills etc.'* – (NM12)

'Spreading the benefits of a retrofitted building through adverts is beneficial because of the huge awareness it would have created. This is because we see funding a s a major barrier, but no some key stakeholders that can afford are ignorant of the benefits, so creating awareness is very important'. – (NM12)

'Awareness with attractiveness can go a long way to convince people to take up the retrofit project. If we are asking clients to invest 10 or 20 thousand pounds, it has to be attractive and appealing... It is the same sort of money as if you were buying a brand-new car, so you have to give people a reason to want to buy it. However, you have people who know about it, but have decided that they do not want it and but then certainly you will have most people, who probably have not even heard about it hence the need to create awareness'. – (NM3)

'There is absolutely no awareness and promotion on retrofit especially in saving money in energy use. Think about fuel poverty and we're in this slightly strange position at the moment where the fuel prices have been flat for two or three years and seem likely to remain so 'till 2020, but people forgot we had very steep rises in fuel prices in the last decade, which caused significant pain to lots of low-income households and we have more rises coming after 2020, according to Department of Energy and Climate Change (DECC) and depending on what happens in the Middle East, so I think that protecting family households from the social impact of steeply rising fuel prices is going to be quite a critical thing and that ought to be a big driver for retrofit and the problem is that when we've had fuel poverty issues in the past, like when the fuel prices went up when Gordon Brown was Prime Minister, the politicians suddenly leap up and they just bash the energy companies and actually, what we need to do is bash the houses and sort the houses out and I think unfortunately this government is particularly obsessed with the supply side of the

energy and not the demand side, so we've got a situation where they're not really interested in interacting with homes and businesses to promote sustainability; they're more interested in building nuclear power stations to satisfy that demand, and if it goes wrong, it'll go really badly wrong, but that might be what we need in order to get people to wake up and do something'. – (NM10)

7.4.1.3 Lack of funding/grants/incentives to retrofit

Lack of funding, grants and incentives is a critical barrier and enabler in the embarking on and delivery of sustainable retrofitted building projects. This is corroborated by different studies (Ambec and Lanoie, 2008l; Pitt *et al*., 2009; Azizi *et al*., 2011; Klöckner and Nayum, 2016). The interviewees expressed that it is a major barrier and some suggested that the banking institution should be part of retrofit projects, by providing soft loans, retrofits, and mortgages since a retrofitted building project has an advantage over a non-retrofitted building. The interviewees stated that the government should provide more grants rather than loans to the key stakeholders to encourage them to embark on the project. Some literature supports this, for example Persson and Gronkvist (2015) and Dowson *et al*. (2012) affirm that financial incentives are needed to increase the number of energy improved homes.

Interviewees added that energy improved homes are not very expensive to achieve, but people still have the view of cost misconception (see Section 2.12.1). Hence, positive incentives can be used to stimulate a variety of behaviours to consolidate behavioural change. The NEF-EEPB (2014) also discovered, in their study, that there is a lack of stakeholder interest because retrofit is seen as 'unsexy' and stakeholders need to be inspired with incentives because they need to prioritise against competing demands for time and money and other desires (lifestyle, cars, and holidays). Therefore, the inspiration will come from either incentives or grants. Below are some excerpts from the interviews.

Interviewees' supporting quotes on lack of funding, incentives/expensive to retrofit

'There were the Green Deal loans, and the Green Deal Home Improvement Fund and the Home Improvement Fund was ridiculously in demand, oversubscribed because it was grants; it was cash. Whereas the Green Deal loan, it was not cash, it was a loan. So there is no shortage of demand because people were desperate to get

their hands on these grants to do the work. However, at the same time, the green deal, which was not offered as a grant, but was offered as you no doubt understand an expensive loan, there was no demand for that almost. I will not talk more about the finance side of Green Deal too much, but it was a disaster and never worked out'. – (NM1)

'The other thing they can do is probably to have incentives because maybe that could be an opportunity, because when we have innovations when we can look for technologies that qualify for tax rebates and things, you know, they tend to have a better potential of being tried. So maybe some incentives to encourage or to support the initial capital cost is essential and great driver'. – (NM2)

'Well, a Housing Association two or three-bedroom house. To get the emissions down by 80%, you would need to spend £80,000 for a Housing Association two or three-bedroom house. If you were doing it at scale, doing a whole estate, you might do it at £50,000 a house – but that is a lot. Moreover, if it was 50 or 60%, it costs about half that. So you're then talking, you know, 25 grand house, but even over 20 million houses, which is probably how many we've got to do, that still adds up to £500 billion, so... That is quite a lot of investment. Therefore, it needs to be funded through government grant or loan because that will go a long way for the uptake of such projects and if we have to achieve government target of 60% emission reduction by 2050'. – (NM5)

'So, I think the main point is still around funding. I think people can see the benefits of it, but we need to be able to actually value the long-term benefits and also the short-term investments that people are making anyway, so maintenance etc. are all probably grouped as part of that, to deliver the retrofit funding is essential, but at the moment no strategic funding by the government of financial institutions, it's a driver depending... Especially the public side it remains one of the greatest challenges'. – (NM6)

'Well that would drive them is money. So many different things need to happen at once. It will never be one thing. Therefore, it is about trying to get conditions such that people are encouraged to do it in the first place. So having the right incentives, whether they be financial or about low-interest loans for helping people of things,

but also, an incentive often is almost like a stick waving the carrot. There should be enough incentive for people to want to do it'. – (NM7)

'I think lack of money and incentives money remains a big barrier and driver on the opposite. I do not think people want to invest in this kind of technology. Retrofit projects save people money in the long run, but actually, what people are interested in really is making a profit in the short term, so there's minimal kind of long-term view of looking at the kind of overall life cycle of the building'. – (NM8)

'Remember we discussed earlier lack of demand within the key stakeholders. I can assure you that even if there is a slight increase in demand, the ability for that demand to be met will be decreased because of the lack of funding or reasonable incentive, so the financial institutions need to buy into the retrofit project, not just the government and that is where the issue of awareness echoes'. – (NM9)

'Lack of funding remains a big barrier towards the uptake of retrofit projects. Still, things could be done, and the government could give subsidies for instance, or could help developers who go beyond minimum requirements. They can champion that by adequate funding'. – (NM10)

'Financial institutions definitely have a role to play. There is some work that the UK Green Building Council was doing… Some work on green mortgages, and it would be worth looking into that if you have not heard of it. They are working with some of the major banks, led by HSBC on it'. – (NM11)

'You know, to actually say, this is the thing that you could be doing, should be doing to your property that will make your property better. That is for the housing sector. And I think there is space for funding, for grant funding of emerging technologies and things where we actively want to build a market for a new technology or for things that are strategic, like heating, where it might not happen on its own, but it's important on a social scale for it to happen, but funding by relevant financial authorities can make the retrofit market to boost and at the same time reduce greenhouse gas emission'. – (NM12)

'I think there is a lot of goodwill in local authorities and housing associations. Many people, if the resources could be found want to do a retrofit. We have lots of Housing Association clients that are quite keen to do retrofit, but they've just got no money;

they’ve been given a 1% rent reduction; they’ve been given deregulation; their tenants have been given the right to buy, and there are all sorts of other factors which are preventing them from improving their stocks and it’s very hard to get them to see beyond the pressure that’s coming from the regulators and the government and say: well what you’re here for is to provide affordable housing and affordable housing means energy efficient housing, so I think it is quite difficult for them’. – (NM3)

7.4.1.4 Lack of compelling legislation and political will

The majority of interviewees indicated that lack of political will to implement regulations is a critical barrier to the uptake and delivery of sustainable retrofitted building projects, and it is equally a critical enabler. One of the interviewees disagreed with the majority of the view, stating that the government believes they are on track with the sustainability agenda. However, the majority of the interviewees agreed that the government should establish a standard for delivering and enforcing retrofits. They state that for even the existing standard regulation, there is a lukewarm attitude to enforcement. Some authors have acknowledged this as a major barrier to delivering sustainable retrofit projects (Pitt *et al*., 2007; Pitt *et al*., 2009; Winston, 2010; Klöckner and Nayum, 2016). In a similar finding, Persson and Gronkvist (2015) reveal that various governments had not ‘put their feet down’, hence not compelling regulations, and that they lack the political will to enforce even the existing ones. They further discovered that there is no assistance from politicians because they do not care.

In a similar study, the NEF-EEPB (2014) affirms that whole house retrofitting is not on the government agenda and there is a lack of legislation and incentives. The publication emphasised that transparency, longevity, and certainty are required in policy implementation for retrofit market growth. The changes in the planning system in the UK suggests difficulties for local authorities to set standards and their powers are limited. Hence, it is necessary to be more proactive in persuading developers and other key stakeholders to embark on energy improved building projects (Pitts, 2017). Some excerpts of the interview in relation to this are presented.

Interviewees’ supporting quotes on lack of compelling legislation, enforcement and political will

'Yes, I agree that legislation is compelling the stakeholders to retrofit their houses to at least minimum standard to be put in place. However, I question whether it can be enforced as well is another issue. However, but if you look at homeowners, if you put a penalty on me, no, I am not going to do a retrofit. If you penalise me, again, it is about you enforcing it, but again, it is about who wants to be with the government that says "Oh, you must raise your hand to an energy standard or else" because it is not what people want'. – (NM1)

'I think we should have some standards that people are expected to bring their homes up to. I am chair of a thing at the British Standards Institute (BSI), called the Retrofit Standards Task Group and our job is to establish British standards for retrofit regarding insulation and efficiency and all those kind of things, but I think we need some political standards. We need to be able to say: by 2025, all our houses must be retrofitted, or something like that and so I think we… It is lack of leadership in a way, and I think the problem is that the stride of the environmental problem and therefore of retrofit is longer than the stride of a parliament, you know. It's just that… if the problems of not retrofitting comes, it, will be way beyond when all the politicians have retired, so they don't really have any interest in setting all our lives to respond to a challenge which isn't going to affect us during their period in office, so I think there's a big contradiction in there about… One of my colleagues said that we need a big climate change disaster in order to…Have a political will to tackle lack of uptake of retrofit projects and delivery issues'. – (NM2)

'Some regulations force a minimum standard on people, but at the moment, no enforcement and a stricter regulation needed because the existing regulations on retrofitting are very poor. I think it is about having legislation that compels stakeholders that would be a great driver may be for people to improve their homes' energy performance'. – (NM4)

'I am not sure that legislation is the answer to everything, no. People need to be inspired to do the right thing; I think they need a good demonstration of where this technology has been used successfully, so promotion, in my opinion, is one of the greatest drivers to achieving sustainable retrofits. I think legislation should be an absolute last resort'. – (NM5)

'I think it has to do with lack of compelling legislation on sustainable retrofit… it is essential for the government to have a sort of realisable mandatory legislation that will go a long way to necessitate the key stakeholders embark on retrofitting of their houses. They should develop and introduce a sustainability standard for retrofit and enforce it. One way that would drive uptake would be to regulate for it, so as we have regulations, minimum building regulations for new builds, to impose regulations for retrofit. That would make it happen, but it might not be popular, and the government does not always like regulation, but certainly, it will go a long way'. – (NM7)

'There are all sorts of levers. So you can subsidise, you can incentivise, you can tax, you can have grant funding in place, but it is how you govern those things as well, so if you look at Scotland, they do it very different from England and Wales. Wales do it differently. So the first thing is about the political will, and I don't think the government have political will really at the moment to do this in England, because it's been difficult. You know, it is done for more than one politician's career. My view is it probably would be better at the regional level, so maybe at the city level, because people understand the stakeholders that are involved, but some national companies are engaging with it, but a lot have been bitten because of the changes. We need political stability and will around this so that businesses can understand that there will be a market there and the market will not be whipped away. It is about stability fundamentally first because this is not a five-year project. You know. Five years is the government, a comprehensive spending review… That cycle is too short, but certainly, political will is needed'. – (NM8)

'Well lack of political will on the side of the government is exactly one of the major barriers to delivering retrofits. If you look at private landlords or property owners, minimum energy standards already have a driver on that. I question whether it can be enforced. However, if you look at homeowners, for example, me, if you put a penalty on me, no, I am not going to do a retrofit. If you penalise me, again, it is about you enforcing it, but again, it is about who wants to be with the government that says "Oh, you must raise your hand to an energy standard or else…." because it's not what people want. So, you see the issue of political will comes up'. – (NM9)

'Yeah. I am slightly uncertain about the government thing because when they interfere with stuff, it seems to me they usually make a mess of it. The Green Deal is

a good example of that and Eco is a good example. But I do think that the industry could deliver a lot of retrofit at scale and would be keen to do so, 'because there is money in it, if the government would just tell people why they need to do it in order to promote it and a few things, like reducing stamp duty on high performing homes or having a minimum engineering, procurement, and construction (EPC) grade that you have to achieve in order to sell your house, you know, maybe with five years' notice, or in five year steps, so that perhaps by 2020, you can't sell a house that's less than a D or an E and then in 2025, less than a D and then 2030, less than a B, so people would know that they would have to improve their homes to get to that point. I think that would be a very controversial policy because it involves people having to spend money. Nevertheless, that kind of things, a mixture of what Brenda Boardman calls sticks and carrots, you know, would probably be what we need'. – (NM10)

'Well, that's a difficult question, because the government interventions have notoriously been unsuccessful, at least in the construction industry; it might have worked in other industries, in the medical industry and education, for instance. However, in construction, whenever they have, for instance, the idea of having energy performance certificates for buildings before a property owner can rent them out, Standard Assessment Procedure (SAP) assessment, standard assessment procedure, I mean they are notoriously mediocre, and they just do not reflect the realities of building performance. So, even if there is compelling legislation no political will to enforce it'. – (NM11)

'Yes, there is a need for a long-term mandatory law for retrofit. I mean, I think what we need are two things; we need the zero carbon standard for new build back, so the new stuff we build shouldn't be allowed to add to the burden, but then you're absolutely right; there's no way you could get to 80% reduction in emissions when 25 to 30% of emissions come from home, and the rate of replacement is half a per cent per year, so there's not a chance of replacing inefficient homes with new ones to enough extent by 2050; we have to improve the existing ones. So… And that's why I think the measures I mentioned before, the idea of setting a standard of performance at, say, five year intervals for the next 20 or 30 years and saying that you may not rent or sell a house that has worse performance than this, means that people, if they're buying a house now, will know that they have to do some work on

it by 2020 or some more by 2015. Some people will say, "Well, we'll improve our house to the 2030 standard". Some people will do it bit by bit, and so I think we do need that kind of standards in place in order to provide the stick that goes with the carrot that says well if you do it, you'll get a more comfortable home that's cheaper to run and all that. So I would say it is around standards really, at the point of sale or the point of letting'. – (NM12)

'Government can train more people so they can be a bit more stringent with enforcing the existing building regulations because we know for instance that developers who build buildings to the minimum requirement now, the planning officer that goes to certify those buildings is there for tick-boxing measure. In addition, some of those walls are not as good as, what they have been designed to. So, there is a huge political challenge, and it would upset a lot of people, for example, Balfour Beatty has to spend 25, 30 million pounds developing a site and then they want to get the certificate and then go on to sell those sites and if the planning permission officer stands in their way and says: I'm not going to sign it because it didn't meet our standards, you would have a revolution and those big companies are powerful; they have lobbyists, they pressurise the government, so it's a very difficult goal to achieve unless there is political will'. – (NM3)

'I think there should be more legislation about what needs to be done, yeah. However, I am not a huge fan of government interventions, but I think under the Conservatives, the current administration, they… If anything, they want to deregulate; they want to remove regulation, rather than to introduce more regulations. Nevertheless, I think what this country needs to do is, as much as it can, continue to support renewable energy and tighten up building regulations. I think that would be probably the best we could do'. – (NM4)

'Oh, the political will is critical to retrofit uptake. I completely agree that there should be more legislation and political will to implement it. However, the question is how popular is retrofit in the industry and different part of the country obviously it is not, but I think retrofitting is far more important than building new, but we do need… We have many people that do not have homes to live in. We do have many empty properties. Nearly a million empty properties. Therefore, if incentives were to change in the legislation around gaining access to empty properties would be very

important in my view. However, yeah, at the moment, everything is all about new-build. Whether we like it or not retrofit legislation is very important'. – (NM6)

'I think moving towards mandatory legislation would really make it happen, which is putting out signals now to say that by a certain point, all properties would have to meet a minimum energy efficiency standard and to help people and support people and maybe grant some people who choose to do it ahead of deadline, but at a certain point in time, you will not be able to rent out or sell your property if you haven't made improvements to it and maybe you penalise people through council tax or you reward people who've done better through council tax at that stage. However, I think that you have to give people warning that this is coming because it is a lot of investment in your house, so it almost needs ten years or so before the first regulations come in and that way, you are starting to make the market happen. The market or up to take of sustainable retrofit won't happen on its own at the scale that we need unless the government make it happen'. – (NM8)

However, one of the interviewees stated that there is an existing regulation on the minimum standard of energy improvement to be achieved with a penalty, but stressed that the government lacked the political will to enforce the penalty: *'Well there already is, isn't there? There is a minimum energy standard, which has a penalty clause attached to it, but again, that is all about enforcement, so I would suggest it depends on whom you are dealing with. If you are dealing with a business, the penalty is the right way to go in some respects. If you are dealing with an owner-occupier, putting penalties on them is politically untenable, and they should be more carrot than stick. However, I think it has to do with going back to the drawing board for the government to have short of mandatory legislation. Again, going back to my point that they need to be certain and clear about what they are doing. Not that they will set zero-carbon homes and then when the time gets closer, they will just say, "it was not achievable", you know?'* – (NM5)

Another interviewee disagreed that the government does not need more regulations because it states it is on track with the carbon budget, hence no need for more legislation: *'Not really. No I don't, because I think legislation would be required if the country needed to respond quickly to this, but the government is currently saying that we are on track with our carbon budget; we do not need to retrofit more than* *we are doing at the moment. With those statements, stiff regulations will not be achieved'.* – (NM1)

7.4.1.5 Lack of skilled workers or expertise

The findings of this study reveal that lack of skilled workers/expertise remains a critical barrier and enabler to the uptake and delivery retrofit projects. This has been acknowledged by some documented publications (Williams and Dair, 2007; Wood, 2007, Pitt *et al*., 2009; Winston, 2010). However, the interviewees agreed that it is not enough for some qualified construction workers to deliver a sustainable retrofit. In a similar publication, Masrom *et al.* (2017) agree that lacking expertise in delivering sustainable retrofitting projects is one of the major barriers that should be of great concern to the industry. The study also discovered that there is insufficient expertise in ensuring that sustainable refurbishment works can be delivered successfully to achieve the project objectives, especially within the design team. Hakkinen and Belloni (2011) affirm that some designers lack wide competence in sustainable building projects; this is also connected to the fact that designers lack integrated sustainable building design tools.

The interviewees suggested that industry workers need training to be well informed with retrofit challenges when delivering a project. Another interviewee suggested that the training should be extended to some key stakeholders, such as tenants, to reduce the burden placed on industry practitioners after delivering a retrofit project in relation to the management of low carbon installations. Below are some supporting quotes of the interviewees relating to the lack of expertise.

Interviewees' supporting quotes on lack of skilled workers or expertise

'A lot of retrofit measures are still brand new or relatively new; so there's just not much experience in installing solid wall insulation, mechanical ventilation, underfloor insulation; they're all still new, and we don't yet have the skills and the quality in place to make sure we're doing it properly'. – (NM2)

'Yes lack of expertise in the industry remains a big barrier. In fact, it goes back really to training, beyond and above anything else'. – (NM3)

'Oh, lack of expertise absolutely is a critical barrier. Because if all these things are done wrong due to lack of training, there's a good chance that the building will be worse off than it was before you started'. – (NM4)

'There is often less professional members involved in the retrofit team, if you like, on a job where the client is likely to be leading on a small-scale project. On a larger scale, I would say… As far as I know, we haven't really been involved in any really large commercial; retrofit type projects, but on a large project, you're more likely to have few professionals on board'. – (NM5)

*'I mean we have few professionals that knows retrofit measures, training could be helpful. But then it's: how far do you train? Because you might have a tenant in a building and then they move out, then the next tenant comes in, so there should be a cycle of training. Just a very simple example: a washing machine, we use it every time, but every washing machine has its model, and we are actually in my auntie's house here, and I don't know how to operate it. It has got the signs, but I have no idea, and I just press, press, press, so training remains a good option perhaps before tenants move into the property newly they should be properly trained to use the sustainable equipment in the property'. – (*NM6)

'That is one of the major issues particularly in small towns in the UK'. – (NM7)

'Well, I do not know of that, I think we have professionals to do the job, but there are odds against retrofit as the clients don't demand it'. – (NM8)

However, one of the interviewees contrasted that the industry had enough personnel for the delivery of retrofit projects and stated: *'I think we have a fairly reasonable number of expertise at the moment…Not enough though, we have Retrofit Academy that helps to train interested people. But the even if we have enough skilled workers to deliver retrofit projects, if the stakeholders are not aware of the benefits that come with retrofit, if there is no grants or incentives we haven't achieved anything really, and that goes back to the issue awareness and funding, in my opinion, those two are the greatest barriers to achieving retrofit'.* – (NM1)

Despite their different views, most of the interviewees identified a lack of skilled workers or expertise as a critical barrier and a critical enabler.

7.4.1.6 Lack of demand

The results from the interview indicate that the lack of demand from the key stakeholders remains one of the critical barriers to the embarking on and delivery of sustainable retrofitted building projects. All the interviewees agreed that this is a major barrier to embarking on the retrofit project. This has been acknowledged in different studies in academic and industry publications amongst others (Landman, 1999; Wilson and Tagaza, 2004; Klöckner and Nayum, 2016). The interviewees agreed that there is a lack of key stakeholder demand for energy efficient homes and whole house retrofits, with many key stakeholders not wanting to carry out measures because of the lack of awareness of the benefits of retrofits. Osmani and O'Reilly (2009) affirm that there is a lack of demand for sustainable properties, mainly retrofits, amongst the public. This is because of a lack of awareness of benefits of retrofits amongst key stakeholders (Crabtree and Hes, 2009; Pinkse and Dommisse, 2009a; Zhang *et al*., 2011) and KM (Maduka *et al*., 2015a).

Some of the interviewees revealed that lack of demand is caused by lack of knowledge and funding. Some interviewees wondered how the UK would achieve its target of greenhouse gas emission reduction by 2050, since the demand for retrofit is low. To achieve the 2050 target, one of the interviewees stated that the UK needs to complete 20 million retrofits before 2050, which equates to one retrofit per minute. This suggests that the demand needs to be a lot higher than it is now. However, some of the excerpts from the interview on the lack of demand are stated below.

Interviewees' supporting quotes on lack of demand for the uptake of sustainable retrofit project

'So, for some office buildings for household name clients, sustainability is still going strong, but for most tenants, most companies who occupy the building, sustainability is not that important to them or their customers. So they tend not to make it a requirement of the building they occupy to have that standard, and so the developers decide that it is not worth developing to have that standard because that is not what the market wants. So the demand is not there for that part of the market'. – (NM2)

'Yeah, the demand is not there for that part of the market. Therefore, I think you have to break the market down into its different sectors, where you will have those people who know about sustainability, care about it, and only want it and some of the

retailers… Therefore, Marks and Spencer's for instance, or the Cooperative Sainsbury's to an extent, Waitrose, they come into that camp as well, where they understand it; they have teams of people who do it, and that is what they want from their buildings. Then you have people who know about it, but have decided that they do not want it and then you'll have most people, who probably haven't even heard about it'. – (NM1).

'Lack of demand, but even if there is a slight increase in demand, the ability for that demand to be met has decreased because of the lack of funding'. – (NM3)

'Key stakeholders don't aspire to do it and have other priorities such as paying their mortgage or their rent, getting their kids through college and replacing the car and all that stuff, so retrofits seem not to be a priority for a lot of key stakeholders hence the demand is low' – (NM5).

'I think demand at the moment probably isn't as high as it probably needs to be, so I don't know if you know from the research we have completed that the UK needs to complete 20 million retrofits by 2050, which is basically one a minute per retrofit, which means the demand necessarily needs to be a lot higher than it currently is'. – (NM6)

'*The demand for retrofit is low, but to stimulate that demand in the market, unfortunately, that hasn't happened because even if people want it, they usually can't afford it at present. Moreover, the changes in our government's policy sometimes do not add up hence the low demand for retrofit projects'.* – (NM9)

'Yes there is lack of demand for retrofit within the key stakeholders. However, even if there is a slight increase in demand, the ability for that demand to be met has decreased because of the lack of funding'. – (NM10)

'I think it is a mixture of there are many people in the industry who are talking about the negative impacts of external wall insulation (EWI) which is a form of retrofit. I think that with more promotion of that combined with the need for energy efficient measures pushed by the government will lead to greater demand. I think we are probably two or three years off that'. – (NM11)

7.4.1.7 Lack of collaboration amongst the key stakeholders

The interviewees have identified lack of collaboration as one of the major barriers and critical enablers to the uptake and delivery of retrofit projects. Lack of collaboration amongst the key stakeholders has been discussed in Section 2.12.4 as one of the barriers to retrofit project delivery. Mills and Glass (2009) agree that necessary skill-mix collaborations are needed in sustainable retrofitted building projects, and such skills include awareness, communication, experience, comprehension, lateral thinking, leadership, technical knowledge, passion, and negotiation. In suggesting a solution for lack of collaboration, Hakkinen and Belloni (2011) suggest that retrofit building projects require a strong interdisciplinary collaboration within the designers, builders, clients, and other stakeholders right from the planning process of the project (Hakkinen and Belloni, 2011). Different types of clients can demonstrate a distinct influence.

Government and local authority organisations who are part of the key stakeholders that own and develop public buildings can influence the demand of retrofit projects significantly if they collaborate with the industry and its supply chain, and the academics. Therefore, collaboration remains essential to the uptake and delivery of retrofit projects. Below are some of the excerpts from the interviewees on this critical barrier and driver factor.

Interviewees' supporting quotes on lack of collaboration amongst the key stakeholders

'I am not sure collaboration is the problem because the industry practitioners are. Remember Stoke on Trent; the industry came together to make that happen. In addition, they are a lot of cooperation going on within companies, so the industry has a pass mark in my judgement'. – (NM1)

'There's a big disconnect between what people think they want, between what councils and other property owners think they need and what the supply chain is willing to offer. Therefore, it is a case of trying to get them all together to understand what each of them needs in the market and then help them to get on with it. So collaboration is important to the key stakeholders including the industry practitioners to help in the retrofit projects delivery'. – (NM4)

'Well again, it is this cooperative model, I guess, that I described it well. Two sets of members own retrofit Works, so you've got the installers on one side, and we call them 'advocates' on the other, so local authorities and community groups etc. on the other sides and they are all the people pulling for it all to work. So both sides of the market effectively have designed the cooperative hence the essence of collaboration amongst the stakeholders'. – (NM6)

'I think the house building industry is particularly recalcitrant. The house building industry always kicks against every standard that's eve… It always pushes back against every standard that it's offered that's proposed and in fact, they fight tooth and nail against it and then once it arrives, they'll find the cheapest way to deliver that standard'. – (NM10)

7.4.2 Emerging themes

Lack of coordination by key stakeholders has been identified as one of the barriers to the uptake and delivery of retrofit projects, but was not recognised as one of the critical barriers or drivers by the interviewees. In addition, decarbonisation of the national grid was identified as a way of reducing the emission of greenhouse gas and an alternative to retrofits. However, one of the interviewees stated that implementing decarbonisation is very capital intensive and unlike the government to embark on such a 'white elephant' project.

7.4.2.1 Lack of coordination amongst the construction stakeholders

Lack of coordination amongst key stakeholders has been identified as a barrier to the uptake and delivery of sustainable retrofit projects. Interviewees state that the diverse skills of the industry and its fragmentation and complicated nature of some existing buildings require coordinated stakeholders to deliver retrofit projects. The excerpts of the interview are presented below.

'So the supply chain for retrofit is made up of lots of small companies, each of which specialises in one thing, so a heating company, an insulation company, a glazing company… However, to have a good retrofit, you need to think about the whole house and to think about all of those things at the same time. So there aren't very many people who can coordinate across a whole house retrofit at the moment. Therefore,

we do not have… There is not enough understanding of how different measures work together'. – (NM1)

'Key stakeholders and the construction team sometimes are not coordinated to sustainable delivery retrofit, and in my own words it impacts on both the uptake and the delivery of the project and delivery'. – (NM12)

7.4.2.2 Decarbonisation of the national electrical grid to achieve emission reduction

The decarbonisation of the national electrical grid has been identified as one the major ways to the reduction of greenhouse gas and stated it could be an alternative to retrofit if the government is not ready for collaboration. However, the interviewees highlighted that it is achievable but very costly to deliver. Below are some of the excerpts from the interviewees.

As the interview went on decarbonising of the national grid became an emerging theme. Below are some of the excerpts from the interviewees' comments:

'If the UK is to achieve 2050 greenhouse gas emission reduction by 2050, then there is a need to bring on more wind and nuclear in the long term, and that means decarbonisation of the electrical grid will increase in pace. Therefore, what we are left with is the heating and the gas consumption and the emissions associated so that I would focus my mind on… What I think about retrofit these days, I tend to concentrate more on the heating side than on power and heating is a massive issue. We do not know how we will heat our buildings if the global supply chain for gas was to be impacted by for example if Russia is going to war, for instance. Hence, there is a need for decarbonisation of our electrical grid'. – (NM1)

'I think the pace at which the electrical grid is decarbonising means that the carbon emissions of existing buildings are falling anyway. So, the government should invest more on decarbonisation if they're to achieve the 2050 target of greenhouse gas emission reduction, but it's very expensive that is why retrofit should be encouraged'. – (NM2)

'Retrofitting may be difficult to achieve before 2050, but decarbonisation of our electrical grid will go a long way in reduction of greenhouse gas emission. If we achieve decarbonisation then what we are left with is the heating and the gas

consumption and the emissions associated, so I would focus my mind retrofitting those'. – (NM5)

'You could achieve targets without doing any retrofit if you replaced every single bit of energy generation and energy supply in the country through decarbonisation. For example, if we decide we are not doing coal, we are not doing oil, and we are not doing gas. We are only doing renewables. You could just take out fossil fuels from the system, and you would not have to retrofit anything or anybody. However, that would be very expensive, it would not deal with the problems of intermittency of wind and sun only being around at certain times, and it would not deal with the big challenge we have, which is heating because most of our heating is gas. Therefore, if you cannot do it that way, then you have to look at retrofit projectst. That has to be part of the equation, but decarbonisation is very important to emission reduction'. – (NM9)

'If achieving the uptake of retrofit by the key stakeholders become uphill task then the government should tread the path of decarbonisation and map out about 10-year strategy into achieving that'. – (NM11)

7.5 Risk and complications

The need to ask questions about risks and complications involved in delivering retrofit projects was revealed in the survey findings, hence, was considered in the multiple-case studies data collection. This was important because some of the respondents in the survey stated that the industry needs to know about the risks and complications associated with the retrofit project so that it will take it on board to deliver solutions. However, investing in energy-efficient building projects is bound to have some risks and complications due to the complex nature of existing and hard-to-treat buildings in the UK. Risks and complications have been identified to be one of the barriers to the uptake and delivery of retrofit projects. Pinkse and Dommisse (2009a) agree that risks exist in retrofit project delivery and identify some risks to be untested technologies or methods and project managers' tendencies to stick to experienced and proven technologies, even when there are available cost-effective alternatives.

Interviewees stated that lack of knowledge or focus, through the planning and construction process, usually results in an efficiency reduction and bad architectural designs is a risk that causes complications with project stakeholders. They also reveal that the risks involved include the lack of attention to detail at the assessment stage, at the design stage, and the installation stage, on the corners, at the junctions, and the edges. Hence, places where things join can potentially cause complications if not professionally handled in retrofit project delivery. One of the interviewees added that the risks/complications are usually caused by a lack of understanding, knowledge, and awareness from key stakeholders involved in the retrofit project. They suggest that managing knowledge regarding training amongst key stakeholders and the supply chain is essential in reducing the risks and complications involved in the delivery of the retrofit project.

Below are some of the excerpts from the interview:

'There are many risk factors. Most products tend to work on the bench. They will tend to work on the bench. So there is a problem in bringing those products and understanding how they perform as a system, which is what we do at the energy so understanding how products work together to function as a system because they're more complex'. – (NM1)

'What we have been working on a lot recently is managing technical risks in retrofit. Therefore, condensation risks, thermal bridging, performance gaps and all that kind of stuff. So a lot of the work I've been doing in the last three years has been about techniques to manage technical risks to give people more confidence to do it and to help them to understand how to do it successfully'. – (NM2)

'Well, in the end, it's all about attention to detail at the assessment stage, at the design stage and the installation stage, but it's also about a focus on the corners, the junctions, the edges; it's where things join that retrofit goes wrong. You know where the wall insulation joins to the window or where the wall insulation joins to the roof insulation or the floor insulation. It's that kind of places where you get the air leakage, that kind of thing, so it's attention to detail at the corners, junctions and edges and also the interfaces. The interfaces between the building's fabric and the ventilation system for instance. How airtight, how well insulated, what about ventilation. Interfaces between the building's fabric and the heating system. If you

are retrofitting, you are increasing the insulation, so you're reducing the heat loss, so it becomes too big and the interface with the people, which is really what we just touched on'. – (NM3)

'Well risk exists like wall insulations, but not in our market; not the way we do it, but there is in the market where people do external wall insulation (EWI) wrongly, which generate issues. We don't do that wrongly, so it's not an issue for us, but in the market space EWI's, are dangerous for a lot of reasons for example because they want to make the home very airtight they make it wrong leading to a lot of health problems, especially respiratory-related issues'. – (NM4)

'Yeah, there are risk factors. To specify, retrofit does not work as planned; the contractors install what they want to install, rather than what is best for the client and they provide no guarantees. In addition, poor quality and late delivery are part of the risk factors that could prevent key stakeholders from embarking on the project'. – (NM5)

'Of course, there are risk factors. I mean, the primary risk is that people are not getting what they pay for. Moreover, the performance needed for the design is very rarely achieved, you know'. – (NM6)

'Yes, absolutely risk factors exist. I've been involved with so many different designs… The fact that we have one of the oldest building stocks in this country. You know, I was born in Iran. People do not live in 200-year-old houses in Iran. You know, a 200-year-old building is a museum, but in this country, it is just completely accepted to have a 200-year-old cottage and people live in it quite happily. The age of the building stock in Britain makes it very difficult to treat. The fact is that construction is just so expensive in Britain, although a huge amount of our labour comes actually from overseas immigrants because they are cheaper. That makes it very difficult as well'. – (NM7)

'Well, yes, for larger projects, yes there are risk factors. For smaller projects, for domestic projects, probably few risks. So if somebody comes in and says "Oh, well you know, you've got a 200-year-old cottage, and I can do this, that and the other; we'll change the windows, we'll add internal wall insulation, we'll render it outside, and yes, it would be £75,000, please. But nobody really tells them anything about an architectural drawing of their retrofit and if there is an extension, of their extension

design, but nothing on the energy part, unless it's a large project, like a complex office building, or a hotel, where you would have an energy specialist building virtual models, energy models and then simulating the differences. So sadly, the architectural design exists, but it does not especially in smaller projects. From my perspective, which is what I would think I'm entitled to talk about, because of lack of architectural design in most retrofit projects it doesn't have a *very clear energy benefit in numbers and percentages, and these negate or reduces the energy performances delivery in the retrofitted building'.* – (NM8)

'Yeah, I mean quite many risks is just about*… The complication normally is just a lack of understanding from everybody involved so that we would describe something fairly simple to a householder or a builder; it might be that they don't know what we're talking* about. *Thus, making this kind of things a bit more normal is very important, and a sort of general level of awareness, even education on the issues would be great. You know, builders going through college; architects going through university. They are not all trained up on all the items, so I think that is the biggest complication'.* – (NM9)

'Well, in the first instance, it just might be that you will not make the savings that you have promised. Actually, if you are dealing with things like airtightness and you do not put any ventilation in, the air quality of the building will be much lower. If you're dealing with things like internal wall insulation *on a solid wall, which is cold, then you might be creating interstitial condensation, so there is a chance that the building will be worse off than it was before if you don't do it right'.* – (NM10)

'In the company, *I'm in at the moment, in a new build project, an architect draws a drawing, and there's a bit of dialogue about that drawing and how well it would work and how accurate that would be built; we manufacture to the agreed sizes, and it all works, usually. Whereas the retrofit, either there is a lot of confusion by the customer or the builder about actually what the referenced point is, what do you mean? Where are we measuring? So that could potentially lead to things going wrong in delivering the projects'.* – (NM11)

'Well, people are the risks… They are not concerned about sustainability as such, to be honest, so it makes things go wrong in construction delivery.

The only thing is, retrofit is more likely to need bespoke solutions, which cost more money and therefore make it appear more expensive than a new build. Because it is made to measure, rather than using a standard size. So that is in a way a complication for construction workers'. – (NM12)

'There are a lot of complications with installed materials. To improve complication, it is better to have simple 'fit and forget' solutions, rather than have complicated ones that are tied to computer programmes and which are maintained and all that. They are more complicated to manage if it is not fit and forget'. – (NM3)

'It depends upon the type of renovation, doesn't it? If it is one that… That the Building Manager System (BMS)… Those are very complicated and to be honest, rather than it be helpful, they are more of a pain and could be more energy intensive because the users don't know how to manage it, so there is not a proper line of educating the end users, but then if it's a technology that is 'fit and forget', they don't have to do anything'. – (NM5)

'Some people do not have very strong environmental beliefs, and some people do not; know what they are supposed to do. I mean, heating controls are notoriously difficult to understand, and even if you're shown how to use your heating controls, you may still not use them properly, so there is a need for fit and use products. It is better to have simple 'fit and forget' solutions, rather than have complicated ones that are tied to computer programmes and which are maintained and all that. They are more complicated to manage'. – (NM7)

7. 6 Six answered research questions

7.6.1 Research question 1

What do you understand by 'knowledge' and 'knowledge management' if we are to relate it to sustainable retrofitting with the key stakeholders?

The interviewees acknowledged that the lack of knowledge and its management is bad for the industry, but some of the interviewees struggled with the definition in the context of delivering sustainable retrofitted building projects. Key definitions of knowledge and KM by key stakeholders are presented below. This demonstrates or corroborates with the lack of managing knowledge in the construction industry (Maduka *et al*., 2015a).

Interviewees' quotes in answering this research question:

'I think knowledge and knowledge management is the understanding of the performance of construction, the impacts, the benefits and the delivery and again, it's by experiencing it and testing it and understanding what the consequences are that form the knowledge'. – (NM2)

'Well I think knowledge management in retrofit is the experience that's been codified into guidance and training and standards and I think the people who've been leading the cutting edge retrofit for the last ten, fifteen, twenty years have got lots of knowledge, but we need to get it out to everyone else, so the only way to do that is to embed that knowledge in first of all, standards, secondly, guidance about how to meet those standards and thirdly, training about how to apply that guidance. Therefore, I think that the knowledge… It is a knowledge transfer process, really'. – (NM3)

'Okay, I would say knowledge is the… I am not quite sure what this has got to do with anything, but anyway. Knowledge is the combination of research, analytics, experience and evidence that combines to give certain views and opinions about sustainability and retrofit'. – (NM4)

'Well, the knowledge of the best modern engineering materials, modern local generation equipment, like photovoltaic, winds, biomass, whatever. The possibility of joining a retrofit project with a wider neighbourhood if the opportunity for, for instance, district network exists, process intensification in the industry where low-grade heat from one producer can help the farm next door to grow tomatoes in a greenhouse. So that's what I would call knowledge. Knowledge of the material and the equipment and of the management of course'. – (NM5)

'I would say knowledge management is the understanding of what the people's level of knowledge is, to begin with, and then inform and educate to fill any knowledge gaps, whether that's training, informal talks, courses, etc.'. – (NM6)

'What knowledge is…? Well, we inform… Like, if you deal with architects, they have something called 'continual personal development', where they are tasked to… And other business, to acquire additional knowledge of what's happening in their

particular industries. So I will go along and give presentations and informative meetings to allow that to happen. Therefore, that's on the knowledge side; it is engaging with universities, which we do with engineers and architects primarily, so... Yes'. – (NM7)

'Knowledge management in particular and actually about... Almost like a passport for the delivery of retrofit building projects, really. You know, what has been done on it before? What are you planning on doing with it now? Moreover, what could be done about it once you have finished that particular phase of the project? So specifically for this, what you'll find is: whenever a house is sold, any knowledge of what's going on with that building is lost and you might end up doing work over and over again, and it builds cost in, it's expensive, it slows things down and I think that particular area, I would like to see a lot more work done because the industry is poor at managing knowledge'. – (NM8)

'I would say that knowledge is information applied in the right way. So knowledge is information with experience in practice'. – (NM9)

'Knowledge management is probably by having some sort of... A process that others can come and follow so that they are not reinventing the wheel every time'. – (NM10)

'I guess... Knowledge would be the total of the things that we know to do in a retrofit project... Shared and deployed so that you get the best outcome and then with a loop at the end of it that says: Hang on, why didn't that work? It kind of linked back to learning and building on that knowledge, so it is not fixed'. – (NM11)

'There is a huge amount of stuff. I think it depends on the kind of knowledge that you mean and what the context is because it could be anything from how buildings are built regarding processes/patterns, and ways of going about things, all the way through to operating the building from a facilities perspective. I mean there are loads of knowledge that is required actually to produce the outcomes of buildings'. – (NM12)

7.6.2 Research question 2

What is the role of knowledge management in delivering sustainable retrofit?

Interviewees' quotes in answering this research question:

'Well, I think it is setting… It must not be onerous, as in too much work for them to do… However, it is the monitoring of it. I assume you've heard of SMART, as in Specific, Measurable, Achievable, Realistic and Timed. You know, so you get somebody to do that. They know what they're doing; they know the standard they need to achieve, the timescales and what resources they've got and then they review how they performed against those part way through the project and at the end of the project, so they learn by doing, and that can be as an individual or as a team'. – (NM1)

'The role? Yeah, I think we are a company that likes to inform people; we are all about to tell the story, and that is, as I've said before, the planet needs to be sustainable; here's how you can do it, these are the benefits and not just to you, but to the environment and the people that you live and work with, so that role, so the role of knowledge is very powerful. Knowledge is power, isn't it? So yeah. In addition, the transfer and spreading of that knowledge are very important'. – (NM2)

'I think the role of knowledge management enhances decision-making because it makes it easier; it actually would explain something that's otherwise, that someone would see as a problem. Knowledge management delivers a solution in a way that the customer understands, which helps them proceed to another stage'. – (NM6)

7.6.3 Research Question 3

How do you capture knowledge in the sustainable retrofit projects since knowledge exist in tacit and explicit knowledge?

Interviewees' quotes in answering this research question:

'Well, every project is different, but it could do by keeping a learning log'. Case studies are a good way as well. To say, Look, this is what someone's done before, and this is how they did it'. – (NM1)

'The things that I have seen that have worked well… Because on a project, there is not always a meeting room and there is not always computers for everybody; there is not always somewhere to write stuff down and store it. So I'd say that things like meetings across all the people who are involved, short meetings that just capture what's happened and somebody taking note of everything and organising it that way can be really helpful'. – (NM2)

'I think it is about spending time with the people on site and in the project meetings and writing activities down. I think that is the only way to do it, really'. – (NM3)

'I guess… I do not really know. I mean, I do not know enough about it, but it could be either individual coming to the site to take part in interviews, or it could be apps that would allow people to record things live. You know, create diaries and that kind of thing. That might be one way to do it'. – (NM4)

'Case studies and best practice and sharing those with other people in the industry. Also by developing standards could be by appointing a knowledge administrator for big companies and for small companies everyone should participate in the documentation of retrofit activities… You know, a standard should be achieved for retrofit. And legislating for that standard'. – (NM5)

'By documentation of successful retrofits. Well, in the form of case studies because that can inform the complete hierarchy of professionals, right from the top of the hierarchy, engineers and architects and planners, all the way down to the average person on the street'. – (NM6)

'On the delivery side of things, it is quite easy to do. You know, you can do it from reviews, from product specifications; you can do it from all sorts of stuff on the assessment side, but actually capturing good and bad practice in retrofit projects and it requires somebody to go to the site, talk to people, watch what they are doing as projects progress, photograph things, and have daily toolbox talks for reviews. That is a very difficult thing to do and unless you have a project of sufficient magnitude to add that additional cost in like employing a knowledge expert… On the other hand, it's separately funded as a research aim that you can achieve all that'. – (NM7)

'What my view would be is… Depending on the scale and the scope of the project, you might be able to do that. If you are a large company with an infrastructure to do that. If you're a builder who's doing one house then another house, it is all experiential, and it's all tacit, and you will never in a million years capture that, so that is more about training for product manufacturers; it's more about things they learn about building up a good practice. At that small project level, you will capture it and then it will move on'. – (NM8)

'Well I would say standards, guidance and training. Moreover, one thing we are very bad at is going back to schools of building, schools of architecture, schools of engineering and making sure that the basics of retrofit training courses and indeed, the basics of energy efficiency are in the training courses that people take for their first degrees. And quite often, the local colleges and university departments and things have quite a lot of autonomy, and there isn't any kind of common curriculum, but there should be one where we say we expect a certain level of knowledge and expertise in everybody that graduates in the industry'. – (NM9)

'I think we haven't quite got there yet and the professional institutions, RIBA, CIBSE and so on are not particularly good at capturing knowledge in my view. Well, there's a sort of tension between professional institutions who say: "this is what we ought to be teaching people" and the academics who say: "well, you know, knowledge is wider than that and we want to be in charge of our curriculum" and I respect those points of view, but in the end, we need to turn out people who've got these skills to capture such knowledge through training'. – (NM10)

'It does need that specialist knowledge and skill, which at the moment is far-fetched in the industry, but basically in the experience of a few hundred people and needs to be codified a bit more into training'. – (NM11)

'By recording retrofit activities live on the project. However, the problematic area does we know what we're trying to capture… Moreover, there is no harm in trying, but if you come as a separate person to look at that, then it is a question of if you are capturing it, sometimes do you have the knowledge to know whether what you are capturing is potentially problematic? That is quite a lot of technical knowledge capturing sometimes'. – (NM12)

7.6.4 Research question 4

How do you think that managing project knowledge can enhance decision-making in sustainable retrofitting?

Interviewees' quotes in answering this research question:

'There is something called the "performance map", and it is the architectural designs and things that would contribute to the energy efficiency level. Then when you get to the site, some of the contractors do not do that, and I guess they need to

be… Educated to be able to install what they're supposed to install and I also guess knowledge for the regulators that they understand the key things about what needs installing, so it's about quality inspections as well'. – (NM1)

'Well, I mean people with the right knowledge and experience will make the right decisions. A lot of very poor decisions have been made in programmes like Eco, because they were made by people who don't; really understand what they're doing, so we've got lots of very poorly performing external wall insulation because there was no attention to the corners, junctions and edges, because the people who did it didn't think it was important and we've got lots of very poor external wall insulation that's to do with rain getting behind the insulation, because the people who installed it didn't understand that closing the top would make a difference to the performance of the stuff, so it's just kind of ignorance that causes stuff to go wrong, so we need to get experts people out there in positions of influence to manage knowledge in the industry'. – (NM2)

'I think few construction companies manage their knowledge properly. I think most people in do not test the results that clearly support the knowledge so when decisions are made they are made wrongly. I think you need to do a lot of testing and specification of knowledge to enable it to enhance decision-making in retrofit projects'. – (NM3)

'The issue is that the people in the industry are not aware of knowledge management. Therefore, if they are aware that it cannot enhance decision-making. So knowledge management is a product that needs to be marketed to enhance decision making in retrofit buildings projects'. – (NM8)

'I think it goes back really to the rest of your interview. If the knowledge exists and if it exists freely and if it's in the form of relevant case study buildings, if some of these retrofitted buildings are high rise buildings, they could have 16, 18, 20 previous case studies that they can go to and get knowledge to apply it rightly in deciding for reasonable options in embarking on a new retrofit projects'. – (NM11)

7.6.5 Research Question 5

How do you think we can avoid information overload relating to sustainable construction?

Quotes from the interviewees in answering the research question:

'I do not think information overload is an issue; I think the issue is not having enough right information on retrofit issues'. – (NM1)

'Well, I guess… I do not know. I mean, I do not know enough about it, but it could be either individual coming to the site to take part in interviews, or it could be apps that would allow people to record things live. You know, create diaries and that kind of thing. That might be one way to do it'. – (NM3)

'Information overload. There is plenty of it. I think it needs to be captured at different levels. For instance, with the work that we do, it needs to be captured at a detailed level for the work that we do and for the presentation in conferences and journals papers to the scientific community which is usually peer-reviewed. Then it needs to be captured and distilled at a more accessible, more friendly – forgive the expression – "Disneyfied" form, which could be published for the public. This will help reduce information overload hence allowing relevant and specific information to the organisation or public'. – (NM8)

'There is a lot of information overload. There is an organisation, the BRE, the building research establishment; they have done a lot of work on the subject of energy and retrofit would come into that a lot. I guess organisations like that no doubt have built up a good reputation as being a good resource for the industry. There are… organisations, like in London, there is something called the building centre, which is seen as the place to go for information from clients. There are other building suppliers, like big building merchant companies, who have their building centres, which are showcased for the product ranges that they sell; they're always good places for people to go for ideas, to get the right knowledge for retrofit to avoid overload'. – (NM12)

7.6.6 Research Question 6

So what criteria are used to determine the relevance of new knowledge, for example, in a retrofit project?

Quotes from the interviewees in answering the research question.

'Obviously following every completed retrofit build, you do your Engineering, Procurement, and Construction (EPC) results, do air test results, do thermal image

results, do 3D imagine, a whole combination of different test results provides the raw data that supports new knowledge'. – (NM1)

'It is about those case studies and best practices into the hands of the people who are doing those kinds of projects'. – (NM2)

'Well… New is anything that we haven't come across, so it's possible that the knowledge might have been, maybe for argument's sake, like in our own business, we are split properly between housing and commercial big and commercial small, so something that's been done in the housing could be new knowledge to us, even though it's one company, so it's the definition of 'new', meaning that it is the first time they are getting to know about it, and they haven't used it, so in my example, it's not new to the company, but it's new to the sector of the business'. – (NM3)

'I think it has to come from two directions. One, it has to come from an evidence base with some science behind it. It's also got to come from experience because when you try out stuff that's been thought out in a laboratory or by an academic, it usually doesn't work exactly the way you expect so the new knowledge must be from evidence-based' mixed with experience'. – (NM5)

'So we have to bring together the experience of the people who have been doing stuff and trying stuff with the more rigorous research and so it's university groups, working on sustainability all over the country who I think are leading the way and are helping to validate the experience of people who are trying things out related to retrofit on the ground. Therefore, once rigorous research finds results and validates by the relevant authority, then it is a new knowledge'. – (NM7)

'I think the only way you can do that is to ensure that certified sources are the ones that are publishing the information rather than it coming from everything else, but I don't think you'll be able to manage that, because that's the whole point of the internet; there's loads of information, so I don't think you can stop information overload'. – (NM8)

'The relevance of new knowledge. Well, for the industry scientific community research collaboration in retrofit research that can be published… because if the research can be peer-reviewed and if your peer scientific colleagues regard it as good scientific work, then it is high quality'. – (NM9)

'Relevant to new knowledge in retrofit projects means when the information is specific, achievable, realistic and timed'. – (NM10)

7.7 Chapter summary

This chapter presented the results of the multiple-case studies with twelve industry organisations. The presented results were analysed, and the analyses were mainly based on identifying critical barriers and enablers to sustainable retrofit project delivery, identifying emerging themes, the risks and complications involved in the uptake and delivery of retrofit projects, and answering some research questions. As stated earlier, a major barrier can turn into a critical enabler, hence, the structure of the results presentation. Risks and complications involved in the delivery of sustainable retrofit project were revealed. Therefore, this chapter contributes to the development of the decision support framework in this research. The emerging themes identified in this chapter have added to the richness of the research. This chapter has been delivered; the next chapter integrates both industry surveys and multiple-case study findings, which contributed to the development of the sustainable retrofitted building process (SRBP) and sustainable retrofitted building decision support framework (SRBDSF).

CHAPTER EIGHT: DEVELOPMENT OF RETROFIT BUILDING PROCESS, DECISION SUPPORT FRAMEWORK AND VALIDATION

8.1 Introduction

This chapter presents a sustainable retrofitted building process (SRBP) and sustainable retrofitted building decision-support framework (SRBDSF). Both the retrofit building process and framework are UK-specific, informed by the key stakeholders in UK construction organisations. One of the objectives of this research is the creation of an SRBP which gives an overview and better understanding of an SRBDSF. The development of an SRBDSF is the aim of the current research. Firstly, the structure and components of both the process and framework are explained. Based on the synthesis from literature, survey findings in Chapter 6 and case study findings in Chapter 7 the participants' opinions are statistically and qualitatively significant as they represent the views of key stakeholders in the industry as well as being grounded in academic qualifications in building development, practical experience in construction works, and specialist knowledge in delivering retrofitted building projects. Thus, their opinions have provided a broad spectrum of knowledge, experience and expertise regarding barriers and enabling factors in achieving sustainable retrofitted building projects. These were valuable in developing an SRBP and SRBDSF with knowledge management procedure/processes.

Besides, the developed retrofit process contributed to the development of an SRBDSF. The decision support framework was developed with knowledge management (KM) procedures and principles to enhance key stakeholders' decision-making capabilities in the uptake and delivery of a sustainable retrofitted building project. The framework will also assist the key stakeholders in reducing the barrier factors and avoiding reinventing the wheel in delivering retrofit projects. The chapter also discusses the validation of the SRBDSF, which is also one of the research objectives. Validating the framework is vital to the research and to establish that it is fit for purpose and identify its limitations.

8.2 Sustainable retrofitted building process for the UK construction industry

In this section, the development of an SRBP for the UK construction industry is justified and demonstrated. The empirical evidence in Section 6.3 established that a sustainable decision-building process could provide potential solutions to the uptake and delivery of sustainable retrofitted building projects in the UK because of the varied processes that exist in the industry. The need for a building process for the construction industry is essential and has been suggested (Kagioglou *et al*., 1998, Wu *et al*., 1998) mainly for sustainable retrofit projects (Empirical Evidence, Survey, Q14). The critical barriers and enabling factors established from the data suggest the relevance of a sustainable retrofitted building process to properly manage knowledge in making informed choices in delivering retrofit projects. The developed retrofit building process is essential in guiding key stakeholders in the delivery of sustainable retrofitted building projects. An SRBP is a standard set of definitions, documentation and procedures that provide the basics in allowing a wide range of key stakeholders involved in a retrofit project to work together (Kagioglou *et al*., 1998) to deliver project parameters and standards.

The SRBP also aims to map the entire retrofit project process from the client's recognition of a need to design, construction, retrofit evaluation, and building operations and maintenance to feedback loop. Additionally, the SRBP takes the form of a framework detailing the sustainable design and construction processes within a retrofit building project. The idea of the building process was for the key stakeholders to deploy the processes and use them as guiding steps to assist them in delivering sustainable retrofitted building projects. However, the investigation of literature and the findings from the industry survey and multiple-case studies formed a good foundation and contributed to the development of the SRBP. SRBP development has delivered Objective 7 of this study. The research validated the SRBP seen in Appendix W, and the findings demonstrate the relevance, fitness for purpose and acceptability of the study. Figure 8.1 highlights the SRBP while subsequent sections present the explanation of steps to employ in sustainable retrofit project delivery.

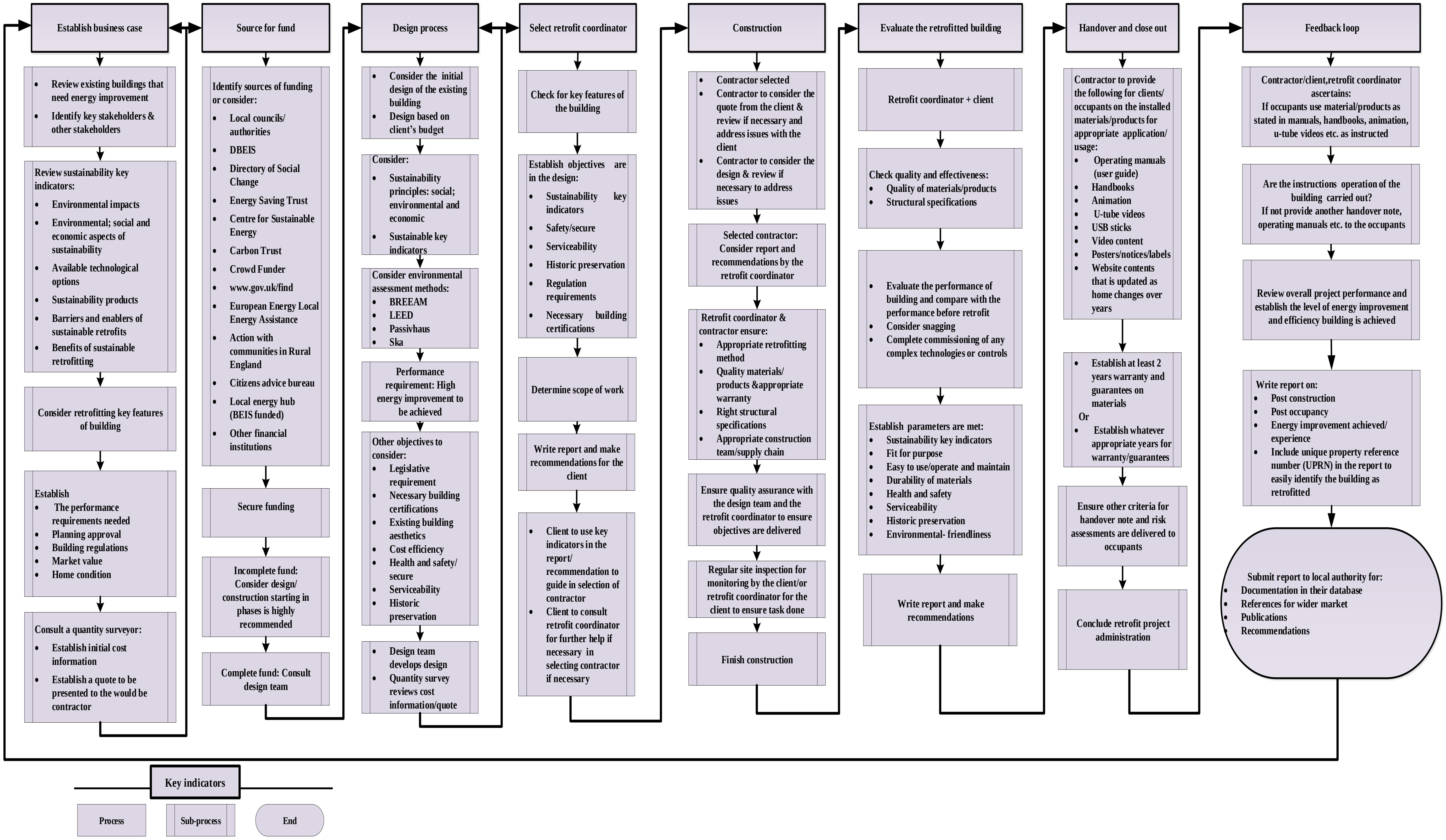


Figure 8.1 Sustainable retrofitted building process (SRBP) for the UK construction industry

8.2.1 Stage 1 Establish a business case

Establishing a business case refers to the justification of embarking upon the sustainable retrofit project. A business case captures the reasons for initiating the project (RIBA, 2013). The client must have considered the essence of the project and its benefits that justify the rationale for the preferred solution. However, the business case considered includes:

Identification of key stakeholders and other stakeholders: The identification of key stakeholders in a project assists the client to know how important they are and their overarching influence in the projects (Bourne and Walker, 2005). According to the research Empirical Evidence (Survey, Q15), the key stakeholders to be identified in the retrofit project include architects; civil/construction engineers/builders, project managers, site managers, suppliers of the product, contractors, product manufacturers, technical consultants, quantity surveyors, building users, funding agencies, auditors, NGOs (if applicable) and other stakeholders.

Review existing building that needs energy improvement: This is very important in order to help the client or the building owner to determine which particular building needs to be retrofitted if there are more than one in consideration (JSCE, 1999, Design-Building, 2017b). After the review has been carried out and building to be retrofitted established, the next phase will be to consider retrofitting key features of the building.

Consider retrofitting the key features of the building: Design-Building (2017c) and Empirical Evidence (Survey, Q18) suggested that the key features are essential in delivering retrofit projects. The key features include:

- Walls: cavity wall insulation, internal and external insulation, and cladding of external and internal wall insulations
- Roofs: insulation of the roof and ventilation system
- Windows: this involves installation of double or triple glazing; draught proofing of existing glazing
- Floors: installation of insulation
- Tanks and pipes: this involves lagging

- Lighting: this involves new controls, Light-Emitting Diode (LED) lighting and considering other low-energy lights
- Boilers: consider installation of high-efficiency condensing boilers or micro combined heat and power (CHP), new controls, connection to low-carbon public heating systems
- Chiller plant improvement: these include pipes, pumps, piping and control upgrade
- Controls: this involves the installation of smart controls and building management systems
- Air-conditioning: this requires upgrading or replacing with air or ground source heat pumps or passive cooling
- Renewable energy system: this requires the installation of photovoltaics, solar thermal heating, passive solar heating, wind energy, micro hydropower, organic waste power sourced heating or power plant
- Water conservation: this involves the installation of low-flow equipment, for example, water fittings, shower heads, dual flush, WCs and rainwater harvesting system
- Electricity: this involves peak saving through thermal energy storage, onsite electricity generation or combined heat and power.

However, considering these key features involves the careful balancing of various features and their effects on the overall performance of the building to avoid irreversible defect (JSCE, 1999, WBDG, 2016, Design-Building, 2017c). Thus, a change in one part of a building can affect another that may lead to an irreversible defect.

Establish these objectives

Identify performance requirement needed: It is essential to identify the performance of the existing building to be retrofitted in other to make a comparison after retrofitting (JSCE, 1999, Design-Building, 2017b). After that, the clients or building owners have to determine an estimated building requirement they can afford.

The client has to obtain where necessary planning approval, building regulations, market value of retrofitted buildings and home condition of the existing building (i.e. where the property is occupied then construction phases have to be established).

Consult a quantity surveyor: This is necessary to assist the client or building owner to have an estimate of how much is needed to embark on the project from start to completion. The cost analysis should be detailed for the client to have a good understanding of the cost (Fema.gov-EPP, 2017). Once cost information is established the quantity surveyor has to prepare a quote to be presented to the contractor that would be engaged. The next step is to source for funding if there is no available funding or the funding available is not enough to deliver the projects.

8.2.2 Stage 2 Source for the fund

At this stage, the client or building owner has the cost information of the retrofit project which will assist the client/property owner in ascertaining if their savings can deliver the building (Empirical Evidence, Survey, Q18). However, if there are no savings, the client will explore options to get government loans and grants to carry out the projects. CSE (2018) suggested Energy Saving Trust (EST), Carbon Trust, Action with Communities in Rural England (ACRE), Smart Energy, European Local Energy Assistance, Nesta Sustainable Communities (NSC); European Local Energy Assistance (ELENA), European Regional Development Fund (ERDF) and Energy Company Charitable Trusts (ECCT). In the same vein, Mayor-of-London (2017) publicised some sources of funding to delivering sustainable retrofit projects that include local council/authorities, Crowdfunder, Microgenius, Peoplefindit, Spacehive, Awards for All, the Directory of Social Change and gov.uk/find. DECC (2015) revealed more sources of grants and loans, which include Joint European Support for Sustainable Investment in City Areas (JESSICA), Public Works Loan Board (PWLB), Green Investment Bank (GIB), local energy hubs, which are Department for Business, Energy and Industrial Strategy (BEIS) funded, and Salix Finance. Citizens' bureau is a very good source for getting information on funding of retrofit projects. These suggested organisations have their websites using the same names for detailed information and contact details.

In situations where the client's savings cannot deliver the project and there is no other source of funding, the client should consider executing the project in phases until it is fully delivered. However, if the client has the money or funds to implement the project, the next stage is to consult the design team, who are also key stakeholders in the project.

8.2.3 Stage 3 Design process

At this stage, the client should employ a design team having established funding for the completion of the project (Empirical Evidence, Survey, 18). In retrofitting, the design team must consider the whole building design process to ensure key design objectives will be achieved. This is in line with its purpose of use, safety and durability. Consideration should be given to the ease of retrofitting construction and post-retrofitting maintenance, and also overall economy and environmental-friendliness (JSCE, 1999). Hence, there is a need for the design team *to request the original architectural drawing* of the building to give the team an overview of the building architecture (WBDG, 2016). However, if the client has lost the original design, the design team should use their expertise in designing for the retrofit project. It is vital that the design team considers some design parameters as explained below. The design team should consider designing according to the client's budget and quote (see Appendix W). This is necessary in order to deliver the project on time.

The next phase is to consider the *sustainable principles* in the design: these include the environmental, economic and social aspect of sustainability (Design-Build, 2011). Discussions on sustainable principles can be seen in detail in Section 2.9.3.

Then the design team consider the *environmental assessment method*: the need to acknowledge the impacts of construction and take responsibility in addressing it during the design stage of a building, which has been emphasised (Greenwood *et al.*, 2011). Hence, environmental assessment methods are essential in designing sustainable retrofitted building projects. The environmental assessment methods to be considered according to Empirical Evidence (Survey, Q19) are BREEAM, LEED and Passivhaus including others that are relevant to the delivery of the retrofit projects. Consideration of these methods in the design of the retrofit building is vital to reduce the environmental impacts of buildings. Detailed discussion on environmental assessment method is seen in Section 2.9.4.

Performance requirement: The design team must ensure in the design that the building achieves a very high standard of energy improvement after the retrofit (JSCE, 1999), hence, the need for performance requirement. The need to properly evaluate the building performance before and after a retrofit project has been suggested (Stafford *et al.*, 2012). This is because of the difficulty experienced in ascertaining building performance before it is retrofitted and the difficulty in determining that what has been specified in the design was built (JSCE, 1999, Stafford *et al.*, 2012). Hence, building performance can be achieved through scientific field, for example those used in Innovate UK – 'Building Performance Evaluation Programmes' (Innovate-UK, 2013) and those carried out by the Centre for the Built Environment (CeBE) group at 'Leeds Sustainability Institute' (Gorse *et al.*, 2012, LSI, 2013).

Other objectives to consider: Ensure the design is in line with *government specifications or regulations/legislation and necessary building certifications*. It is important to consider *existing building aesthetics*, which relate to the physical appearance and image of the building elements (JSCE, 1999, WBDG, 2016). The client/occupants may reject a measure that scores high for all contemplations except aesthetics. In other words, what may be aesthetically attractive to the client may not be technically applicable to the retrofit project. Therefore, the design team needs to apply its expertise considering the client's preferences and at the same time not endangering the structural functionality of the building in order to achieve the overall success of the project. Thus, the design team will help to achieve common ground between the client's need and the technical or buildability of the project.

Cost-efficiency needs to be considered in the integrated design, and this relates to selecting materials that will be of quality, but cost-effective, and also to allow budget control (WBDG, 2016, Design-Building, 2017b). It is essential to consider the *health* and *safety/security of* the building concerning failure or collapse (Fema.gov-EPP, 2017). This involves the performance needed to ensure that the structure does not threaten the lives of users or persons in the surrounding area, for example making sure that the building does not fail or collapse. It is also essential to consider the *serviceability* of the building. This involves ensuring performance does not cause discomfort beyond the acceptable level to users or occupiers of the building and neighbours (JSCE, 1999). Thus, this means ensuring that, for example, the client/occupants and neighbours have free drive-in access and walking comfort, that no vibration occurs after the building has been retrofitted, that the building has resistance to noise and also that the building's appearance and visual stability is pleasing to users/occupants.

The design team has to consider *historic preservation*, which relates to definite actions within a historic region or definite action affecting a historic building whereby building features and strategies are categorised into one of the four approaches: preservation, rehabilitation, restoration, or reconstruction (JSCE, 1999, WBDG, 2016). In this case, *restoration* of the building is very important. This involves performance that can be easily fixed if there is damage to the building during its service life. This also involves considering a design that will avoid cracks, deformations and failure of the building (JSCE, 1999), for example, ensuring that residual displacement, deformation or failure of the structure can easily be restored without complication or complexity.

After considering all these, the design teams should develop the design. After this, the quantity surveyor should review the cost against the initial cost provided. This will assist the client in ascertaining if there are discrepancies with the initial cost information. From developed design information, the quantity surveyor should be able to compare this with the initial cost information on quantities of materials and cost of labour for the project (Design-Building, 2017c). If there are huge discrepancies, the client should be informed. This will assist in guiding the client in selecting an auditor to assist in delivering the project.

8.2.4 Stage 4 Select a retrofit coordinator

This stage is about choosing a retrofit coordinator. However, retrofit coordinator’s duties are to assist in monitoring construction processes and activities with the goal of identifying problems and recommending solutions (Empirical Evidence, Survey, Q18). The retrofit coordinator to be appointed or selected by the client must have knowledge of the primary and necessary concepts and peculiarities of the retrofit project and embrace them for newer challenges (Azizi *et al*., 2011).

Who is a retrofit coordinator? A retrofit coordinator is a qualified industry practitioner who can achieve quality assurance and manage and coordinate retrofit construction activities from the UK national point of view to assist the client mainly and other stakeholders in achieving quality, energy improvement and delivering the project on time and budget (The-Retrofit-Academy, 2017). In a similar vein, Designingbuildings (2017) describes a retrofit coordinator as a construction industry professional who takes responsibility for managing the retrofit building by providing effective management and leadership to the client.

Three roles of retrofit coordinators according to The-Retrofit-Academy (2017), and Designingbuildings (2017), include:

1. Manage: the ability to undertake the traditional role of a construction project manager with regard to planning, organising and managing projects to deliver on time and budget.
2. Coordinate: the ability to provide relevant advice and support to contractors and consultants to prompt understanding and teamwork to achieve the needed energy performance in the retrofit project.
3. Quality assurance: assuring retrofit clients that the project risks and complications will be minimised and managed.

In addition, Designingbuildings (2017) state that a retrofit coordinator could undertake the following roles in the retrofit project:

- Provide project management and client assistance from the project start to finish in respect to planning, organising and managing the retrofit project.
- Assist the client in suggesting consultants and contractors.
- Ensure that projects risks are managed effectively and quality is maintained through the project life.
- Identify and deliver solutions for potential risks and complications to the retrofit project process.
- Assist the client on post-occupancy assessment to establish overall success and ensure that lessons are learned for future retrofit projects.

The-Retrofit-Academy (2017) and Designingbuildings (2017) state a range of backgrounds retrofit coordinators could come from, and these include:

- Architects
- Civil Engineers
- Asset Managers
- Building Services Engineers
- Building Surveyors

- Construction Managers and Site Foremen
- Construction Project Managers
- Energy Assessors and Consultants
- Energy Managers
- Housing Managers
- PAS2030 Accredited SMEs
- Structural Engineers

PDP (2017) stated that there is a need for retrofit coordinator qualification to become a requirement for retrofit designers and project managers. They further indicated that retrofit coordinators are essential in delivering sustainable retrofitted building projects. The skills needed by retrofit coordinators according to The-Retrofit-Academy (2017) include:

1. **Domestic retrofit background knowledge:** this involves knowledge about the principles and practices of building retrofits in the UK. Hence, retrofit standards are considered from a national point of view.
2. **Evaluating improvement options:** this involves knowledge on site constraints and planning context; the construction type; the condition and need for repairs; the occupants' or property owners' objectives, constraints and budget; and the opportunities for other improvements alongside retrofit. Procedures for comparative evaluation of improvement options are reviewed, including simple-payback analyses, ECO scores (emissions savings) and 'carbon cost-effectiveness'.
3. **The business case for retrofit:** this aspect involves current schemes for funding domestic retrofit in the UK and explains how they can be used to support individual retrofit projects or large-scale retrofit projects.
4. **Retrofit building fabric and solid wall insulation:** this emphasis is on retrofitting domestic buildings to improve insulation and air tightness, minimise thermal bridging and eliminate or control the migration of moisture through the building fabric. The unit covers strategies, principles and standards for improving insulation and air tightness; insulation materials and products (including both sealed and vapour-permeable options); insulating walls; floors and roofs; detailing to maintain the continuity of insulation and the integrity of the air-tightness barrier at corners;

junctions; edges and around openings; and post-construction testing of the building fabric.

5. **Building services retrofit:** this involves retrofitting of buildings with new services: ventilation, heating, hot water, lighting and appliances, and their controls. Knowledge about low-carbon technologies such as heat pumps, micro combined heat and power (CHP), solar water heating and solar photovoltaics are essential in the building services retrofit.
6. **Air-tightness and ventilation for retrofit:** this is concerned entirely with knowledge of ventilation processes, which include the vital role of ventilation in retrofit; measurements for ventilation; establishing a retrofit ventilation strategy; ventilation system options and their performance; issues with mechanical ventilation with heat recovery (MVHR) in retrofit; and emerging ventilation techniques such as demand control.
7. **Retrofit building physics:** this is having essential technical knowledge of building physics for retrofit, with specific emphasis on how energy is used in and flows through buildings, and on how moisture interacts with and migrates through the building fabric.
8. **Retrofit coordination and risk management:** the knowledge of the retrofit coordinator is critical in providing an end-to-end retrofit project management and customer care embracing assessment, procurement, design (including improvement option evaluation and statutory approvals), construction, handover, evaluation and feedback loop involvement. A key aspect of the role is risk management, so this aspect also evaluates ‘retrofit forensic’ work, which has identified how and why retrofit projects go wrong, what the consequences are and how risks may be mitigated by good project management.

   Furthermore, the need for a construction coordinator is to ascertain that the design developed by the design team complies with consideration of sustainable principles, the environmental assessment method, aesthetics, cost-effectiveness, health and safety, serviceability and historic preservation (Barnett *et al.*, 2010, Azizi *et al.*, 2011). The retrofit coordinator will evaluate the design to determine the scope of the work and deliver a report with key recommendation(s) to the client/building owner in order to either proceed with the project or not. If the outcome of the report suggests that the design did not meet the required standard, then the design team has to include the proposed recommendations from the coordinator in line with the objectives of the project. However, if the design is in line with the project objectives, then the client should comply with the recommendations in the report and proceed with the project. The key indicators in the report will assist in guiding the client with the help of the coordinator in the selection of a contractor that will deliver the retrofit project.

8.2.5 Stage 5 Construction

This is the construction stage, having ascertained the appropriateness of the developed design, and it precedes the selection of the contractor that will deliver the retrofit project (JSCE, 1999, Design-Building, 2017c, Fema.gov-EPP, 2017). The contractor is to consider the report and recommendation(s) from the construction auditor before the continuation of the project. This consideration is essential in order to ensure the key indicators and objectives are achieved after the retrofit project is delivered. Hence, when retrofitting it is vital that the contractor ensures accessibility, safety and sustainability initiatives as specified in the design to reduce operation cost and environmental impacts and increase building adaptability, durability and resiliency (JSCE, 1999, Design-Building, 2017b, WBDG, 2016). At this stage, it is vital that the contractor with the client will evaluate the quote presented and address issues where necessary before the commencement of the project.

During the construction, the retrofit coordinator will be the ‘retrofit watchpoint’ to ensure that there is no poor construction method and sequencing. It is important that appropriate retrofitting/construction methods be applied. This will help establish that the quality of materials and the right structural specifications are used. It is essential that the coordinator ensures the use of quality materials/products to ensure sustainability, and that the right structural specifications and appropriate construction team/supply chain are established and implemented appropriately. Hence, the retrofit coordinator is to perform an oversight function including regular site inspection with the client when necessary; the contractor and design team to deliver the objectives of the retrofit project.

8.2.6 Stage 6 Evaluate the retrofitted building

This stage involves the retrofit coordinator together with the client evaluating the retrofitted building to establish that the appropriate structural specifications were implemented and also complete commissioning of any complex technologies or controls (JSCE, 1999, Design-Building, 2017c, Fema.gov-EPP, 2017). However, the process of retrofitting involves the careful balancing of different elements and their effects on the overall performance of a building. It is essential that the auditor evaluates the performance of the retrofitted building (Gorse *et al.*, 2013) because according to Design-Building (2017c) and Empirical Evidence (Interview, Q2) a change in one part of a building could affect another; hence it is suggested that the following have to be examined.

1. The insulated roof cannot cause decay on the timber used for the roof.
2. Ensure the internal wall insulations will not remove the benefits of thermal mass, which may have an adverse effect on the use of fuel.
3. Ensure the external wall insulation will not prevent the thermal store heat from the solar gain and can be utilised in the building.
4. Ensure there is no poorly installed cavity wall insulation capable of creating damp and increased cold.
5. That existing problems or issues in the retrofitted building have been addressed.

At this stage, the snagging list is essential in the evaluation process. The snagging list is important to consider before the handover. Thus, it is necessary to consider the snagging list for two to three weeks at least before handing over the retrofitted building. After one month of handing over, the snagging list should be removed. Inclusively, the retrofit coordinator is to evaluate the overall performance of the building against the building performance before the building was retrofitted. It is thus establishing whether the retrofitted building will accomplish performance requirements. Furthermore, to assess the performance of the retrofitted building and verify that it achieves its performance requirements, it is essential to measure performance regarding quantifiable physical quantities that represent performance (WBDG, 2016, Design-Building, 2017c, Fema.gov-EPP, 2017). The indices needed may depend on the performance evaluation techniques employed.

After the evaluation, the retrofit coordinator should be able to establish in a report that the sustainable retrofitted building delivered is fit for purpose; the installed materials easy to use and operate; quality and durability of the materials/products;

health and safety; serviceability, historic preservation and environmental friendliness of the building have been achieved.

8.2.7 Stage 7 Handover and close-out

At this stage, the contractor will hand over and close out since the construction is completed (Empirical Evidence, Survey, 18, and RIBA, 2013). Morse (2011) recommended that five things have to be accomplished during close-out:

- Acceptance – ensuring that the client or building occupants are satisfied and the project team or contractor delivered all obligations.
- Commissioning – this is when products (buildings) are transformed from a ‘raw’ product into an operational asset. Hence, the building occupants/users take over the building and become familiar with how to operate it. This can be achieved through training of the occupants.
- Transfer of responsibility – at this point building users assume formal ownership.
- Project team dissolution.
- Disposal of project facilities and assets.

However, the retrofit coordinator should ensure that the materials have at least two years’ warranty or whatever years appropriate depending on the product/materials supplied. It is essential that the contractor or the construction team provide any of the following to the client/building occupant on how to use the installed materials and maintain the building. These include operating manuals (user guide), handbooks, animation, YouTube videos, USB sticks, video content, posters/notices/labels and website content that is updated as the home changes over time (Empirical Evidence, Survey, Q18; Validation Survey and RIBA, 2013). It is vital that the contractor ensures that the handover note including the risk assessment criteria is given to the client or occupant as a reminder or reference point as regards the operations and management of the building (Design-Building, 2017c). This stage concludes the retrofit project.

8.2.8 Stage 8 Feedback loop

This stage is for the feedback loop, which has been considered necessary post construction and occupancy (Empirical Evidence, Survey, Q18). The feedback loop is essential to evaluate at least six months of post construction to assist in determining overall success and ensuring that lessons are learned for future retrofit projects (JSCE, 1999, Design-Building, 2017c, Fema.gov-EPP, 2017). At this stage, the contractor and retrofit coordinator will ascertain if the client or building occupants use the installed materials as specified. The contractor has to ascertain if the client/occupant complies or complied with the instructions in the handover note. If they did not comply with the instructions and guidelines as a result of forgetfulness, etc., the contractor would provide the occupants with a new handover note and user guide, manuals, etc. However, the review of overall building performance has to be undertaken, for example establishing that the retrofitted building has achieved high energy performance improvement (WBDG, 2016). This involves the contractor and the retrofit coordinator conducting an occupants' survey to determine fuel use, air permeability and thermographic tests and materials used for retrofitting. After that, there should be a report by the retrofit coordinator with the contribution of the contractor or the construction team on post construction, post occupancy, including the level of energy improvement/efficiency delivered.

It is essential that the report captures all the construction activities including mistakes and lesson learned. There is a need for the report to include a unique property reference number (UPRN) to easily identify the particular property that has been retrofitted (Empirical Evidence from validation). The UPRN can be obtained from Royal Mail and ordnance survey (national mapping agency). The report has to be presented or submitted to the local authority for documentation in their database, reference to the wider market, and publication as a case study and recommendation(s) (JSCE, 1999, Design-Building, 2017c). The report sent to the local authority would assist in promoting the retrofit coordinator roles, the contractors and the design teams. Presenting to the local authority will also encourage the retrofit coordinator, contractor, design team and product manufacturers to deliver quality retrofit in future because their reputation will be at stake if the project objectives are not delivered. Additionally, it will also achieve competitive advantage amongst construction organisations.

8.3 Development of a sustainable retrofitted building decision-support framework for the UK construction industry

This section presents the developed sustainable retrofit building decision-support framework (SRBDSF) for the UK construction industry. The literature investigations and empirical evidence in the qualitative and quantitative chapters (see Chapter 6 and 7 respectively) were fundamental and contributed to the development of a decision support framework (see Figure 8.2). The decision support framework aims to enable key stakeholders involved in sustainable retrofitted building projects to make informed and appropriate decisions in delivering retrofit projects. The processes involved in the framework will assist key stakeholders in the project to address the knowledge gaps (such as lack of knowledge capturing, storage, review, integration, update, application and reuse of knowledge) towards making an informed decision.

The need to employ knowledge management procedures and principles in developing a decision support framework in the delivery of sustainable retrofitted building projects has been documented (Maduka *et al*., 2015a, 2015b, 2015c and 2015d). Lack of knowledge management is identified as a key barrier to the uptake and delivery of sustainable retrofitted building projects, hence, the framework development. The framework consists of different stages that need to be employed by the key stakeholders in embarking on, uptake and delivery of the sustainable retrofit project. The development of an SRBDSF has delivered the aim of the current research. Further detailed discussion on the review of decision support tools, particularly frameworks, is seen in Section 4.9. The ensuing sections present the rationale for developing the framework, the SRBDSF (see Figure 8.2) and explanations on how to use it.

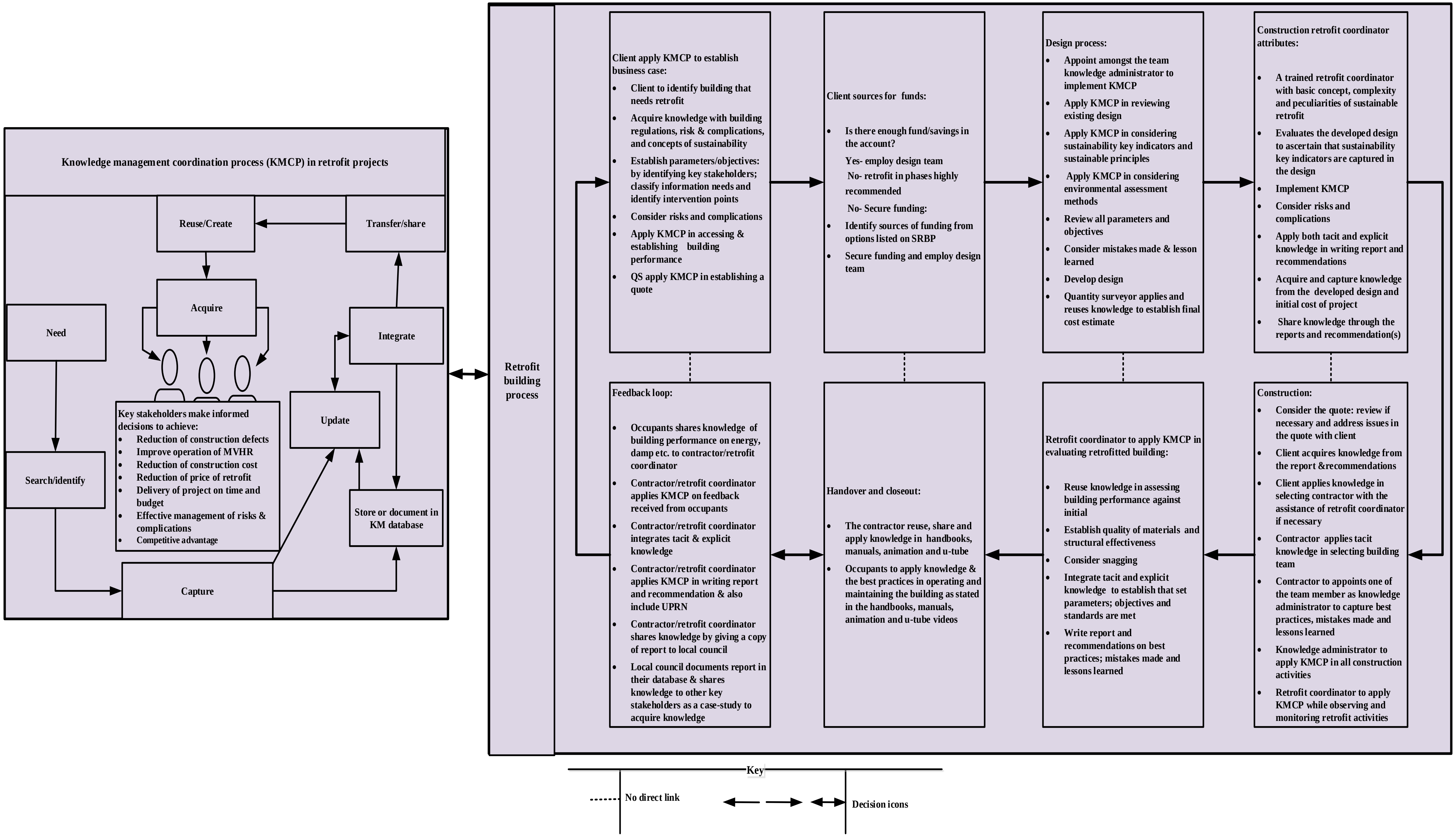
8.3.1 Rationale for the development of a decision support framework

There has been a reasonable lack of interest from the key stakeholders in embarking on and delivery of sustainable retrofitted building projects in the United Kingdom, hence, the need for a decision support framework. This is supported by Empirical Evidence (Survey, Q23), which suggests the need for a decision support framework to be developed. This is partly because delivering sustainable retrofit projects has been considered complex and complicated (Menassa and Baer, 2014) mainly due to lack of managing project knowledge in making informed decisions in their uptake and delivery (Maduka *et al.* 2015d). Reddy and Painully (2004), Wang *et al*. (2009), Pan and Dainty (2012), and Dangana and Pan (2013) argue that one of the main challenges of achieving sustainable construction is due to the nature of the multifaceted decision-making tasks and stakeholder needs.

The critical barriers and enabling factors established from the data recommend the relevance of a sustainable retrofitted building decision support framework to properly manage knowledge in making informed choices in delivering retrofit projects. Hence, factors such as lack of skills, uncertainties, lack of knowledge management, higher cost, risks and a multi-disciplinary profession with conflicting interests and huge number of different technological options have complicated the decision-making process for stakeholders (Reddy and Painully, 2004, Dainty and Ison, 2005, Wang *et al*., 2009, Buchholz *et al*., 2012). These factors have influenced stakeholders into tried-and-tested sustainable decisions instead of assisting in making informed choices. Hence, the need for stakeholders in the built environment to adopt implementation strategies that promote and support sustainable decision-making through knowledge-based decision criteria in the uptake and delivery of retrofit projects has been emphasised and suggested (Pan and Dainty, 2012, Menassa and Baer, 2014, Maduka *et al*., 2015d).

The construction industry has been recognised as being poor at learning consistently, and it is also slow in adapting to progressive change (KLICON, 1999). The fragmented and sometimes unstable nature of the industry has led to steady loss or 'leakage' of knowledge compared to other sectors (Carrillo *et al*., 2003, Shelbourn *et al*., 2006, Udeaja *et al*., 2008b, Tan *et al*., 2011, Duah *et al*., 2014). Knowledge management has been considered to be a means of harnessing and utilising intellectual resources to address some existing construction problems especially in sustainable retrofitted building projects (Abdul-Rahman and Wang, 2010). It could, of course, be argued that construction organisations have been managing knowledge informally for years, but the challenges facing the industry suggest that it needs knowledge to be managed with a more structured, coherent approach (Hari *et al*., 2005, Tan *et al*., 2006, Petri, 2014) in order to enable better-informed decisions.

However, Zhang *et al*. (2009) argue that knowledge would not generate any value unless it is actively used and this can be elucidated in a framework for optimal benefit. The framework development is essential for the key stakeholders in making informed decisions and choices. Menassa and Baer (2014) described *key stakeholders* in this context as the people who directly or indirectly have a stake in the building, its operation and the outcome of a future sustainable retrofit project. Section 4.9 documents further discussion on decision-making and evaluation of existing decision support tools. However, Figure 8.2 presents the developed SRBDSF, and the ensuing section explains the application in a retrofit project.



Key stakeholders make informed decisions to achieve:

- Reduction of construction defects
- Improve operation of MVHR
- Reduction of construction cost
- Reduction of price of retrofit
- Delivery of project on time and budget
- Effective management of risks & complications
- Competitive advantage

Client apply KMCP to establish business case:

- Client to identify building that needs retrofit
- Acquire knowledge with building regulations, risk & complications, and concepts of sustainability
- Establish parameters/objectives: by identifying key stakeholders; classify information needs and identify intervention points
- Consider risks and complications
- Apply KMCP in accessing & establishing building performance
- QS apply KMCP in establishing a quote

Client sources for funds:

- Is there enough fund/savings in the account?

  Yes- employ design team

  No- retrofit in phases highly recommended

  No- Secure funding:
- Identify sources of funding from options listed on SRBP
- Secure funding and employ design team

Design process:

- Appoint amongst the team knowledge administrator to implement KMCP
- Apply KMCP in reviewing existing design
- Apply KMCP in considering sustainability key indicators and sustainable principles
- Apply KMCP in considering environmental assessment methods
- Review all parameters and objectives
- Consider mistakes made & lesson learned
- Develop design
- Quantity surveyor applies and reuses knowledge to establish final cost estimate

Construction retrofit coordinator attributes:

- A trained retrofit coordinator with basic concept, complexity and peculiarities of sustainable retrofit
- Evaluates the developed design to ascertain that sustainability key indicators are captured in the design
- Implement KMCP
- Consider risks and complications
- Apply both tacit and explicit knowledge in writing report and recommendations
- Acquire and capture knowledge from the developed design and initial cost of project
- Share knowledge through the reports and recommendation(s)

Feedback loop:

- Occupants shares knowledge of building performance on energy, damp etc. to contractor/retrofit coordinator
- Contractor/retrofit coordinator applies KMCP on feedback received from occupants
- Contractor/retrofit coordinator integrates tacit & explicit knowledge
- Contractor/retrofit coordinator applies KMCP in writing report and recommendation & also include UPRN
- Contractor/retrofit coordinator shares knowledge by giving a copy of report to local council
- Local council documents report in their database & shares knowledge to other key stakeholders as a case-study to acquire knowledge

Handover and closeout:

- The contractor reuse, share and apply knowledge in handbooks, manuals, animation and u-tube
- Occupants to apply knowledge & the best practices in operating and maintaining the building as stated in the handbooks, manuals, animation and u-tube videos

Retrofit coordinator to apply KMCP in evaluating retrofitted building:

- Reuse knowledge in assessing building performance against initial
- Establish quality of materials and structural effectiveness
- Consider snagging
- Integrate tacit and explicit knowledge to establish that set parameters; objectives and standards are met
- Write report and recommendations on best practices; mistakes made and lessons learned

Construction:

- Consider the quote: review if necessary and address issues in the quote with client
- Client acquires knowledge from the report &recommendations
- Client applies knowledge in selecting contractor with the assistance of retrofit coordinator if necessary
- Contractor applies tacit knowledge in selecting building team
- Contractor to appoints one of the team member as knowledge administrator to capture best practices, mistakes made and lessons learned
- Knowledge administrator to apply KMCP in all construction activities
- Retrofit coordinator to apply KMCP while observing and monitoring retrofit activities

Figure 8.2 Sustainable retrofitted building decision-support framework (SRBDSF) for the UK construction industry

8.3.2 Section 1: Knowledge management coordination process in retrofit projects

This section presents a decision support framework in the form of a knowledge management coordination process (KMCP) for key stakeholders in sustainable retrofit projects. The knowledge process as discussed in Section 3.4.1 needs to be applied in the delivery of sustainable retrofit. The KM database is highlighted in Figure 8.3 and it is important that the knowledge captured from the retrofit building activities is integrated and updated and is shared and accessed amongst the key stakeholders, which include the client, design team and retrofit coordinators. Figure 8.3 is an overview of knowledge adoption, integration and implementation in embarking upon, uptake and delivery of sustainable retrofitted building projects.

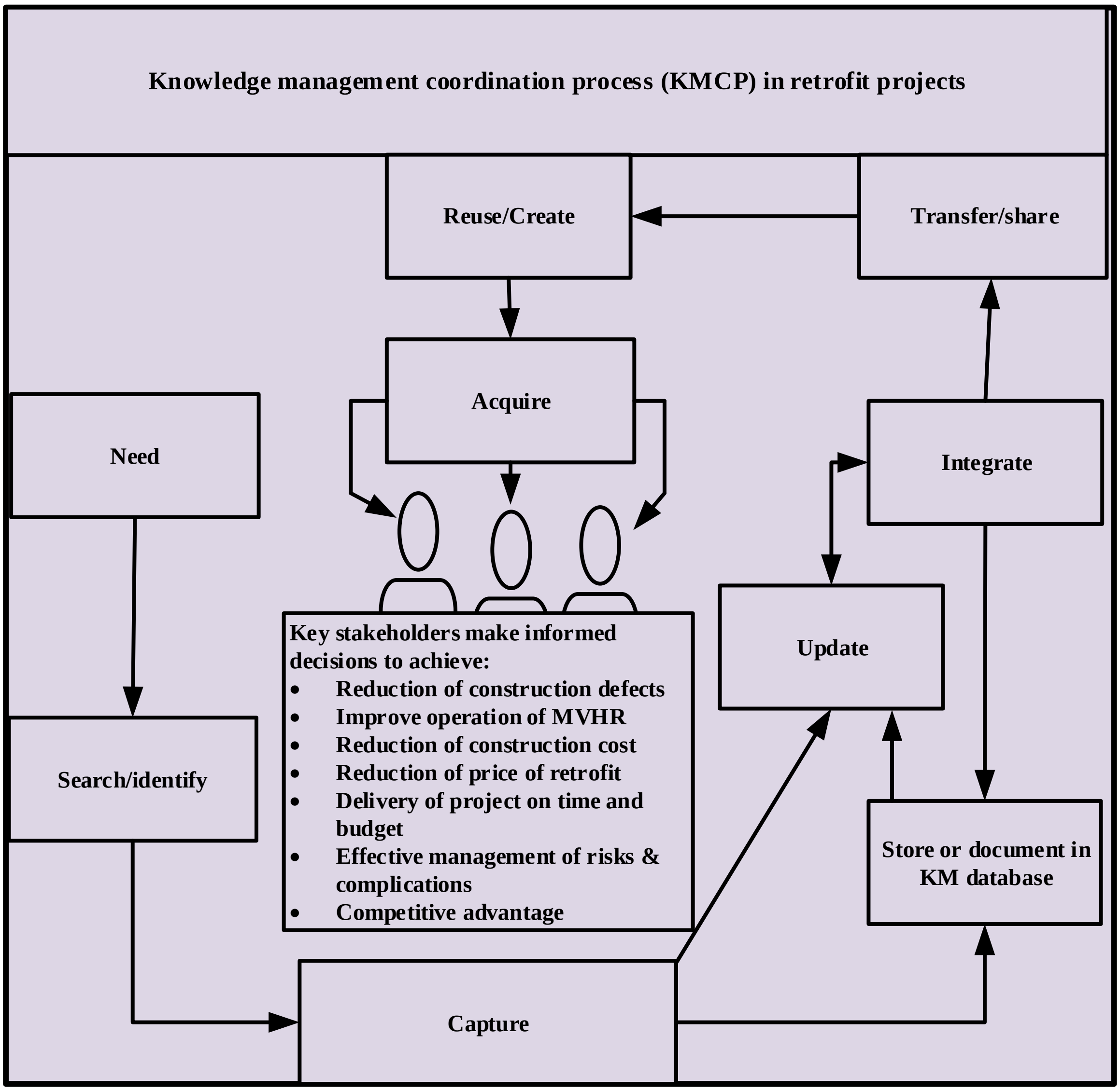


Figure 8.3 Knowledge management coordination process (KMCP) for retrofit projects in the UK

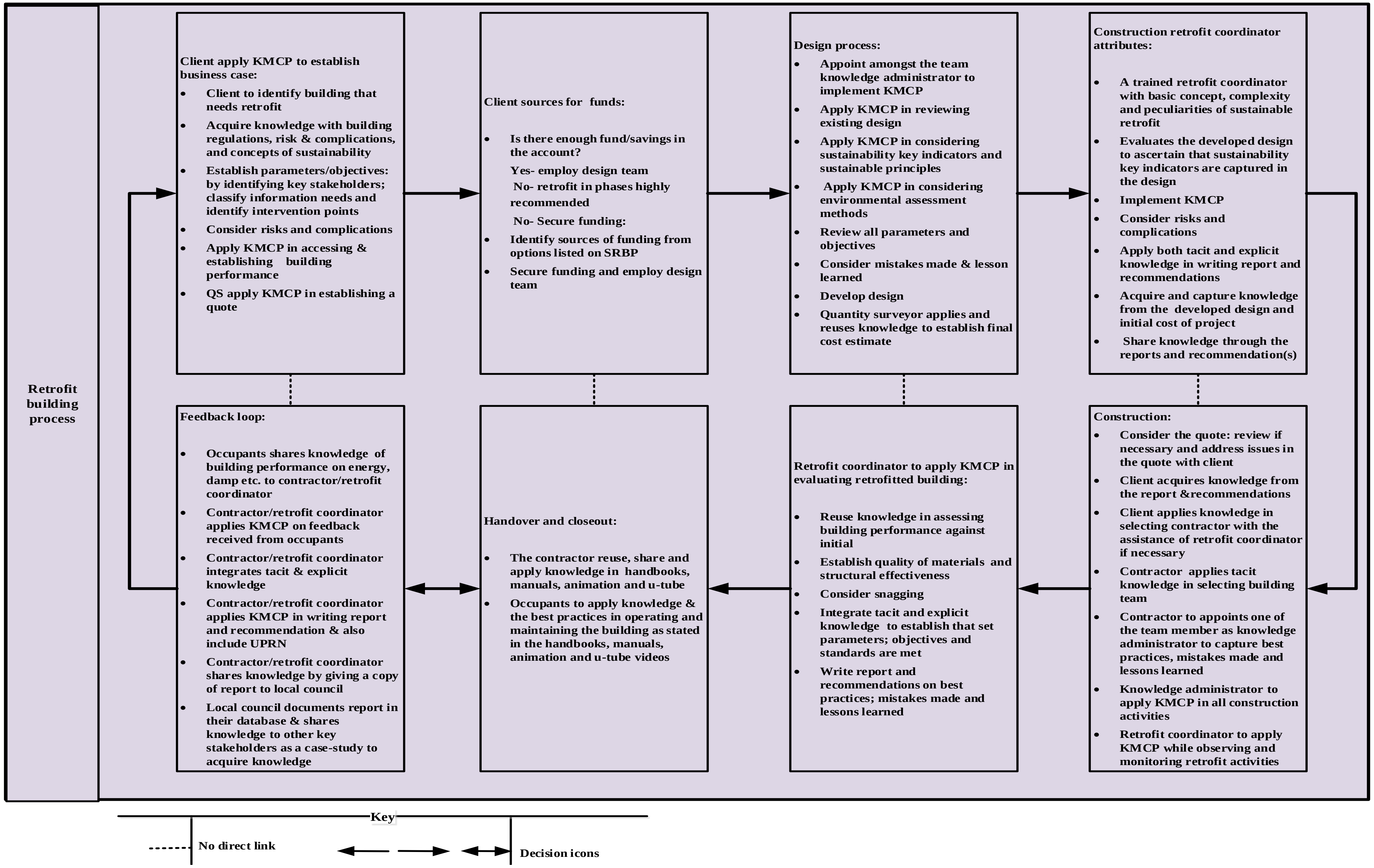
The retrofit KMCP activities are the very centre of all other activities in the building process as everything is initiated and organised from here. This aspect is vital for the key stakeholders, other stakeholders/supply chain to have an overview of what knowledge management entails, and how the process will assist key stakeholders in managing retrofit project knowledge to enhance their decision capabilities in the uptake and delivery of sustainable retrofitted building projects. Using a KMCP is essential for key stakeholders making informed decisions in achieving (a) reduction of construction defects, (b) improved operation of mechanical ventilation with heat recovery (MVHR), (c) reduction of price of delivering retrofit projects, (d) effective management of risks of complications and (e) reduction of time overrun hence, delivering of project on time and budget.

Firstly, you need to identify the need for the retrofit project that leads the client to search for the required knowledge, which precedes the capture of the knowledge. After the knowledge capture, it is essential that the key stakeholders store the knowledge in the best acceptable format so that knowledge gained/captured cannot be lost (Maduka *et al*., 2015a). Knowledge is, however, updated and integrated then shared; created and acquired (Ahmad and An, 2008). Knowledge is created through interactions between explicit and tacit knowledge, rather than from tacit or explicit knowledge alone; hence, knowledge is captured and integrated. This is acknowledged by French *et al.*’s (2009) study that revealed that organisational learning and knowledge creation is achieved through interactions between different knowledge conversion processes that provide the basis for appropriate decision-making.

When knowledge is created, it should be shared amongst the stakeholders; hence, knowledge is acquired. This stage is essential that all key stakeholders capture the process to assist in enhancing abilities in making informed decisions and choices. The knowledge management process should be continuous in the uptake and delivery of retrofit projects. Managing knowledge should be a culture and norm that have to be cultivated in delivering construction projects (Shelbourn *et al*., 2006), particularly retrofit projects because of the fragmented nature and diverse workforce of the construction industry. In addition, because the retrofit project as aforementioned has been identified to be complicated or complex, it is essential that this process is adopted in making informed decisions and choices in the uptake and delivery of the retrofit project (Maduka *et al*., 2015b). It will also create an avenue for competitive advantage within construction organisations in delivering sustainable construction mainly in retrofitting.

8.3.3 Section 3 Delivering Retrofit building project: Retrofit building process

This section has sub-processes that depict how project knowledge should be managed to enhance decision-making amongst key stakeholders in delivering the retrofit project. Figure 8.4 highlights the activities of knowledge management in delivering sustainable retrofit projects.



Client apply KMCP to establish business case:

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- Is there enough fund/savings in the account?

Yes- employ design team

No- retrofit in phases highly recommended

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- Implement KMCP
- Consider risks and complications
- Apply both tacit and explicit knowledge in writing report and recommendations
- Acquire and capture knowledge from the developed design and initial cost of project
- Share knowledge through the reports and recommendation(s)

Construction:

- Consider the quote: review if necessary and address issues in the quote with client
- Client acquires knowledge from the report &recommendations
- Client applies knowledge in selecting contractor with the assistance of retrofit coordinator if necessary
- Contractor applies tacit knowledge in selecting building team
- Contractor to appoints one of the team member as knowledge administrator to capture best practices, mistakes made and lessons learned
- Knowledge administrator to apply KMCP in all construction activities
- Retrofit coordinator to apply KMCP while observing and monitoring retrofit activities

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- Contractor/retrofit coordinator shares knowledge by giving a copy of report to local council
- Local council documents report in their database & shares knowledge to other key stakeholders as a case-study to acquire knowledge

Figure 8.4 Delivering a retrofit building project with KMCP

8.3.3.1 Establish a business case: managing knowledge in establishing a business case to deliver a sustainable retrofit project

In establishing a business case, the need for the client to evaluate available case studies is significant because the client can acquire and capture relevant knowledge and store for decision-making (Dooley, 2016). It is also essential that the client is updated with building regulations/legislation information pertinent to retrofit. This can be achieved by visiting local authorities and some construction organisations to request such information is captured. It is also vital the client checks relevant websites to know the impacts of buildings on the environment. These same measures are to be applied in checking the risks involved in retrofitting a building. After the client has captured and stored this information, it is essential to review (Empirical Evidence, Interview Q5) and update stored information regularly to avoid the loss of information that would assist in making informed decisions and also to avoid information overload (Tan *et al.*, 2010b). According to Zhong (2008), reviewing or analysing knowledge ensures coherence amongst the stakeholders and helps in resolving any decision conflicts that may exist. Examining all the knowledge acquired and stored will also enable the client to make an informed decision on the uptake of the project. Hence, the key stakeholder is well informed about the retrofit building and what it entails to embark on the project.

This section highlights knowledge managed in the activities of establishing the business case and its outcome. The client identifies a building that needs to be retrofitted and applies the KMCP in making informed decisions. At this stage, the client defines the problem, and this involves specifying the purpose or decision-making goals (for example, articulating the parameters of objectives, functions and relationships). Afterwards, information has to be captured in establishing the parameters, standards and objectives of the project, for example in accessing the performance of the building that needs to be retrofitted. It is essential to capture knowledge and recommended to document or store it in the KM database, for example by audio-video recording (Kucza, 2001) or whichever method seems more convenient and appropriate. The quantity surveyor (QS) has to capture and store knowledge while estimating the bill. This enables the QS to have relevant information in costing the project. Then the QS effectively integrates the tacit and explicit knowledge in establishing the quote, which will be presented later to the contractor that will be selected for the project.

8.3.3.2 Sources of funding: managing knowledge in securing the funds for the sustainable retrofit project

In this stage the client applies the KMCP in securing the funds. The client acquires knowledge of the initial cost estimate or project quote from the QS and weighs available options. If the client lacks enough money or funds to carry out the project it is highly recommended that the client identifies sources of funding available, and this includes loans and grants through relevant websites, the local authorities, financial institutions and other relevant agencies (Empirical Evidence, Survey Q18 and Interview Q5 & Q6) and as stated in Figure 8.4. As the client is searching for appropriate knowledge for the identification of funding sources, it is important and recommended that the key stakeholder captures relevant information by audio and video recording/conferencing, or pictures, and stores it in the KM database for future reference and knowledge application and reuse. After knowledge storage or documentation, the knowledge acquired in the whole process has to be evaluated and updated in the KM database in order to assist the client in making an informed decision in securing funding.

8.3.3.3 Design process: managing knowledge in developing the retrofit design

In reviewing the existing design of the retrofit project, the design team has to acquire and capture knowledge to enable them to realise mistakes made and best practices in the design. After capturing the information, the team needs to store or document it in the KM database. The same steps are employed in reviewing the environmental assessment (Empirical Evidence, Survey Q19). The design team will acquire knowledge in reviewing the existing environmental assessment. Hence, the relevant information reviewed is captured and stored, and this precedes a decision on the best assessment to be used in delivering the projects. There is a need to compare other retrofit options available and document the information. Evaluating and integrating the documented knowledge of different options by the design team will assist them in identifying and considering mistakes made, and the lesson learned in developing the design (Anumba et al., 2005b). The developed design will assist the QS to apply and reuse the knowledge from the initial cost estimate or quote to integrate and update the knowledge acquired from the developed design in establishing the final cost estimate/quote for the retrofit project. Hence, new knowledge is created for the client regarding cost estimates.

8.3.3.4 Retrofit coordinator: managing knowledge by a retrofit coordinator

At this stage, the retrofit coordinator manages knowledge. The client hires the retrofit coordinator to assist in achieving the objectives of the projects. It is highly recommended that the coordinator must have a fundamental knowledge of other sustainability requirements to understand basic concepts and peculiarities of retrofit projects and apply such knowledge in auditing a retrofit project. Empirical Evidence (Survey 18 and Interview, Q4) suggests that the retrofit coordinator is to review the developed design to achieve needed project objectives and capture information on all key areas of the project: processes, risks/complications, daily logs, funding strategies, material purchases, and verification of contractor's scope, quality assurance, post construction and post occupancy.

The retrofit coordinator will also be involved in submittals, which include shop drawings, material data, samples and product data. Regular review of retrofit processes and quality systems for effectiveness are vital to obtaining relevant information for knowledge capture. The information captured is documented and examined by the construction team and will be integrated and updated in the KM database (Empirical Evidence, Survey Q22 and Interview Q5 & Q6). The experience gathered should assist in writing a report and recommendation(s) to ascertain the state of the building before construction. Hence, tacit and explicit knowledge is applied in writing the report and recommendation(s). This is similar to Nonaka *et al.*'s (2000) study which affirmed that tacit and explicit knowledge are complementary to each other indicating that it is not possible to use explicit knowledge without the application of some tacit knowledge. In other words, knowing how to apply explicit knowledge is itself a tacit skill and any application of explicit knowledge consists of some aspects of tacit knowledge. Thus, the key stakeholders who are the decision-makers essentially rely on both explicit and tacit knowledge during the decision-making process (French *et al.* 2009) in sustainable retrofitted building projects. However, the report and recommendation(s) are essential because this is an opportunity for sharing knowledge amongst other key stakeholders.

8.3.3.5 Construction: managing knowledge in retrofit construction activities

At this stage, it is vital for the contractor and client/retrofit coordinator to review the project quote to resolve any issues that may arise. At this stage, it is highly recommended that the contractor appoints one of the project team members to capture relevant knowledge in the construction activities till close-out or end of the retrofit project (Empirical Evidence, Survey Q22 and Interview Q5). The need to appoint a knowledge administrator has been suggested (Empirical Evidence, Survey Q22 and Interview Q5 and Q6) because sometimes knowledge is generated only in people's minds, hence, it is tacit (Nonaka and Takeuchi, 1995a), and also knowledge is very complex. In addition, knowledge may arise unconsciously from every project activity; it is not principally identified, except in the case of consciously driven knowledge generation or capture (Dooley, 2016) hence the need for a knowledge administrator.

The idea of appointing a knowledge administrator to implement the KMCP is so that this person can observe, monitor and access project activities in order to capture knowledge while in the workflow as regards delivering of the project. According to Empirical Evidence (Survey Q22 and Interview Q5) the knowledge to capture includes best practice; mistakes made; project arguments; face-to-face meetings; seminars; risks experienced; case studies; phone calls; daily learning logs; trainings; video and audio conferences; brainstorming sessions; and the auditor's suggestions in terms of monitoring the projects to ensure the set parameters, standards and objectives and indeed other activities of other stakeholder's/supply chain are achieved.

The Empirical Evidence also suggested that the knowledge administrator should capture and document information/knowledge using some technologies: cameras/photographs, video and audio recording, and intranets. While knowledge itself is something intangible, the knowledge administrator has to cover various aspects specified such as the way people work together (sociology) and the specific way people react to particular situations and changes in the retrofit project activities (psychology) (Empirical Evidence, Survey Q22 and Interview Q5). For example, the knowledge administrator will capture as aforementioned new knowledge, mistakes made and lessons learned when the project team selects the construction method, materials/sustainable products to be used, when the materials are supplied and every other activity between other key stakeholders including the supply chain (Empirical Evidence, Survey Q22 and Interview Q5 and Q6). Whenever new knowledge is generated, the knowledge administrator needs to recognise it by effective observation in order to capture and store it in the knowledge management database. The storage may be achieved by creating retrofit diaries or saving using the most appropriate and effective method.

However, there may be potential challenges and limitations for the knowledge personnel within the project team and other stakeholders especially when the knowledge initiative is not planned (Ahmad and An, 2008). Therefore, to overcome these potential challenges and limitations, the contractor and the key stakeholders should deploy a compelling vision and mission within the project team so that the key stakeholders and other stakeholders can 'buy into' the knowledge management strategy. This can be achieved through effective communication with the project team members to set the right expectations with all stakeholders to reinforce the value and benefits of the knowledge management (KM) approach/strategy. Effective communication will help tear down barriers that will limit any stakeholder in participating in managing project knowledge, hence it becomes a norm and an integral part of stakeholder's role particularly the key stakeholders involved in the retrofit project. Knowledge management adoption in the retrofit project should also be built into performance management for the compensation programme and be recognised and rewarded (Design-Buildings, 2016). However, the steps employed by the contractor and the client will make it easy for the knowledge administrator to manage knowledge in the retrofit project activities.

The knowledge administrator can capture project knowledge through the recommended medium. The knowledge administrator stores the captured knowledge throughout the construction activities depending on the type of medium adopted by the contractor or project team. In addition, the knowledge stored can be reviewed by the project team (Empirical Evidence, Survey Q22) to avoid information overload (Empirical Evidence, Interview Q7), and subsequently knowledge is updated by the administrator and afterwards can be codified (describes the task of turning knowledge into code) and processed and integrated into a KM base or repository (Kucza, 2001, Dooley, 2016).

The retrofit coordinator is to ensure quality assurance is established and also capture and review information as regards minutes from various meetings, contractor's logs, contract with materials testing and quality control (Azizi *et al.*, 2011). Reviewing contractor submittal shop drawings (to verify that the correct products will be installed on the project) and spreadsheets is also a vital part of auditing a retrofit project (Barnett *et al.*, 2010) for a retrofit coordinator in order to apply and capture relevant knowledge in facilitating continual improvement. The retrofit coordinator has acquired and reuses (from the initial report) knowledge and at the same time captures and stores knowledge (Udeaja *et al.*, 2006) in the course of carrying out specified tasks. The outcome will assist in making an informed decision throughout the construction activities because knowledge is acquired/created, captured, stored, reviewed, updated, shared and reused. Continuous learning from the project team (involving the key stakeholders and other stakeholders/supply chain) and integration of knowledge to project routines and activities avails a culture of learning, where new ideas are generated and hence, best practices are established.

8.3.3.6 Evaluate retrofitted building: managing knowledge in evaluating the retrofitted building

Knowledge needs to be properly managed in evaluating the retrofitted building. The retrofit coordinator manages knowledge in evaluating the retrofitted building by applying and reusing knowledge from the construction and design processes and ensuring that the parameters and standards have been delivered. The same procedures of KM are employed in terms of snagging and evaluating the quality and effectiveness of the materials used in the building and ensuring that the KMCP is implemented alongside. There is a need to integrate both explicit and tacit knowledge gathered all through the construction process including design stages in establishing that the aim(s) and objectives of the retrofitted building have been delivered. After that, the report and recommendation(s) will be produced and documented in the KM database. The report and recommendation(s) will highlight mistakes made, best practices and lesson learned which would be shared between key stakeholders and other stakeholders.

8.3.3.7 Handover and close-out: managing knowledge in handover and close-out of the retrofitted building

At this stage, construction administration comes to an end (RIBA, 2013). It is vital that the contractor provides the clients/building occupants with the required information in order to create the knowledge needed for the smooth operation and management of the retrofitted building (Empirical Evidence, Survey Q22, Q24 and Interview Q2). It is highly recommended that the required information for the smooth operation of the building is in the following format: operating manuals (user guide), handbooks, animation, YouTube videos, USB sticks, video content, posters/labels/notices and website content that is updated as the building changes over the years. Clients/building occupants applying, transferring and sharing knowledge through these formats demonstrate that knowledge is created and acquired by building users for informed decision-making in the operation and maintenance of the building (Empirical Evidence, Survey Q22 and Interview Q5 & Q6). It is essential that handover notes are given to the building occupants for necessary knowledge documentation, storage, application and reuse.

8.3.3.8 Feedback loop: managing knowledge in a feedback loop in post construction and post occupancy

At this stage, knowledge is managed in a feedback loop. Managing knowledge in the feedback loop can be achieved when the occupant captures experiences and mistakes made in managing and operating the building (Design-Buildings, 2016). The captured knowledge is stored and handed over to the retrofit coordinator/client/contractor depending on who will conduct the post-construction reviews and post-occupancy activities and experiences. However, it is recommended that the retrofit coordinator and project team members/contractor conduct the post-occupancy and post-construction evaluation for knowledge creation and sharing (Empirical Evidence, Survey Q18). The shared experiences from the occupants enable the key stakeholders to acquire and capture both existing and new knowledge. Post-construction and occupancy evaluation provide the key stakeholders with the opportunity to capture best practice, mistakes made and lessons learned through chats and meetings. This knowledge is captured during the evaluations by recording the chats and interviews with occupants, questionnaires and making notes, which precedes the knowledge stored in the KM database. However, if there are issues in the evaluation, the key stakeholders can evaluate the existing reports and recommendations from the construction activities to apply and reuse knowledge therein in proffering solutions. After the evaluation has been conducted, the acquired knowledge has to be integrated, updated, documented and applied in writing a report and recommendation(s) that will be available to the client/occupants and to other key stakeholders involved in the projects to enable them to make an informed decision in subsequent projects. While writing the report, it is important as aforementioned to include the unique property reference number (UPRN) for easy identification of the retrofitted building. All reports of the construction activities including post-construction feedback are integrated, documented in the KM database and subsequently presented to the local authorities. Presenting the report to the local authorities provides an opportunity for knowledge creation, acquisition, capturing, storing and sharing amongst key stakeholders that were not involved in the project and the wider community (Empirical Evidence, Survey Q18). This can be achieved through publications on the relevant website, and the information has to be free and accessible to key stakeholders and the wider community for effective sharing and disseminating of retrofit knowledge (Empirical Evidence, Survey Q22).

The need to share retrofit knowledge is essential in order to assist the key stakeholders and indeed other stakeholders/supply chain to make an enhanced and informed decision to avoid reinventing the wheel. The report and recommendation(s) will serve as a knowledge-based case study/repository with the step-by-step activities involved in the uptake and delivery of the sustainable retrofitted building project. Sharing of intellectual property through the report will help in bespoke undertakings and solutions needed in the delivery of retrofit projects. Knowledge is part of what makes a ‘person’s personality’. Hence, disseminating one’s knowledge to others also means enabling others to perform according to tasks, thus making the originator more easily replaceable (Davenport and Prusak, 1998) in the sustainable retrofit project. The report and recommendations will consolidate retrofit building improvements and help the KM initiative to gather momentum amongst the stakeholders particularly key stakeholders in the construction industry, and in sustainable retrofitted building projects. The feedback is essential because the output of the project (mistakes made, lessons learned and best practice) will be employed for effective subsequent (new input) delivery of similar retrofit projects.

8.4 Validation of sustainable retrofitted building decision support framework

The primary aim of validation is to have a better understanding of the framework capabilities, appropriateness and limitations in addressing the problem that was investigated (Macal, 2005). Balci (1994) states that ‘framework validation is demonstrating that the model or framework within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives’ (p.121). Model validation deals with building the right model. In a similar vein, Cheung (2009) affirms that framework validation is essential to establish the quality of the research outcomes. Kennedy *et al*. (2005) state that validation is a critical aspect of the framework development process that increases confidence in the research and makes it more valued. Borenstein (1998) affirms that validation is the process of defining whether the framework or model is an important and accurate representation of the real system in a specific problem area.

Given several perspectives on framework validation definitions, this research adopts the definition of Macal (2005). Thus, the design of the appraisal should focus on investigating the appropriateness and effectiveness of the proposed framework in assisting the industry practitioners/key stakeholders in making informed and appropriate decisions when delivering sustainable retrofitted building projects in the UK. However, Winter (2000) argues that validation is not a single, fixed or universal concept. Instead, it is a contingent construct, inescapably grounded in the process and intentions of specific research projects and methodologies.

Nevertheless, there are various methods for validating a model and framework, each of which can be used either subjectively (through interviews by experts to ascertain whether the validation is fit for purpose) or objectively (through the use of some statistical or mathematical procedures to verify the framework is fit for purpose) (Sargent, 1998, Qureshi *et al.*, 1999). The fundamental reason behind any of these methods is the gathering of evidence regarding the credibility and applicability of the framework by an independent, but interested party (Gass, 1983). It is common practice to use each or a combination of techniques or methods when validating a framework (Akadiri, 2011a). Brief explanations of these methods, as defined in the literature (Gass, 1983, Sargent, 1998, Kennedy *et al*., 2005), are presented amongst others below:

1. Degenerate tests: The model or framework behaviour is identified as degenerate in certain situations. The model can be tested to see if it degenerates as expected by simulating such situations in the model using a correct selection of values of the input and internal parameters.
2. Comparison to other models or frameworks: The output of the model being validated is compared to the outcomes of other valid models of the actual system. This is applicable if such valid models are already available.
3. Extreme condition tests: This method is similar to the degeneracy tests; the framework can be verified by applying it under extreme conditions to see if the framework or the model would achieve what it is developed for.
4. Event validity: This method is achieved by comparing the 'events' of occurrences of the model being validated to those of the real system to determine similarities.
5. Face validity: This is achieved by asking people who are knowledgeable about the system whether the model or framework's performance is reasonable. This method can be used in ascertaining if the logic in the conceptual framework is correct and if the input and output relationships are vital.
6. Historical data validation: This ascertains whether historical data exist (or if data are collected on a system for building or testing the model), part of the data is used to develop the model and the remaining data are used to test whether the model performs accurately in the system as expected.

Having considered the literature on validation methods, the research adopted face validity in order to explain the framework comprehensively to the key stakeholders involved in the delivery of sustainable retrofitted building projects. According to Gass (1983), the appropriate method used for framework or model validation mostly depends on the real-world aspect being analysed and the type of framework being used. The research considered three options for carrying out the validation, which are (a) focus group, (b) semi-structured interviews and (c) questionnaire surveys. Hence, the research adopted a mixed-method approach for its framework validation. The mixed-method research validations were achieved through face validity to having a comprehensive explanation of the framework to the key stakeholders.

Hence, this provided the researcher with the opportunity to clarify participants' doubts and gather criticisms, suggestions and recommendations for further framework improvement.

The ensuing sections discuss the detailed procedure of the validation process, which includes the development of validation questions, selection of key stakeholders and presenting findings.

8.4.1 Designing of qualitative (interviews) and quantitative (survey) validation questions

In designing the validation questions, the aim is to examine the appropriateness, applicability and relevance of the SRBDSF. Appropriateness has been considered as an essential criterion in achieving framework validation (Sharp *et al.*, 1993). Baume (1991) and Balci (1994) affirmed this by stating that it is vital to consider the appropriateness of the framework or model through the validation to judge the substance of the findings. Effectiveness is another important criterion in checking an intervention (Kumar, 2011). In the question design, the effectiveness of the framework was investigated mainly to ascertain comprehensibility/clarity and applicability. Questions on the comprehensibility/clarity of the framework are vital in framework validation (Macal, 2005). Hence, it was considered necessary to ascertain if the framework delivered the key stakeholders' expectations and whether the framework is understandable to the intended users. The applicability question attempted to determine whether the framework is useful and user-friendly and also its strengths and weaknesses. Finally, questions need to ascertain the extensiveness of the framework (Balci, 1994, Macal, 2005), thus, whether the framework includes all essential decision variables vital in making informed decisions in embarking on and delivery of sustainable retrofitted building projects.

8.4.1.1 Selection of key stakeholders for qualitative (interview) validation

For the framework to be accepted as a standard for decision-making, it is essential that the validation generates comments of commendation, suggestion and criticism. However, in choosing the industry practitioners who are the key stakeholders to validate the framework, the researcher considered the key stakeholders that participated in multiple-case studies as regards collection of data in the current study (sees Section 7.3.2). The use of the previous participants was vital because they are familiar with the research and relevant to it, having being involved in sustainable retrofit projects. In addition, the use of the same key stakeholders was essential to review the internal validity and consistency of the current study (Creswell, 2003). Hence, emails were sent out to 12 of the previous interviewees to validate the framework. Out of the 12 previous participants, only six responded. Due to time constraints on the part of key stakeholders, the researcher scheduled appointments that suited their availability. However, out the six stakeholders, only three were available within the time allocated to validate the framework.

This necessitated the researcher seeking an audience with new key stakeholders in the research with relevant experience in the industry to validate the framework in order to meet the deadline in submitting the thesis to the university. Industry practitioners contacted are key stakeholders who were new to the study. Hence, the researcher carried out an extra three validations, which offered different viewpoints and tested the applicability of the framework in a wider scope (Wellington, 2000). It is essential to enable key stakeholders to assess and identify any process and decision limitations not addressed in the framework (Babatunde, 2015). In the end, the researcher conducted six validations. The six key stakeholders are available for the validation work in construction companies involved in sustainable retrofitted building projects as highlighted in Table 8.1.

Table 8. 1 Background information on the key stakeholders that participated in the qualitative framework validation

Key stakeholders	Organisational disciplines	Designation/roles	Is your organisation involved in retrofit projects?	Years of experience
1	Consultancy social housing	Senior sustainability consultant	Yes	8
2	Architectural and design consultancy	Project manager	Yes	10
3	General construction	Site manager	Yes	5
4	Consultancy specialises in architectural designs and construction	Director	Yes	34
5	Consultancy and suppliers	Technical sales manager	Yes	16
6	Architectural and design consultancy	Lead architect	Yes	12

8.4.1.2 Presentation of findings of the qualitative validation (interviews)

In presenting the results of the qualitative validation, it is vital to state that two key stakeholders from the same construction organisation validated the framework through a focus group whereas the researcher conducted semi-structured interviews with the remaining four key stakeholders. It is essential to state that the validation generated useful and relevant comments from the key stakeholders as discussed below.

Ascertaining the comprehensiveness of the framework as regards sustainability and retrofitting

The key stakeholders stated that the framework is comprehensive in addressing sustainability issues. They stated that it covered the necessary area especially as it relates to sustainability principles, criteria and objectives.

Excerpts from the interview quotes:

'The need to cover sustainability principles has demonstrated that the framework is contemporary with the yearnings of the industry and society'. – (V2)

*'I think it has in-depth coverage. Personally, I do not really know about sustainability principles, so this is good and commendable'. – (*V3)

'The framework is useful, and of course, sustainability is a global issue. For the industry, we need to be educated more about sustainability in construction, and I think that is one of the achievements of this framework, but there is room for improvement'. – (V6)

2. Ascertaining whether the framework addresses the gap of knowledge management in embarking on, uptake and delivery of sustainable retrofitted building projects

The key stakeholders were interested in the framework and affirmed that a knowledge management based framework is very commendable. They stated that it is a contemporary need of the industry, especially with the risks and complications involved in delivering sustainable retrofitted building projects. They emphasised the importance of the framework because the industry is a knowledge-intensive one. The interviewees indicated that they were educated about the framework and its application not only in sustainable retrofit but also in general construction activities.

Excerpts from the interviews:

'It is strange that in the industry a lot of old schools do not want to share knowledge. The old schools need to support the adoption of knowledge management in construction projects. Knowledge management needs to be adopted in construction activities, and it is important that the industry establish a knowledge management system. Presently there is no central control for knowledge or central knowledge system'. – (V2)

'The framework is interesting and of course, addressed or will address knowledge gaps because managing knowledge is lacking in the industry. We have experienced recessions, but at the moment the industry is doing fairly well, so there is a need for knowledge not just for retrofit projects, but also for entire construction projects'. – (V3)

'In this company, we capture knowledge; however, after the knowledge capture it ends there. Unfortunately, it does not go any further. So the idea of knowledge management procedure is an excellent idea, and you have thought me a lot by this framework via knowledge management procedures'. – (V4)

'Knowledge is something lacking in the industry. The industry is building up again after the recession, so the need to manage knowledge is essential'. – (V5)

'You included the reports at every bit. That is commendable and more commendable is for wider market through the local authorities'. – (V6).

3. Ascertaining the relevance of the framework as regards embarking on and delivering sustainable retrofitted building projects and can be adopted by the industry

The key stakeholders acknowledged the relevance of the SRBDSF as regards the knowledge management procedures and principles that contributed to developing the framework. The six key stakeholders accepted that lack of knowledge management remained a challenge in the industry and commended the framework, stating that it will assist the key stakeholders in making informed decisions not only in retrofit projects but also in all construction projects. They also applauded that presentation of the framework has educated them to have a fair view of what knowledge management entails. They suggested that the SRBDSF should be presented at industry conferences for debate to ascertain the possibility of its adoption.

Excerpts from the interviews:

'Well, knowledge is power; the more knowledge you have, the more powerful you become. I will sincerely tell you that I would not want my knowledge to be traded. However, if this framework is adopted, I will be part of the system that will be compelled to disseminate knowledge'. – (V1)

'Well the idea is a welcome development and should be promoted further than this interview. You should go out there and talk to big companies and local authorities. The idea of knowledge administrator should be adopted across the board. It will set the stage for the adoption of knowledge in all construction projects'. – (V2)

' The framework is good because it has a sustainable retrofit process too, though not perfect, but needs a little adjustment and more key stakeholders to evaluate it. I think the knowledge base framework is an interesting idea. I think you should try to present it to the UK 5 big construction companies to adopt it and probably develop it further so it can cascade down to the small construction companies. Please, let me know how it goes'. – (V3)

'There is a need for knowledge to be managed in retrofit projects and all construction projects. However, knowledge doesn't come easy, you work hard for it, and that is why some of us don't give it freely unless an eagerness to learn. To be honest, I will gladly be part of the process that will promote knowledge adoption in construction industry'. – (V4)

'The framework will certainly improve the decision abilities not only for the key stakeholders but the entire supply chain. It is a brilliant idea and should be considered. I advise you come with it to industry conferences and present it to a bigger audience for debate.' However, the question is will it be promoted? Will it be accepted? – (V5)

'There is a need for knowledge to be managed in retrofit projects and all construction projects. To be honest, I would not like to share my knowledge with those that think it is their prerogative. I have devoted time and energy to come this far so I would not be compelled to share. Nevertheless, it is a brilliant idea if adopted'. – (V6)

4. To establish if the framework can assist key stakeholders in making an informed decision.

The key stakeholders affirmed that the framework would improve the decision-making capabilities of the key stakeholders in making informed and appropriate choices. They stated that managing knowledge in embarking and delivering of retrofit projects is relevant in decision-making in every aspect of the construction project.

Excerpts of the interview:

'Absolutely, there is no way you will not be informed by the knowledge management process involved in this framework'. – (V1)

'Decision-making is about being well informed, and that is what the framework has demonstrated in every step of the way'. – (V2)

'Yes, of course, and it is commendable'. – (V3)

'It is simplified so yes; it will enable good decisions and good practice'. – (V4)

'Yes, an informed decision will be achieved using the framework, no doubt'. – (V5)

'The issue of managing knowledge needs to penetrate the industry for every stakeholder and the supply chain to understand it properly. Now there is a big gap in understanding what knowledge management is. The framework should not be only for key stakeholders, but for the entire supply chain, so when that happens, I will agree that it will inform decision-making in delivering sustainable retrofit'. – (V6)

5. Ascertaining whether the framework is unambiguous and user-friendly

The key stakeholders maintained that the framework embodies clarity and is easy to understand. They also stated that the framework is user-friendly and doubt if any stakeholder will struggle with understanding it because it comes with the retrofit building process.

Excerpts of the interview:

'No, no, I do not think it's ambiguous.' – (V1)

'It's easy to understand; I am not sure anyone can struggle with it since you have the theoretical part.' – (V4)

'No, it's easy to understand, just consider my suggestions.' – (V5)

'With the explanation of the knowledge management process included therein, I do not think anyone will struggle with the understanding. The theoretical part of the framework explanation should be attached to the framework, not included but attached.' – (V6)

6. Obtaining criticism, gaps, suggestions and recommendations of the framework

The key stakeholders commended the framework as discussed in earlier sections. However, they made some suggestions and recommended what they considered missing in the framework. For example, some of the key stakeholders stated that there is a need for 12 months' defect period for contractor responsibilities and liabilities in case anything goes wrong. Hence, the contractor within the 12 months' defect period would have repaired any defects. After that, the facility manager takes over. The researcher argued that the client might not be able to afford a facility manager. One key stakeholder responded: *'Well, it is important that facility managers be employed because if you don't employ them, who is going to handle the maintenance issues in the building?'* Another interviewee asked: *'If you don't employ them, how will the building be maintained after one year of contractor defect elapses? I think you tend to look at smaller pictures in retrofit, but that shouldn't be the case because we have got a lot of high-rise buildings that need to be retrofitted in the UK'.*

Excerpts of the face-to-face interview:

'I think the principal contractor, tendering stage and bidding stage are important and should be considered in the framework. The retrofit coordinator is important to be included. In addition, it is recommended that the client should have a principal designer and the contractor will have his or her designer too'. – (V1)

'Consider design responsibilities to be transferred to the contractor. In addition, BREEAM is for big companies and I am not sure it can properly be adopted in sustainable retrofit. F10 should be considered earlier. Applying for HSE for F10 (notification to commence work on the site) should be included earlier in the framework. Consider a one-year post-construction defect. I recommend including the facility manager to maintain the house after the post-construction defect of one-year ends'. – (V2)

'Post construction should be in stages say three to six months and six months to one year. The principal designer should be the client's representative to be paid by the client'. – (V3)

'Clerk of works or independent certified will have to check or monitor the building. The clerk of works will have the intent of all the parties or key stakeholders. The international standard organisation (ISO) should be included while sourcing for materials as regards environmental issues. The quality assurance manager should check the quality of the materials and equipment used or installed in the retrofitted building projects. However, it seems the retrofit coordinator does the job of both clerk of works and assurance manager, so maybe they are not necessary anymore'. – (V4)

'The snagging list is not included. The list is important to be considered before the final audit and handover. The snagging list should also be considered at least for two to three weeks before handing over the retrofitted building. Then allow one month to remove the snagging after handing over'. – (V5)

'Regarding years as regards guarantee or warranty for materials, it should be in stages depending. Like windows should be 10 to 15 years, carpets one year to two years and roofs about 15 years. On average, the warranty should be from 12 months to 15 years'. – (V6)

While the criticism is a welcome development in its entirety, it is essential to point out that the design team selection is the prerogative of the client to take the responsibilities or allow the contractor selected for the project to assume that responsibility. This is because, under the traditional contract, the contractor is not responsible for the design, other than temporary works, although some traditional contracts do provide the opportunity for the contractor to design specific parts of the building (JCT 2011: p.9). In addition, according to JCT (2011) which affirmed that under construction management procurement: '*The client will start by appointing consultants to prepare project drawings, a project specification and a cost plan. Involvement of the contractor at an early stage can be beneficial through his/her expertise in such matters as buildability and programming of work packages. The client retains overall design control through the professional team'* (p.4).

8.4.2 Validation through a questionnaire survey

The questionnaire is aimed to examine the appropriateness, relevance and applicability of the SRBDSF as discussed in Section 8.4.1. A questionnaire survey was employed on a similar validation process undertaken by previous researchers. For example, Chen (2012) adopts questionnaire survey to validate the Strategic e-Business Framework explicitly designed for the senior IT management staff to assist them in defining organisational level e-business strategies and the implementation plans in construction organisations. Akadiri (2011b) used a questionnaire survey to validate a conceptual framework for the selection of sustainable building materials. Babatunde (2015) used a questionnaire survey to validate the capability enhancement framework for stakeholder organisations in PPP projects implementation in Nigeria. Theunis (2012) employed a questionnaire survey to validate a conceptual framework for evaluating the tax burden of individual taxpayers in South Africa.

The questionnaire survey was divided into two sections. The first section is designed to elicit the purpose of validation, gather background information about the industry practitioners, their construction organisations, positions and responsibilities, and their experience in the industry in general and particularly in sustainable retrofit projects. These questions were designed to ensure that the practitioner’s organisations are involved in retrofit projects, and practitioners were those who had sufficient knowledge about sustainable retrofit projects. The second section comprises 13 structured validation questions (see Appendix S), which were open-ended questions to obtain comments against each validation criteria.

Open-ended questions allow respondents to express their views spontaneously, without any real influence by the researcher (Theunis, 2012). Reja *et al.* (2003) suggest that to overcome the risk of missing data and of eliciting inadequate answers with open-ended questions, the questions need to be very explicit in their wording, especially in the case of self-administered questions. This was achieved as seen in Appendix D. Altogether, the second part of the questionnaire included 13 open-ended questions (see Appendix). Thus, the respondents were asked to rate the framework based on a scoring scale from 1–5 where 5 = Excellent; 4 = Above Average; 3 = Average; 2 = Below Average; and 1 = Poor (see Appendix S for details). In addition, at the bottom of the questions, further comments were sought from the key stakeholders/industry practitioners for recommendations for improvement and future development of the framework.

8.4.2.1 Pilot study for the validation questionnaire survey

The questionnaire survey was subjected to a pilot study. Thus, before the questionnaire surveys were deployed to the key stakeholders, a pilot study was carried out with two university academics and two industry practitioners to provide feedback to ascertain the appropriateness and clarity of wording used in asking the questions and also to determine that the validation criteria employed meets the acceptable standards (Saunders, 2007). The validation result suggests that the validation criteria are relevant and the wording understandable and straightforward.

8.4.2.2 Selection of industry practitioners/key stakeholders and deployment of the questionnaire survey

For the framework to be of an acceptable standard, a survey questionnaire needs to be conducted to carry out another validation to establish the reliability and validity of the framework. This can only be realised if the industry practitioners selected to participate in the validation have the required expertise. Hence, the questionnaire survey was based on the following criteria for the respondents: relevant expertise, experience, and academic and professional qualifications. In view of this, four validations were undertaken by the key stakeholders who were selected from the list of practitioners who took part in the multiple-case studies described in Chapter 7, which aided in the development of the framework. The involvement of the same personnel sought to inspect the internal validity and consistency of the current research (Creswell, 2003). Additionally, the use of the previous industry practitioners involved in multiple-case studies as a sample frame has two main advantages. Firstly, most of the industry practitioners are key stakeholders in senior management positions with relevant expertise. Secondly, their prior involvement in the earlier survey ensures that they are familiar with this research, which will ensure a good response rate.

However, the researcher made efforts to contact new industry practitioners/key stakeholders and succeeded in getting two new key stakeholders from different construction organisations to validate the framework. Hence, the industry practitioners/key stakeholders who were new to the study carried out another two validations, which offered different perspectives and tested the acceptability and relevance of the framework in a wider scope (Wellington, 2000).

The research had six validation respondents overall from the questionnaire survey as discussed above. Prior to sending out the questionnaire, emails were sent to the practitioners requesting their kind assistance in the validation exercise. Following this, a brief description of the framework was sent via email to the key stakeholders seeking their availability for the validation. Following this, the researcher scheduled appointments with practitioners and travelled to each of their destinations with the structured questionnaire survey for validation. Table 8.2 displays the industry practitioners that participated in the framework evaluation processes.

8.4.2.3 Presentation of findings of the quantitative (survey) validation of sustainable retrofitted building decision support framework and discussions

Table 8. 2 Background information of respondents for the questionnaire-survey

Org. & respondents	Construction Discipline	Annual turnover of £	Size/number of employees	Age of Org.	Job role/position	Professional background	Yrs of experience	Do you retrofit?
1	Executive non-departmental public body specialises in research & innovation. Funds sustainable construction	≥5600 M	≥350	11	Regional manager Northwest England	PhD Chartered mechanical engineer/sustainability consultant	10	Yes /funds retrofit projects
2	Energy & environment consultancy	≥150,000	≥2	14	Director	Engagement/marketing/ valuing	16	Yes
3	Cooperative of retrofit specialist	≥3M	≥ 5	5	Director	Civil engineering	23	Yes
4	Building science centre	≥1.5M	≥ 650	98	BREEAM scheme manager	Domestic energy efficiency	10	Yes
5	Construction/consultancy/contractor	≥1.62 B	≥4000	100 +	Sustainability Research & develop	PhD sustainable construction	14	Yes

					ment manager	management		
6	Government endorsed quality scheme for trades in around home	≥2M	≥10	13	Head of Programme Management	Energy and IT	30	Yes

Table 8. 3 Mean scores from the validation

S/N	**Validation Criteria**	**Scoring scales: 1 (Poor) 5 (Excellent)**						**Mean Score**
		Respondents						
1	The retrofit framework addresses the issue of lack of managing knowledge in the industry	4	3	3	4	5	5	4.0
2	The retrofit framework is relevant to the industry as regards retrofitting of buildings	5	3	3	4	5	5	4.16
3	The retrofit framework is relevant to your current practices in retrofit projects	4	4	4	5	N/A	5	4.4
4	The retrofit framework will benefit your organisation	4	3	3	5	4	4	3.83
5	The retrofit framework is useful as a decision support tool	4	2	3	5	4	5	3.83
6	The issues covered and overall content are comprehensive and relevant	5	5	3	5	4	5	4.50

7	The retrofit framework is easy to read, understand and use, implement or apply	5	3	3	5	4	4	4.0
8	The decision logic icons are adequately placed and helpful for decision-making	4	2	4	3	4	4	3.50
9	The retrofit framework defined activities at an appropriate level	4	3	4	4	4	4	3.83
10	The retrofit framework specified appropriate roles and responsibilities for the activities	4	3	3	4	4	5	3.83
11	The retrofit framework is replicable	5	3	4	5	4	4	4.16
12	Would you recommend the retrofit framework to the key for use in retrofit projects? Yes or no?	Yes	No	Yes	Yes	Yes	Yes	
13	Is there anything missing that needs to be considered? Yes or no?	No	Yes	Yes	Yes	No	No	

Table 8.3 highlights the result of the survey framework validation and the criteria or parameters employed to ascertain the relevance of the framework in delivering retrofit building projects. The mean scores are presented in Table 8.3. From the mean scores, the comprehensiveness of the content of the framework has the highest mean score of 4.50. This demonstrates that the framework covered the relevant contents as it relates to sustainable retrofitting. Following this is the relevance of the framework regarding current practices in the retrofitting of buildings, which scored 4.4, which means that the framework is relevant to delivering sustainable retrofitted building projects. Relevance of the framework to the industry and its replicability are both in third

position with a score of 4.16, and in the comment sections one of the respondents stated that it ‘seems relevant in a general sense and applying it to real scenario(s) would demonstrate its relevancy in practice’.

The issue of the framework addressing the issue of knowledge management in retrofit project delivery scored 4.0. This is essential because the framework will assist key stakeholders in making informed decisions in delivering retrofit projects. With the fragmented nature of the industry and diverse workforce, the framework will assist in managing risks and complications associated with the retrofit project delivery, achieving the quality of the retrofit project and also assisting the key stakeholders in delivering the project on time and budget. Hence, the framework will assist key stakeholders in making an informed decision in delivering sustainable retrofitted building projects. Additionally, in the comment section of the questionnaire survey, the respondents stated as it regards to the framework addressing the issue of lack of managing knowledge is delivering sustainable retrofit ‘seems a very robust general framework. There could be a lot of impact by applying the framework to one or two opportunities where improved knowledge management would solve a real construction issue’.

The framework is easy to read, understand and use, implement or apply also scored 4.0 while the usefulness of the framework as a decision support tool scored 3.83, and this establishes that the framework is relevant to making appropriate decisions in delivering retrofit projects. The framework means score on defining activities at appropriate level scored 3.83, and the appropriate role and responsibilities as assigned to the key stakeholders in the framework scored 3.83 also. In relation to the question of whether the key stakeholders will recommend for its use in the industry, five out of six respondents answered ‘Yes’ while one of the respondents answered ‘No’. The reason for answering ‘No is because the framework is not yet applied in any retrofit project. The reason for answering ‘No’ as the respondent put it ‘it is certainly ready for the next research project to move the framework into a phase of experimental development’ Hence, it is ‘not ready to be applied by practitioners yet’.

Regarding if anything is missing in the framework, four respondents out of six answered ‘No’ while two answered ‘Yes’ with reasons. One of the reasons was ‘who will ultimately deploy the framework on a retrofit project? Is it one person/organisation involved throughout from start to finish, or is it a platform (perhaps digitally based) that all decision makers across multiple organisations will be required to use as a matter of course of doing the retrofit? The client or their advisors require it perhaps'. The comment of the response argues about the clarity of roles of the key stakeholders that were assigned specific roles and responsibilities.

From the results of the survey, key stakeholders have established that the framework is fit for purpose and relevant to the industry and potentially would be adopted. The survey findings also established that the framework could address the issue of managing project knowledge while delivering retrofit building projects. Appendix H that highlights the responses of the key stakeholders in framework validation establishes the credibility, validity and reliability of the research findings and also the relevance of this research in addressing lack of knowledge management in delivering sustainable retrofitted building projects. Appendix X has the original responses from the key stakeholders and the scoring of the criteria.

8.5 Chapter summary

This chapter has delivered the aim of the current research and one of the objectives of the research. It has extensively discussed the essence of developing both SRBP and SRBDSF. The SRBP is vital to embarking on and delivering sustainable retrofit projects. It also provides guidelines or step-by-step instructions needed in the delivery of retrofit projects. The SRBDSF developed with knowledge management principles and procedures is fundamental to making informed decisions by the key stakeholders in embarking on and delivering sustainable retrofit projects. SRBDSF development was vital due to the absence of a knowledge-based decision support system in delivering sustainable retrofitted building projects. Knowledge managed and elucidated in the form of a decision support framework is necessary due to its relevance in enabling project stakeholders to optimise the benefits associated in delivering sustainable retrofitted buildings and helps them to avoid repetition of mistakes and post-decision dissatisfaction. This is because an understanding of what constitutes 'knowledge' has a bearing on a sustainable retrofit project as regards decision-making; hence, the development of the decision support framework by the key stakeholders. The validation findings demonstrated the quality of the research by ascertaining the relevance of the in addressing the lack of knowledge management in delivering sustainable retrofitted building projects. Hence, assisting key stakeholders in making informed and appropriate choices in embarking upon and delivering of retrofit projects. The mixed-method validation of the sustainable retrofitted building decision support framework (SRBDSF) has further established the reliability, credibility and validity of the research. The validation outcome demonstrates that the framework is fit for purpose and relevant in the current practices of the industry in delivering sustainable retrofitted building projects. In addition, the research further validated the sustainable retrofitted building process (SRBP) as seen in Appendix X, and this further establishes the relevance and credibility of the research.

CHAPTER NINE: CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This chapter summarises the key research findings concerning the aim and objectives of the research. An overview of the research discussed literature review findings and the mixed-methods research approach adopted in the current study. The themes in this chapter include a summary of key research findings, the delivery of research objectives and questions, answering research questions, the development of SRBP and SRBDSF, the validation of SRBDSF, the validity of the research findings, and the theoretical and practical contribution of the research, research recommendations, limitation of the study, suggestions for future research and concluding remarks.

9.2 Discussions of the summary of key research findings and delivery of research objectives

Delivering sustainable retrofitted building projects in the construction industry has many challenges, especially with the inability of key stakeholders to make informed decisions. This is because the industry has neglected the need to manage project knowledge in delivering sustainable retrofitted building projects. The construction industry is known to be knowledge-intensive. Hence, there is a need for knowledge management (KM) to be adopted and harnessed in all construction activities, particularly sustainable retrofitted building projects. This research presents a sustainable retrofitted building decision-support tool (SRBDSF), which is the aim of this research and is delivered through Objective 8.

This aim was delivered using the investigation of the literature in relation to the construction industry, climate change, sustainability, and current practices in providing a sustainable retrofitted building project (see Chapter 2), delivered through Objective 1. In reviewing climate change and sustainability, the researcher discussed these aspects: (a) the environmental impacts of construction (see Section 2.5): identifying the need for adoption of sustainable construction particularly retrofit projects; (b) the need for sustainable retrofitted building projects in the UK and its relevance to achieving the UK’s government 80% greenhouse gas emission reduction by 2015 (see Section 2.10.2); (c) the environmental, social and economic benefits of the retrofitted building (see Section 2.11) and the need to consider sustainability principles and practices, including environmental, economic, and social, in the uptake and delivery of a sustainable retrofitted building project (see Section 2.9.3); (d) the identification of environmental assessment methods and the need to consider them in delivering sustainable retrofitted building projects (see Section 2.9.4); and (e) barriers and enablers to embarking upon, and the delivery of, retrofit projects.

Furthermore, the lack of KM was identified as one of the significant barriers to delivering sustainable retrofitted building projects (as it is, in fact, in construction projects generally). Hence, a review of KM literature was conducted, which achieved Objective 2. The review discussed the benefits of KM as fundamental in retrofit project delivery in relation to achieving informed decision-making, quality, reduction of cost overrun, reduction of mistakes, and delivering the project on a budget (see Chapter 3). Managing project knowledge is essential because of the fragmented nature of the industry, diverse workforce, and lack of skilled workers, amongst other things. The failure to adopt KM in construction activities has been identified as the reason for inappropriate decision-making by stakeholders in delivering sustainable retrofitted building projects.

The review concluded that managing project knowledge would assist key stakeholders in avoiding reinventing the wheel in the delivery of sustainable retrofitted building projects by making informed decisions (Mauka *et al.* 2015a). Having identified KM as one of the significant enablers of retrofit project delivery, the review identified and emphasised the need for KM processes and procedures, including knowledge capture, storing, integrating, updating, sharing/transferring, creation, and reuse in retrofit project delivery (see Section 3.4.1). These processes are relevant to managing knowledge applied to retrofit projects. The findings of the review suggested that KM processes are relevant to decision-making in the uptake and delivery of sustainable retrofit projects (Maduka *et al*. 2015).

The research further reviewed stakeholder management in the construction industry (see Sections 4.2–4.7). The review discussed the need for stakeholder management, stakeholder identification, the essence of key stakeholders, and the roles and influences of stakeholders. The review was essential in assisting the collecting data to ascertain key stakeholders in sustainable retrofitted building projects.

Decision-making, and what it entails, was reviewed in the extant literature, including existing decision support tools (see Section 4.9). This review was done with consideration of decision support tools aligned to the industry context. The decision support tools review focused on the construction context, particularly sustainable retrofit projects. The literature findings guided the researcher to further explore further what makes decisions easy or difficult to make through the survey and multiple-case studies for data gathering. The details on the review of the framework can be seen in Section 4.9.4.

The review of the literature was essential in focusing the research in relation to the philosophical underpinning of the study, which shaped the decision of the study in adopting a mixed-method research approach, comprising of quantitative (survey) and qualitative (case studies) techniques. The choice of the mixed-method research approach, as discussed in Section 5.3.4, was essential in achieving the research aim, objectives, and in answering research questions. The choice of a mixed-method research approach was crucial for the broad purposes of the breadth and depth of understanding of sustainable retrofit issues, KM, and capturing relevant knowledge. It also enabled the researcher to eliminate the respective weaknesses of both quantitative and qualitative approaches.

Therefore, a structured questionnaire (with comment sections) was designed with the aim and objectives of the study in view. Kumar (2011) states that questionnaire-survey layouts should communicate in such a way that respondents would perceive that the researcher is talking to them directly. Saunders *et al.* (2012) argue that the design of the questionnaire is based on the research questions, objectives, and time available to complete the data collection. Hence, the adoption of the progressive question reduction sequence (PQRS) (see Figure 5.6), which is comprised of four layouts/sections for a proper direction of survey questions and understanding of the participants and to enable the researcher to effectively analyse the collected data.

The use of PQRS (see Section 5.6.2) considered the background information of the survey respondents. This information was designed to assist in analysing the survey results and specifically for revealing the distribution of survey responses and the quality and relevance of the respondents. *The background of participants* covered: organisation type, organisation size, job positions/titles, professional education, and years of experience, regular clients, company turnover, and involvement in sustainable retrofit projects.

Sustainable construction and retrofit covered: current practices in sustainable construction, particularly sustainable retrofitted building projects. *Knowledge management issues* ascertained the central challenge of the lack of KM in delivering sustainable retrofitted building projects amongst industry practitioner's/key stakeholders.

The survey (see Appendix A) was based on eliciting information from key stakeholders involved in the delivery of sustainable retrofitted building projects within the UK. It guided the researcher in determining the correct study population. Therefore, the target population for this study was, primarily, key stakeholders from the construction industry, who engage in delivering sustainable retrofit projects across the UK. The rationale for choosing UK construction organisations is that the research is conducted in the UK. Hence, it is cheaper to contact the key stakeholders regarding data collection. Having determined the study population, it was necessary to decide on the appropriate sample size for the research. Hence, the researcher reviewed some sample sizes used in similar analyses as a guide.

Consequently, a pilot study was conducted with 10 participants responding to the questionnaire-survey to ascertain the appropriateness of the survey. After this, the researcher deployed 217 online questionnaire-surveys to participants. Of the 217 questionnaires sent to the targeted sample, 86 were returned. This represents a response rate of 39.6%, which was considered to be acceptable and compares favourably with similar studies by Chinyio *et al*. (1998), Akintoye (2000), Black *et al.* (2000), Dulami *et al*. (2003), and Takim *et al.* (2004), all of whom acknowledge the expected response rate for questionnaires in the construction industry to be around 20–30%. Analyses of the data from the survey were accomplished with the use of SPSS and Microsoft Excel.

To identify the barriers and enablers, the industry survey data were subjected to factor analysis (Principal Component Analysis) using SPSS. Following 27 iterations, nine barriers were identified. These included KM issues (lack of political will, fund related issues, poor awareness issues, lack of expertise and required technology, and change resistance issues). In a similar vein, the Principal Component Analysis identified (after 17 iterations) three enablers including social, economic, and environmental factors. This accomplished Objectives 3 and 4.

Further details on the delivery of these research objectives are given in Sections 6.4 and 6.5. Other relevant findings from the analysis of the survey include the following:

k. The respondents and their organisations are involved in sustainable retrofitted building projects, hence, the reliability and validity of the industry survey are established;
l. The data represented respondents across a range of different organisation sizes;
m. There was evidence of poor management of project knowledge in the industry, particularly in the uptake and delivery of retrofit projects (see Section 6.6) and decision criteria/options that can either make retrofit decisions easy or difficult in the delivery of retrofit projects (see Section 6.7). These findings delivered Objectives 4 and 5;
n. The results established the reliability (internal consistency within the respondents) in the collected data regarding the reliability test conducted for the environmental benefits (economic, social and environmental) of sustainable retrofitted building projects;
o. The results established the key stakeholders in sustainable retrofitted building projects, which answered Research Question 1;
p. There is a lack of retrofit guidance and processes in the industry relating to the embarking upon, uptake, and delivery of sustainable retrofitted building projects. The results indicate the need for a retrofit process that can guide key stakeholders on the systematic processes needed to embark on sustainable retrofit projects. The respondents' ranking in Section 6.3.2 indicated the retrofit processes and its order of application in the sustainable retrofitted building project delivery and this achieved Objective 7 of the study. The findings further revealed the order of priority that should be adopted in developing a sustainable retrofit building process;
q. The study established that the industry recognises environmental assessment methods (particularly BREEAM and Passivhaus) and that some construction organisations apply them in their delivery of retrofit building projects;

r. The results revealed that the industry is favourable to whole house retrofits because they believe passive retrofit has minimal contribution to the reduction of greenhouse gas emission;

s. The industry survey findings were statistically analysed using reliability test inferences to establish the level of internal consistency in the perceptions of industry stakeholders regarding the environmental, economic, and social benefits of retrofitted buildings. Determining the reliability of the benefits is to assist in inspiring confidence amongst key stakeholders to increase their interest in embarking on sustainable retrofit projects. Ascertaining the reliability of retrofitted building benefits contributed to the development of the sustainable retrofitted building process and decision support framework. Further details on the attainment of this objective are seen in Section 6.3.

t. The industry survey findings revealed that the industry exhibits a below-average performance in relation to the capturing of project knowledge; this has contributed to key stakeholders' reluctance in embarking on, the uptake of, and delivery of retrofit projects. Furthermore, the findings of the survey discovered that 68.60% of the respondents (N=86) indicated that they do not capture or document experiences and lessons learned during and after delivering sustainable retrofitted building projects. Only 31.60% suggested that they document retrofit activities, showing that KM is disappointedly rare in the industry. The findings affirm the need to adopt KM. However, to accomplish the remaining research objectives and answer the remaining research questions and gaps that exist after the analysis of the survey-questionnaire data, the research conducted further 12 supplementary case-studies using semi-structured interviews as the main data collection method.

The use of a case study research strategy was necessary to understand the dynamics and contemporary phenomenon present in the industry in relation to the research area. The purpose of case studies is considered appropriate since 'depth of insight' is more appropriate for the development of a strategy that reflects the opinions of individuals and key stakeholders (Petty *et al.*, 2012).

The researcher conducted 12 semi-structured interviews as aforementioned with key stakeholders involved in the delivery of sustainable retrofitted building projects. Some of the issues that were investigated arose from the survey conducted earlier, including: establishing critical barriers and enablers for the uptake of sustainable retrofit projects; establishing what knowledge and KM means to stakeholders and answering of knowledge questions and decision making issues in realtion to the uptake and delivery of retrofit projects. The analysis of the data from the case studies was realised using NVivo and qualitative content analysis.

The case studies result analysis/findings confirmed seven critical barriers and enablers and this accomplished Objective 4. These critical barriers/enablers include: (a) a lack of knowledge management issues; (b) a lack of awareness; (c) a lack of funding/grants/incentives; (d) a lack of compelling regulation and political will; (e) a lack of skilled workers or expertise; (f) a lack of demand; and (g) a lack of collaboration among key stakeholders. It is essential to state that, as mentioned previously, the opposite of critical barriers are enablers to delivering sustainable retrofit projects. The identified critical barriers and enablers can be seen in Section 7.4.1 and 7.4.2.

Furthermore, the interviewees revealed the risks and complications that exist in delivering sustainable retrofitted building projects. They stated that complications could occur where there is lack of attention to detail on the design, i.e. where the wall insulation joins to the window and where the wall insulation joins the roof insulation and floor insulation. They further revealed that attention to detail is necessary at the corners, junctions, edges, and interfaces. Many of the interviewees recommended that delivering retrofit project entails professional and skilful handling by key stakeholders to reduce risks of complications for construction workers and building occupants. Further details are seen in Section 7.6. Additionally, the findings of the multiple-case studies also discovered emerging themes:

(a) Lack of coordination amongst key stakeholders as a barrier to the uptake and delivery of sustainable retrofit projects. The key stakeholders revealed that the fragmentation nature of the industry, diverse skills, and the complicated nature of existing buildings demands for the coordination of stakeholders in delivering retrofit projects;

(b) The decarbonisation of the national electrical grid has been identified as a major way to reduce greenhouse gas emissions. However, the interviewees indicated that it is too expensive and the government would not commit to achieving it, hence, the need for an improved commitment by key stakeholders in the uptake and delivery of sustainable retrofitted building project delivery. Further details can be seen in Section 7.4.2.

9.3 Answering research questions

This research answered all the 12 research questions, which can be seen in Sections 6.3 and 7.7. This is necessary to ascertain current practices in the industry as it relates to applying sustainability issues by key stakeholders in delivery retrofit projects. Some questions were answered through a survey-questionnaire to ascertain: (a) who are the key stakeholders in sustainable retrofit projects (see Section 6.3 and Figure 6.10); (b) how do stakeholders in the industry rate the construction industry in improving sustainable principles in delivering retrofit projects (see Section 6.3 and Figure 6.11); (c) does the industry have a standard building process and decision support framework for the uptake and delivery of sustainable retrofit projects in the UK (see Sections 6.3 and 6.7, and Figures 6.13 and Table 6.9); (d) what sustainable retrofitted building materials do key stakeholders use to retrofit building project (see Section 6.3 and Figure 6.12) amongst others.

Furthermore, the issue of the lack of KM in the construction industry was revealed in the answers to the research questions. During the interview, key stakeholders struggled with some KM questions put to them and agreed that there is a need for the industry to adopt KM in delivering construction projects and mainly in the delivery of retrofit projects. However, the answered research questions include, as seen in Section 7.7: What does knowledge and knowledge management mean to key stakeholders? How can knowledge be capture in the delivery of sustainable retrofit projects? How does KM enhance decision-making in retrofit projects? How can knowledge overload be avoided in construction projects? What is the criteria to determine the relevance of knowledge. The study answered these research questions, and details can be found in Chapters 7 and 8.

After the survey and case study analysis, the researcher integrated the results with the literature review analysis to develop a sustainable retrofitted building process (SRBP) and a sustainable retrofitted building decision support framework (SRBDSF). These were necessary to achieve the remaining research objectives and deliver the aim of the research.

9.4 Development of a sustainable retrofit building process (SRBP)

Objectives 1–6 contributed to the development of the sustainable retrofitted building process (SRBP), which, in turn, achieved Objective 7 and contributed to achieving Objective 8. The need to develop a retrofit process was ascertained through industry survey findings in Sections 6.3.2 and 6.7. For example, the results of the survey findings in Section 6.3.2 and Figure 6.12 revealed that there is no uniform or standard sustainable retrofit building process in the delivery of retrofitted building projects. The survey result in 6.3.2 indicated that most respondents were not aware of any guidance available for delivering sustainable retrofit projects. Hence, there is a need for construction guidance or process for the uptake and delivery of sustainable retrofitted building projects.

However, a minority indicated that they are aware of a sustainable retrofit building process, but a uniform one. There was an option provided in the questionnaire survey for the respondents to specify any building guidance that they use. The findings showed different examples of guidance indicating the need for a general or standard building process map/guidance for the embarking upon and delivery of retrofit projects. However, the survey results contributed to developing SRBP for the industry. Further details on SRBP development can be seen in Section 8.2. The subsequent sections discuss the accomplishment of the research aim and remaining research objectives.

9.5 Development of sustainable retrofitted decision support framework (SRBDSF) with KM principles and procedures

The development of a sustainable decision support framework with a knowledge management approach was the aim of this project and is captured within Objective 8. The need to develop SRBDSF with KM approaches was identified in the literature review in Sections 3.4, 3.5, and 3.6. The findings of the literature were further explored through an industry survey as reported in Sections 6.3 and 6.7 to ascertain the need for a decision support framework. The survey findings in Section 6.7 revealed that there is no standard decision support framework for decision-making in the embarking upon and delivery of sustainable retrofitted building projects. To deliver this objective, the researcher considered Objectives 1–7, which contributed to achieving this objective.

SRBDSF was developed employing knowledge management procedures and principles, and this was necessary to assist the key stakeholders in making informed and appropriate decisions regarding the delivery of sustainable retrofitted building projects. SRBDSF is vital to reduce the knowledge gaps in the uptake and delivery of sustainable retrofit building projects. It is important to state that the SRBDSF is relevant to avoid reinventing the wheel and to primarily promote the adoption of KM in delivering sustainable retrofit projects. Further details about the SRBDSF can found in Section 8.3. The next section discussed the SRBDSF validation with the industry participants to determine whether the framework meets the industry requirement. The development of SRBDSF accomplished Objective 8.

9.6 Validation of a sustainable retrofitted building decision support framework

The validity of the findings was established. The validity of research denotes the accuracy or correctness of the results. Anney (2014) reveals that validity of research ascertains how well a scientific test or piece of research and essentially measures what it sets out to, or how well it acknowledges the reality of the assertions it represents. The researcher employed a mixed-method approach as aforementioned to validate the framework. Hence, the survey questionnaire, focus group, and semi-structured interviews were used to obtain statements and scores in validating SRBDSF. The validation of SRBDSF demonstrates the relevance and acceptability of the framework in embarking upon and delivering sustainable retrofit building projects. The key stakeholders expressed that the KM procedures and principles used in the development of the framework is relevant and might set the stage for the adoption of KM in all construction activities, particularly retrofit projects. They suggested that the framework is presented to prominent construction organisations to see if it will be adopted. The key stakeholders also recommended the presentation of the framework to the wider construction audience for example; an industry conference for a debate to improve the framework.

The validation of the framework established that the key framework is a useful decision support tool and relevant in assisting key stakeholders in making informed and appropriate choices in delivering sustainable retrofitted building projects. Hence, the framework is relevant in managing project knowledge. The key stakeholders indicated few limitations, suggested some recommendations, which will contribute to research recommendations and future work. The validation of the framework using mixed-method research further demonstrated the quality, reliability, credibility, and validity of the research. Further details on SRBDSF validation can be seen in Section 8.4, and Appendix X. Appendix X provides further examples relating to the validity and quality of the research, which highlighted the responses of the key stakeholders with their names and established the validation of both the retrofit building process and the framework. The validation of the SRBDSF accomplished Objective 9.

Section 6.3.1 further discusses the quantitative data collection validation while the qualitative data validity is seen in Section 5.11.

9.8 Theoretical and practical contribution to knowledge and originality

1. The development of a sustainable retrofitted building decision support framework (SRBDSF) with knowledge management procedures and principles is one of the significant contributions of this research. The decision support framework is essential for the key stakeholders in the embarking upon and delivery of sustainable retrofitted building projects. The framework can enhance the capability of the stakeholder to make an informed and appropriate decision in every step of the building process. Previous studies have developed decision frameworks for sustainable retrofit, but this framework is significant because it elucidates knowledge management processes right from the point a client decides to embark on a sustainable retrofit project through to its delivery.
2. The sustainable retrofitted building process (SRBP) is significant in the delivery of the retrofit project. The building process serves as a guiding standard for the key stakeholders or step-by-step activities needed to be employed by the key stakeholders in delivering sustainable retrofit projects. The process reveals sustainability concepts; thus, it can be incorporated into the environmental, economic, and social aspects of sustainable development. Hence, the building process demonstrates the sustainability standards, objectives, and parameters needed in delivering retrofit projects. Additionally, the process incorporates the consideration of environmental assessment methods in the delivery of retrofit projects.

3. The research established the reliability of the environmental, economic, and social benefits of sustainable retrofitted buildings. Establishing reliability with industry practitioners will promote confidence amongst the key stakeholders to engage in sustainable retrofitted building projects.
4. The research established nine principal barriers and three principal enabling factors for embarking on sustainable retrofitted building projects and their delivery. This was achieved through factor analysis. Previous studies have revealed some barriers and enabling factors, but this study's factors are significant considering the components under the established enabling and barrier factors.
5. The research established eight critical barriers and enablers to the uptake and delivery of sustainable retrofitted building projects. These are significant for the key stakeholders to acknowledge the need to adopt critical enablers, and, at the same time, demonstrate the willingness to break the critical barriers using KM approach and strategy. Previous studies have identified some of these critical enablers and barriers, but this study's identification is in-depth. Hence, the research revealed rich that will assist in increasing key stakeholders' demand for sustainable retrofit projects.
6. The research identified key stakeholders in retrofit projects. This is relevant because there is limited literature identifying the key stakeholders involved in sustainable retrofit projects.
7. The research established how knowledge about delivering sustainable retrofitted building projects could be identified, captured and managed. There are previous studies on knowledge capture for all construction projects, but this research demonstrated a richer and more practical approach to how knowledge can be captured, particularly in the uptake and delivery of retrofit projects.
8. The research established how knowledge management would enhance decision-making in the uptake and delivery of sustainable retrofitted building projects. This is essential because the construction industry is a knowledge-intensive sector involving decisions at every point of construction projects.
9. The research established the criteria used to identify the relevance of new knowledge to assist in the delivery of sustainable retrofit projects. This

contribution is essential for the construction industry and other industries. The research also established how sustainable retrofit project stakeholders could avoid information overload in relation to delivering sustainable construction. This contribution is significant because of the large amount of information on the internet about sustainable construction. This confuses key stakeholders in determining the appropriate information needed in embarking on and the uptake and delivery of sustainable retrofit projects. Thus, this research revealed how stakeholders, particularly key stakeholders, can capture relevant information and knowledge and avoid irrelevant ones.

10. The research established the risks and complications involved in delivering sustainable retrofitted building projects. Although previous studies have revealed these, this study revealed the in-depth risks and complications involved in providing sustainable retrofit projects.
11. The research revealed that the key construction industry stakeholders do not value or promote sustainable principles in delivering sustainable retrofitted building projects. This contribution is essential to increase the consciousness of industry practitioners in promoting the values of sustainability to achieve sustainable development in the built environment.
12. The research identified potential areas for future research to further promote the uptake and delivery of sustainable retrofitted building projects.

9.9 Recommendations

Based on the findings of this research, the following recommendations are suggested:

1. The study recommends the full adoption of knowledge management procedures in delivering sustainable retrofitted building projects. KM procedures/processes are simplified and not ambiguous for construction stakeholders, particularly for retrofit building projects. This will facilitate the uptake and delivery of sustainable construction, especially retrofit projects.
2. This research recommends that the industry, in collaboration with local authorities, considers the appointment of a knowledge administrator for each sustainable retrofit project. The industry is a knowledge-intensive sector and knowledge administrators should be appointed for each construction project to oversee the effective management of knowledge.

3. Extensive awareness creation of sustainable retrofit benefits by key stakeholders is strongly recommended. The research's empirical evidence indicates that lack of retrofit awareness creation remains one of the critical barriers to embarking on and delivering sustainable retrofit projects. The study strongly recommends that the industry, government and the media should collaborate to promote the benefits of sustainable retrofit projects to increase key stakeholders' interest and awareness in embarking upon and delivering retrofit projects.
4. The research recommends that the industry should collaborate with financial institutions and the government to provide grants and long-term soft loans for interested key stakeholders who are keen to retrofit their existing buildings. This will reduce the financial challenges faced by key stakeholders in embarking on sustainable retrofit projects.
5. The industry should collaborate with the government, colleges, and universities as a matter of urgency to incorporate sustainable retrofit standards into the academic curriculum. This is important, because as aforementioned, more than 70% of buildings needed in the UK have already been constructed. Hence, the young generation that comprises a higher percentage of the population should be knowledgeable with what sustainable retrofitted building projects entail.
6. This research has revealed the low interest of key stakeholders in promoting sustainable principles and practices. Hence, it is essential for key stakeholders who embark on sustainable retrofit projects to always incorporate sustainable principles and practices in delivering sustainable retrofitted building projects,
7. This research strongly recommends that relevant and most popular environmental assessment methods revealed in the research findings (BREEAM, LEED and Passivhaus and Ska) are made mandatory by the UK government in delivering retrofit projects.
8. There is a need for the UK government to collaborate with the industry to establish realisable regulations specifically for embarking upon a retrofit project and its delivery. The existing regulations lack a holistic approach towards the uptake and delivery of retrofit projects.
9. The UK government should institute a body entrusted with necessary legislative powers to enforce and implement building regulations relevant to the embarking

upon and delivery of retrofit projects. This is necessary, because empirical evidence identified *lack of political will* as a critical barrier in delivering sustainable retrofitted building projects.

10. It is essential for the government to consider adopting the SRBP developed in this study as a standard retrofit building process. This is essential because empirical data revealed that there is no standard sustainable retrofit building process. Hence, adopting the developed SRBP is strongly recommended to assist in guiding key stakeholders appropriately, on what it entails in embarking on retrofit building projects. The process will also support key stakeholders in identifying the sustainability parameters, objectives, and standards required in delivering retrofit projects.

9.10 Limitations of the research

The research conducted in this thesis is significant, and the findings from the study are in-depth, rich, and useful in assisting key stakeholders in incorporating sustainability objectives and adopting KM approaches or strategies in the delivery of sustainable retrofit building projects. However, there are limitations associated with this study that include:

1. The qualitative result was very in-depth and essential; however, it did not cover a broader representation of all the key stakeholders involved in sustainable retrofitting. To include all the key stakeholders was not achievable due to the constrained time allocated to this research. Thus, the findings from the multiple case-studies represent about 60% of the identified key stakeholders in this research, who are involved in sustainable retrofit projects. The implication is that, despite the depth of findings, the views of key stakeholders are not comprehensively reflected or captured.
2. From the validation section, it is apparent that key stakeholders expressed impressive comments about the framework and the means score established the quality and relevance of the research, particularly in managing knowledge during retrofit project delivery. However, the framework validation lacked wider construction audience because of the limited time allocated to this research and finance. Time constraints limited a broader debate that could have potentially generated more interesting findings, for which the outcome would have contributed to further refinement of the framework, research recommendations and future work.

3. It has been stated that the proposed framework is fit for purpose. However, due to time constraints, the sustainable retrofit framework and building process were not tested on a retrofit project.

9.11 Suggestions for future research

1. Responses from professionals who were asked to validate the findings suggest that the SRBDSF developed as part of this study is developed into a web-based decision support system. Hence, research should be conducted in achieving this. This is necessary because the majority of UK construction practitioners have basic knowledge of the use of computers and the internet. It will be vital to translate the sustainable building process and decision support framework developed in this research into a decision support system. A decision support system will be handy and easier to navigate.

2. As suggested by key stakeholders, further research should be conducted to widen the incorporation of sustainable principles and practices in the delivery of sustainable retrofit building projects. This is because this research has discovered unsatisfactory commitment and implementation of sustainable principles and practices in delivering sustainable retrofitted building projects. Therefore, it is essential for further study to be conducted to establish solutions for a significant commitment by key stakeholders in promoting sustainable principles, not just in sustainable retrofit, but in all construction projects for the attainment of sustainable development in the industry.

3. Further research should be conducted to explore the risks and complications identified in this research in delivering sustainable retrofitted building projects.

4. There should be further investigation in the area of knowledge capture, storage, integration, and updating in delivering sustainable retrofit projects, which the framework was not able to extensively address. These are essential in retrofit projects because the management of knowledge in providing retrofit projects remains a challenge for the industry.

9.12 Concluding remarks

This research has delivered its aim, the nine objectives, and has answered 12 research questions. It is essential to indicate that the need to adopt knowledge management in the construction industry in relation to delivering sustainable retrofitted building projects has been emphasised in this research. KM is vital to making informed and appropriate decisions and choices in the uptake and delivery of sustainable retrofit projects. The need to adopt relevant environmental assessment methods in delivering retrofit projects has also been demonstrated.

The identification of sustainable retrofitted building project key stakeholders as influential actors is significant because of the limited literature in the area. This research has demonstrated the need for key stakeholders to promote retrofit projects through the avid awareness creation of benefits associated with retrofitted buildings, and this cannot be overstressed. Key stakeholders could achieve such avid awareness creation through television adverts, handbills, and radio programmes. This is because the increased interest of the key stakeholder in embarking on sustainable retrofit projects will enable the UK government to achieve its target of 80% reduction of greenhouse gas emissions by 2050, as indicated in the research scope in Section 1.4. It is nearly impossible for the UK to attain that set target by 2050 if there are no increased efforts by key stakeholders in embarking upon and delivering sustainable retrofitted building projects. These call for a renewed drive for industry practitioners, the government, NGOs, the media, building owners, and financial institutions to make conscious efforts to address the critical barriers identified in this study, hence, setting the motion for holistic sustainable development in the built environment and setting a standard for other industries to employ. The need for reliable and robust collaboration between the industry, government, and the media is vital in delivering sustainable retrofitted building projects. It is essential to state that key stakeholders also validate sustainable retrofitted building projects; their validation scores and comments can be seen in Appendix X, and this further establishes the validation of this research.

The development and validation of the SRBDSF have demonstrated and established the quality, relevance, effectiveness, applicability, acceptability, credibility, and validity of the research. The validation, according to key stakeholders, could set the stage for the adoption of knowledge management in the delivery of sustainable retrofit projects, and, of course, in all construction activities. To this end, some salient points will increase the delivery of sustainable retrofit projects and valuable contributions to knowledge. The recommendations suggested in this study need to be considered and implemented by key stakeholders to have a holistic approach to achieving sustainable development in the construction industry.

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APPENDICES

Appendix A: Cover letter and questionnaire survey

Dear Sir/Madam,

Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

This survey is conducted for an on-going PhD research project with the permission of department of Mechanical and Construction, Faculty of Engineering and Built Environment at Northumbria University, United Kingdom.

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Terms to Note:

Sustainable retrofit: this means refurbishing of an existing structure or building with low carbon materials and renewable.

Sustainable new build: this means constructing a new structure with low carbon materials and renewable.

Passive or basic building retrofit: this means partial kind of sustainable retrofitting which does not involve the entire house or building retrofit.

Active or whole building retrofit: this involves the entire or whole building retrofitting.

Delivering: means achieving, providing or implementing.

Many thanks for devoting your valuable time to completing this survey.

Yours Sincerely,

Nnamdi S. Maduka
PhD Student
Department of Mechanical & Construction Engineering
Faculty of Engineering and Environment
Northumbria University Newcastle-upon-Tyne, NE1 8ST, UK
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Email : nnamdi.maduka@northumbria.ac.uk

SECTION A: BACKGROUND OF PARTICIPANTS

1. **How do you describe your organisation?** (Please tick ☐ box as appropriate)

1.Civil engineering and building services	
2.Architecture and Design	
3.Quantity Surveying	
4.Real estate	
5.Developer	
6.Government agency	

7.Consulting	
8.Main-contractors	
9.Sub-contractors	
10.Sub-contractors	
11.Suppliers	
12.Sustainable building materials suppliers	
Others (please specify)	

2. What is your job title and position in the organisation? (Please tick ☐ box as appropriate)

1.Senior management	
2.Middle management	
3.Junior management	
Others (please specify)	

3. What is your professional Background? (Please tick ☐ box as appropriate)

1.Civil Engineer	
2.Architect	
3.Quantity surveyor	
4.Real estate manager	
5.Project manager	
Others (please specify)	

4. **Years of experience** (Please tick ☐ box as appropriate)

1. 1-10	
2. 11-20	
3. 21-30	
4. 31-40	
5. 41-50	

5. What is the size of the organisation you represent? (Please tick ☐ box as appropriate)

1. 1-10 staff	
2. 11-50 staff	
3. 51-249 staff	
4. 500 staff and more	

6. Which is your regular client? (Please tick ☐ box as appropriate)

1. Public sector	
2. Private sector	
3. Both public and private sector	
Others (please specify)	

7. What is the age of your organisation? (Please tick ☐ box as appropriate)

1. 0-5 years	
2. 6-10 years	
3. 11-20 years	
4. 21-30 years	
5. 31-40 years	
6. 40 years and above	

8. Please indicate the size of your organisation's annual turnover

(Please tick ☐ box as appropriate)

1. £0-5m	
2. £5-25m	
3. £26-100m	
4. £100 and above	

9. Does your organisation get involved in any of these sustenance construction projects?

(Please tick ☐ box as appropriate)

1. Sustainable retrofitting	
2. Sustainable new build	
3. Both	

SECTION B: SUSTAINABLE CONSTRUCTION AND RETROFIT PROJECTS

10. How long do you rate the construction industry with regards to improving sustainable principles and practices?

Select the most appropriate based on a scale of 1-5. Where 5 is the best and 1 is very poorly.

1.Very poorly	2. Poorly	3. Bad	4.Good	5. Best

11. To what extent do you agree with the following as 'Economic Benefits' of sustainable building retrofits?

Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1.Reduction of operating cost and maintenance					
2.Increased property/asset value					
3.Greater building					

longevity or optimisation of the building life cycle					
4.Helping the growth of renewable/green materials					
5.Minimising energy use and lower cost of energy					
6.Reduced expenses in dealing with occupant complaint					
7.Decrease the risk, liability and insurance rates					
8.Reduced air pollution damage					
Others (please specify)					

12. To what extent do you agree with the following as 'Social Benefits' of sustainable building retrofits?

Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1.Better health improvement for building occupants					
2.Improved comfort, satisfaction and well-being of building occupants					
3.Creating an aesthetically pleasing environment					
4.Minimising strain and local infrastructure					
5.Improved occupant safety and security against burglary through upgraded existing windows					
Others (please specify)					

13. To what extent do you agree with the following as 'Environmental Benefits' of sustainable building retrofits?

Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1.Reduced water wastage					
2.Improved air and water quality					
3.Reduced volume of solid in waste generation					
4.Lower air-pollution greenhouse gas emission					
5.Minimising energy use and lower cost of energy					
6.Reduced depletion of natural resources or environmental preservation of natural resources					
7.Aversion to extreme weather impacts					
8.Improved daylighting through					

photovoltaic or translucent PV roofs					
Others (please specify)					

14. Is there any standard or uniform guidance you can recommend for the construction industry to use in retrofitting? (Please tick ☐ box as appropriate)

Yes	No
Please specify if any other	

15. Tick all the boxes that describe the key stakeholders in a sustainable-retrofitted building project

1.Private client	
2.Public client	
3.Architect and designers or design team	
4.Quantity surveyors	
5.Civil/construction engineers	
6. Project managers	
7.Site managers	
8. Contractors	
9.Technical consultants	
10.Suppliers of product	
11.Product manufacturers	
Others (please specify)	

16. Tick the boxes of stakeholders, which you consider more influential in supporting sustainable retrofitted building projects

1.Private client	
2.Public client	
3.Architect and designers or design team	
4.Quantity surveyors	
5.Civil/construction engineers	
6. Project managers	
7.Site managers	
8. Contractors	
9. Suppliers of product	
10..Product manufacturers	
Others (please specify)	

17. How important do you think key stakeholders value sustainable principles when embarking on sustainable retrofitted building projects?

Statement	1.Very important	2.Important	3.Moderately important	4.Slightly important	5Not important
1.Private client					
2.Public client					
3.Architect and designers or design team					
4.Quantity surveyors					
5.Civil/construction engineers					

6. Project managers					
7.Site managers					
8. Contractors					
9.Technical consultants					
10.Suppliers of product					
11.Product manufacturers					
Others (please specify)					

18. Rank the following process in order in which they are applied during active or whole building retrofit projects?

Statement	1	2	3	4	5	6	7	8	9
1. Identify business case									
2. Secure or allocate funding either by grant or saving									
3. Select auditor									
4. Determe scope of work and select contractor to start construction									
5. Identify design solution sets									
6. Conduct quality assurance									
7. Test efficiency and effectiveness of low carbon materials used									
8. Manage the operations and maintenance									
9. Handover and close out									

Others (please specify)									

19. Please tick the material/products you have used or still using in sustainable retrofit project

Statements	Regularly	sometimes	Occasionally	Rarely	Never	Unsure
1.Thermal mass & water sinks						
2.Thermo syphons						
3.Chmneys						
4.Adaptive thermal defence						
5.Heat sink						
6.Adaptive wind defence						
7.Phase change						
8.Heat storage						
9.Insulation fibre/materials						
10.Radiant and evaporative defence						
11.Wind generators						
12.Photovoltaic roofs						
13.Carbon profiling						
Others (please specify)						

20. Which of the following environmental assessment method do you consider when embarking on deep or whole building retrofit?

(Please tick ☐ box as appropriate)

1. BREEAM (UK)	
2. LEED (US)	
3. ENVEST (UK)	
4. Ska (UK)	
5. Passivhaus (Germany)	
6. None of the above	
7. Others (please specify)	

21. To what extent do you agree to the following as barriers to achieving sustainable building retrofits? Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1.Unclarity of information and information overload about sustainable retrofitting					
2.Inadequate data					
3. Lack of information appropriate sustainable construction materials/technologies					
4. Lack of appropriate decision-making due to key stakeholders' different opinions.					
5.Proper awareness gaps					
6. Perceived as an expensive project to embark					
7. Lack of suitable materials					
8. Lack of skilled installers /workforce					
9. Lack of documenting and reviewing mistakes and lesson learned in retrofitting					

10. Tenant/property owner disagreement over rent increase after sustainable retrofit					
11. Lack of proper government funding or grant					
12. Inadequate engagement between lenders and finance providers					
13. Lack of regulatory enforcement by the government					
14. Lack of legislation for penalties					
15. Lack of legislation on sustainable retrofit					
16. Resistance to change from tradition refurbishment practices					
17. High maintenance cost of low carbon materials					
18. Diminished aesthetic					
19. Lack of clarity, long-term plans and roadmap from government					
20. Hidden cost or retrofit					

21. Low rate of returns on investment of low carbon technologies					
22. Investor and user dilemma (Tenant and Landlord)					
23. Lack of collaboration amongst construction stakeholders.					
Others (please specify)					

22. To what extent do you agree to the following as enablers to achieving sustainable retrofitted building projects?

Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1. Higher profit in long-term					
2. Increased building value					
3. Lower operational costs and maintenance					
4. Financial incentives					
5. Client awareness					
6. Building regulation code					
7. Sustainability brand reputation improvement					
8. Energy cost reduction					

9.Positive public image associated with environmentally responsible practices					
10.Contributing to greenhouse gas emission reduction targets					
11. Better health improvement for building occupants					
Others (please specify)					

SECTION C: KNOWLEDGE MANAGEMENT ISSUES

23. Does your organisation capture or document information about experiences (good or bad) and lessons learned during and after retrofitting a building?

(Please tick ☐ box as appropriate)

Yes	No

SECTION D: DECISION-MAKING ISSUES AND KEY STAKEHOLDERS

24. Does the industry us RIBA plan of work, process protocol or any other decision framework/structured model for making decisions when retrofitting?

(Please tick ☐ box as appropriate)

Yes	No
Please specify if any other	

25. To what extent do you agree that any of the following makes decision-making difficult when delivering sustainable retrofit projects?

Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1.Different stakeholders' interest					
2. Lack of retrofit building process					
3. Lack of decision support system/framework					
4.Key stakeholders' resistance to change					
5. Lack of adequate skills					

26. To what extent do you agree that the following makes decision-making easier during building retrofits?

Select the most appropriate based on a scale

Statements	1.Strongly Agree	2.Agree	3.Neutral	4.Disagree	5.Strongly disagree
1.Capturing and documenting mistakes made and lessons learned during ongoing retrofit projects					
2. Reviewing experiences involved both good and bad					

during construction projects					
3. A more systematic model that addresses the decision challenges in retrofitting process (e.g. standard template)					

27. Is there any question or issues you think that needs to be answered or investigated during the interview process? Please specify or list in the box provided

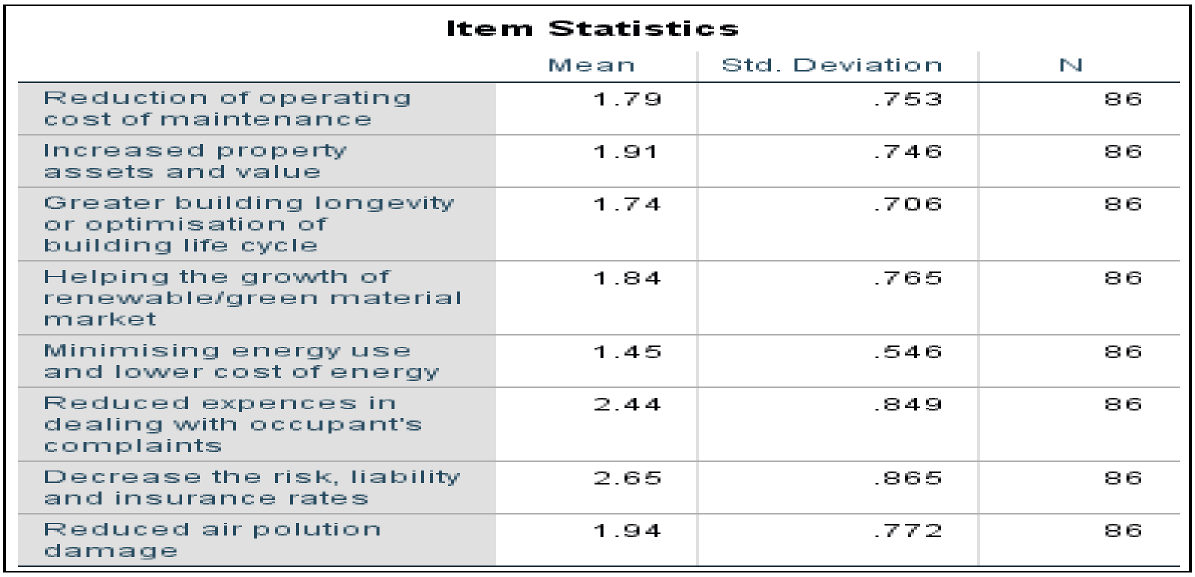
28. It will be greatly appreciated if you will partake in a 30-60 minutes' interview to further help achieve the aim of the research. Can I please contact you?

(Please tick ☐ box as appropriate)

Yes	No

If yes, please can you provide your contact details in the box provided below

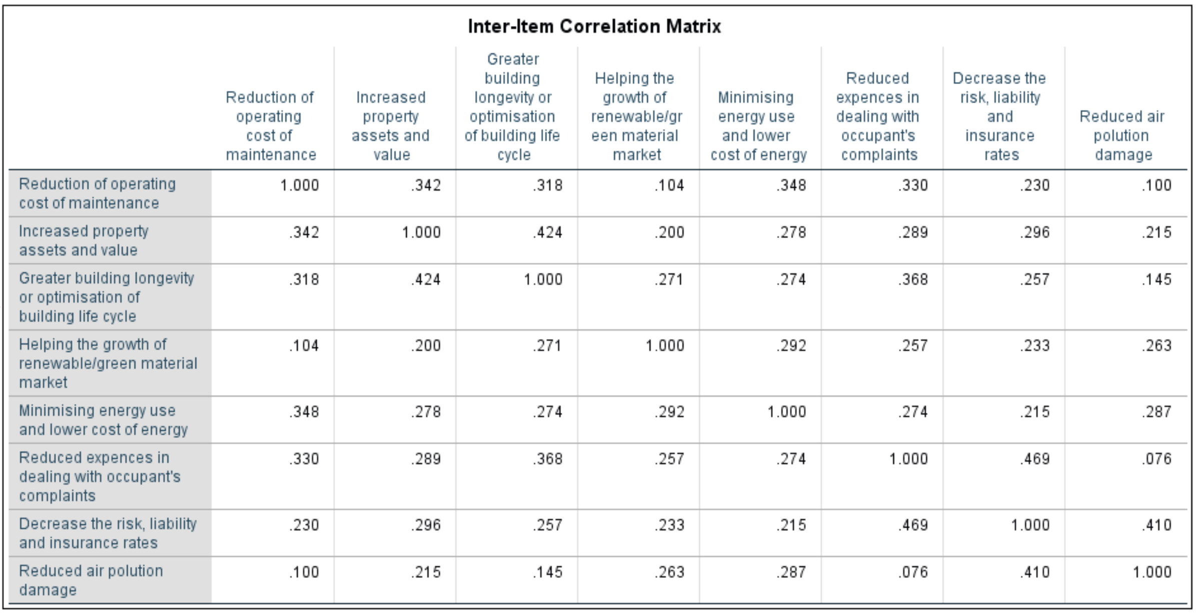
Appendix B: Item statistics for economic benefits of sustainable building retrofits



Item Statistics

	Mean	Std. Deviation	N
Reduction of operating cost of maintenance	1.79	.753	86
Increased property assets and value	1.91	.746	86
Greater building longevity or optimisation of building life cycle	1.74	.706	86
Helping the growth of renewable/green material market	1.84	.765	86
Minimising energy use and lower cost of energy	1.45	.546	86
Reduced expences in dealing with occupant's complaints	2.44	.849	86
Decrease the risk, liability and insurance rates	2.65	.865	86
Reduced air polution damage	1.94	.772	86

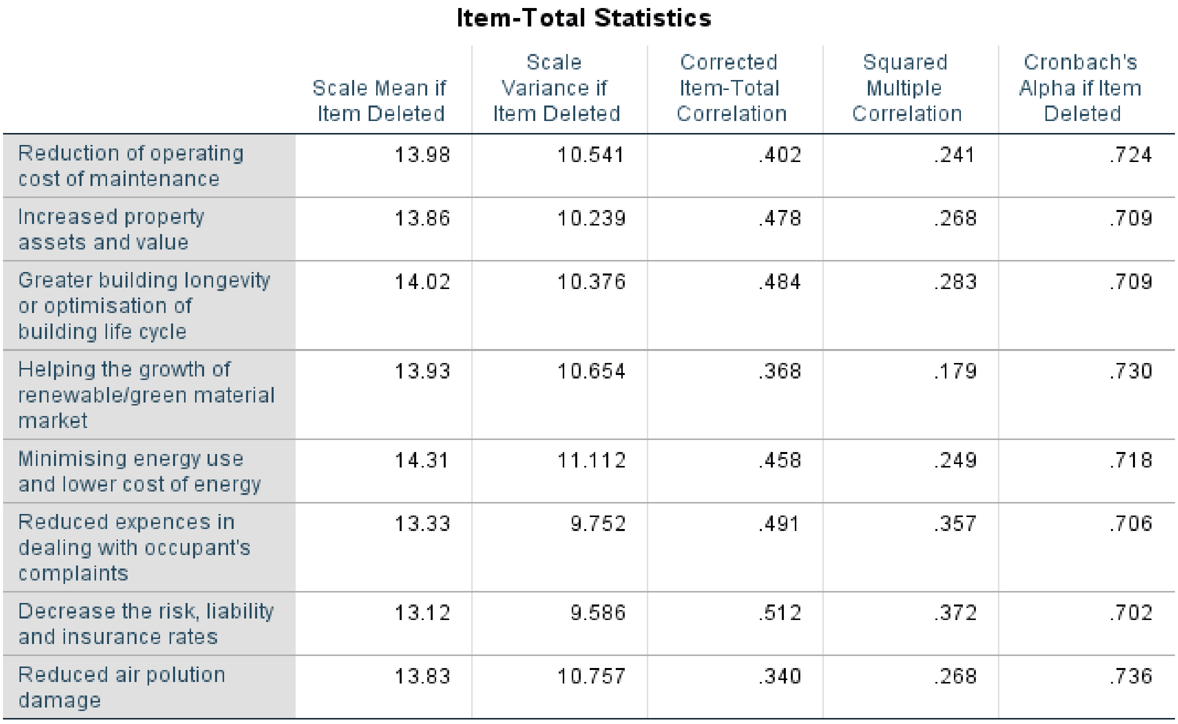
Appendix C: Inter-item correlation matrix for economic benefits of sustainable building retrofits



Inter-Item Correlation Matrix

	Reduction of operating cost of maintenance	Increased property assets and value	Greater building longevity or optimisation of building life cycle	Helping the growth of renewable/green material market	Minimising energy use and lower cost of energy	Reduced expences in dealing with occupant's complaints	Decrease the risk, liability and insurance rates	Reduced air polution damage
Reduction of operating cost of maintenance	1.000	.342	.318	.104	.348	.330	.230	.100
Increased property assets and value	.342	1.000	.424	.200	.278	.289	.296	.215
Greater building longevity or optimisation of building life cycle	.318	.424	1.000	.271	.274	.368	.257	.145
Helping the growth of renewable/green material market	.104	.200	.271	1.000	.292	.257	.233	.263
Minimising energy use and lower cost of energy	.348	.278	.274	.292	1.000	.274	.215	.287
Reduced expences in dealing with occupant's complaints	.330	.289	.368	.257	.274	1.000	.469	.076
Decrease the risk, liability and insurance rates	.230	.296	.257	.233	.215	.469	1.000	.410
Reduced air polution damage	.100	.215	.145	.263	.287	.076	.410	1.000

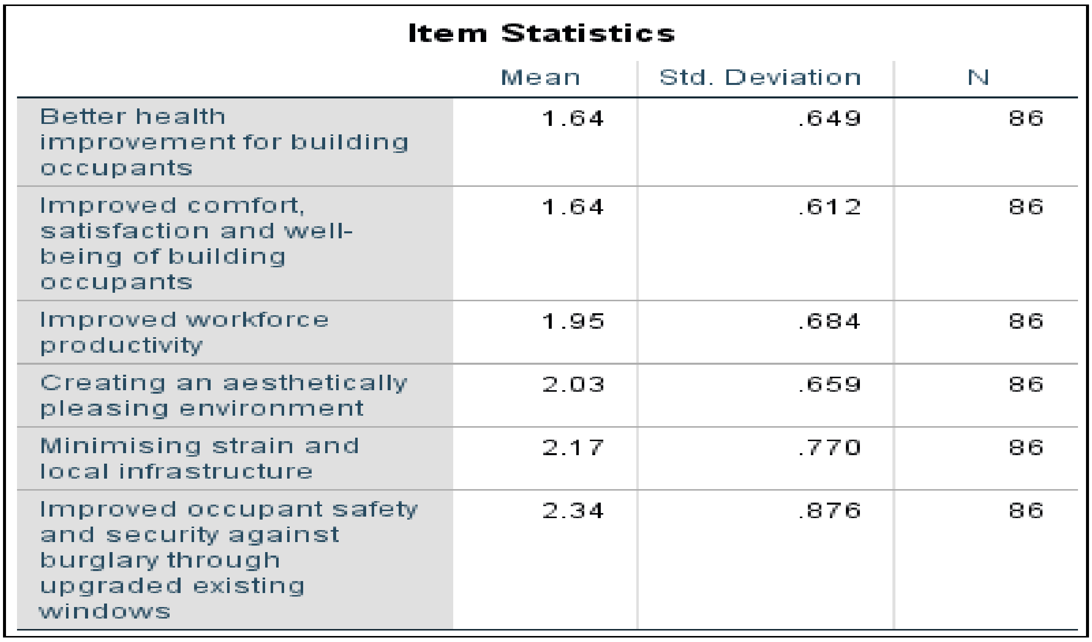
Appendix D: Item-total statistics for economic benefits of sustainable building retrofits



Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Reduction of operating cost of maintenance	13.98	10.541	.402	.241	.724
Increased property assets and value	13.86	10.239	.478	.268	.709
Greater building longevity or optimisation of building life cycle	14.02	10.376	.484	.283	.709
Helping the growth of renewable/green material market	13.93	10.654	.368	.179	.730
Minimising energy use and lower cost of energy	14.31	11.112	.458	.249	.718
Reduced expences in dealing with occupant's complaints	13.33	9.752	.491	.357	.706
Decrease the risk, liability and insurance rates	13.12	9.586	.512	.372	.702
Reduced air polution damage	13.83	10.757	.340	.268	.736

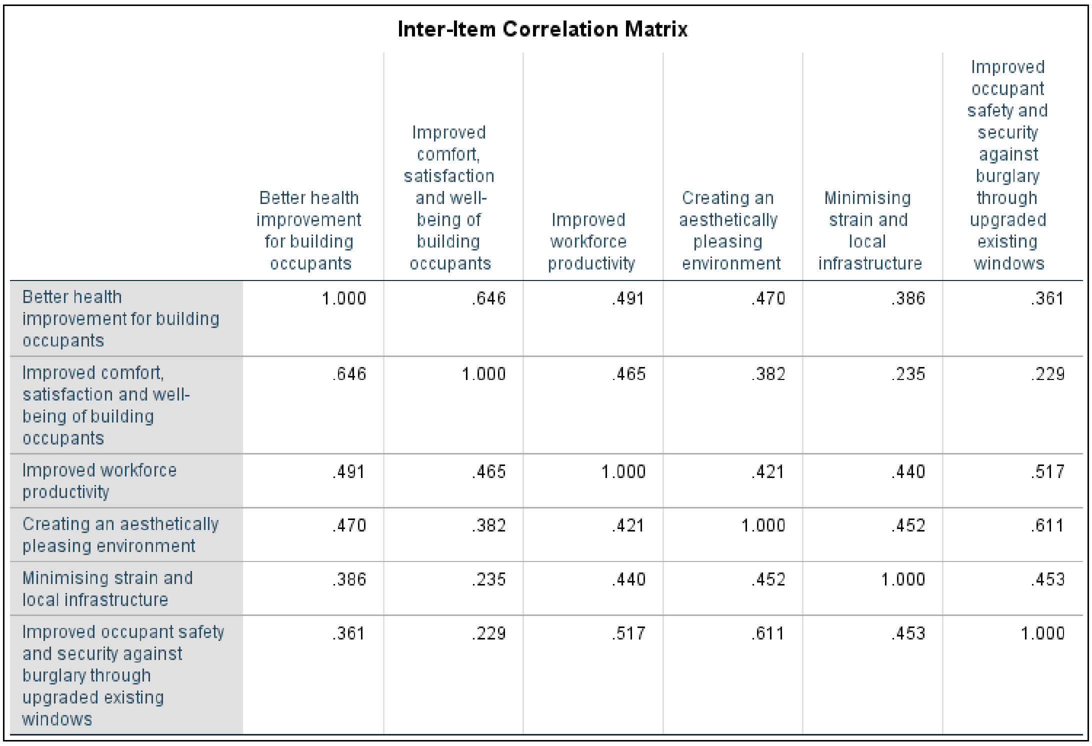
Appendix E: Item statistics for social benefits of sustainable building retrofits



Item Statistics

	Mean	Std. Deviation	N
Better health improvement for building occupants	1.64	.649	86
Improved comfort, satisfaction and well-being of building occupants	1.64	.612	86
Improved workforce productivity	1.95	.684	86
Creating an aesthetically pleasing environment	2.03	.659	86
Minimising strain and local infrastructure	2.17	.770	86
Improved occupant safety and security against burglary through upgraded existing windows	2.34	.876	86

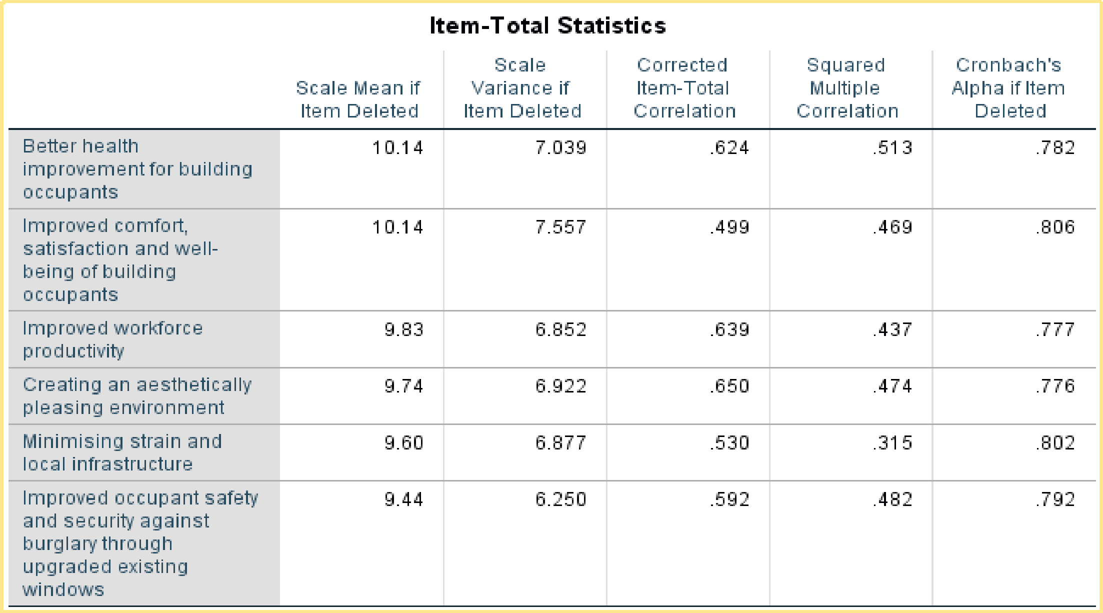
Appendix F: Inter-item correlation matrix for social benefits of sustainable building retrofits



Inter-Item Correlation Matrix

	Better health improvement for building occupants	Improved comfort, satisfaction and well-being of building occupants	Improved workforce productivity	Creating an aesthetically pleasing environment	Minimising strain and local infrastructure	Improved occupant safety and security against burglary through upgraded existing windows
Better health improvement for building occupants	1.000	.646	.491	.470	.386	.361
Improved comfort, satisfaction and well-being of building occupants	.646	1.000	.465	.382	.235	.229
Improved workforce productivity	.491	.465	1.000	.421	.440	.517
Creating an aesthetically pleasing environment	.470	.382	.421	1.000	.452	.611
Minimising strain and local infrastructure	.386	.235	.440	.452	1.000	.453
Improved occupant safety and security against burglary through upgraded existing windows	.361	.229	.517	.611	.453	1.000

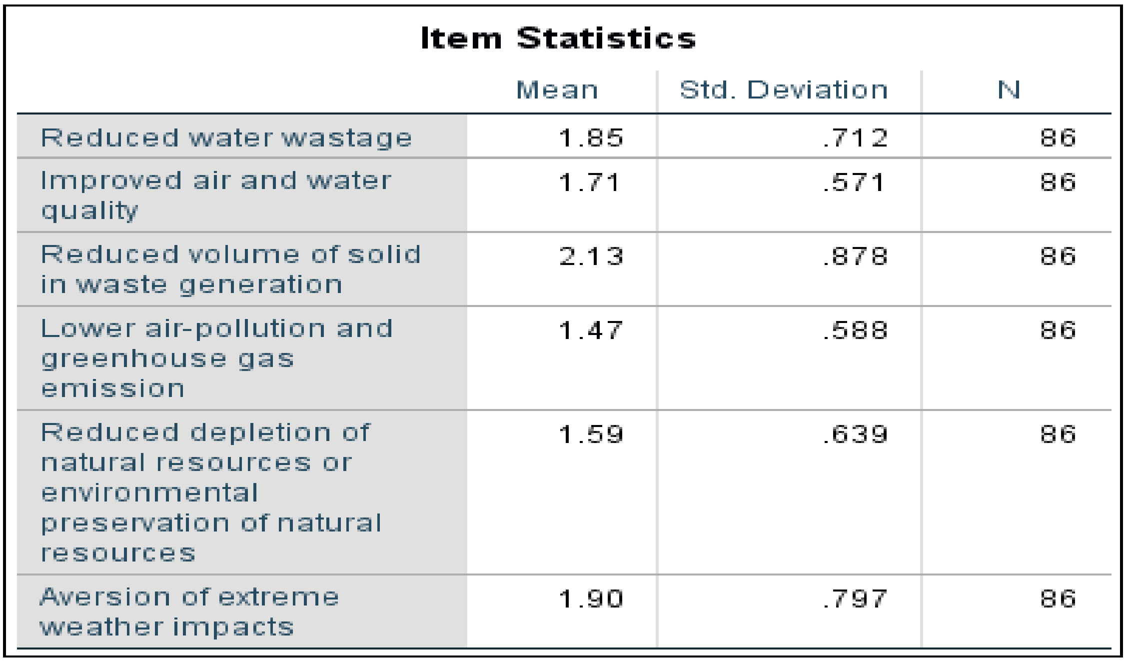
Appendix G: Item-total statistics for social benefits of sustainable building retrofits



Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Better health improvement for building occupants	10.14	7.039	.624	.513	.782
Improved comfort, satisfaction and well-being of building occupants	10.14	7.557	.499	.469	.806
Improved workforce productivity	9.83	6.852	.639	.437	.777
Creating an aesthetically pleasing environment	9.74	6.922	.650	.474	.776
Minimising strain and local infrastructure	9.60	6.877	.530	.315	.802
Improved occupant safety and security against burglary through upgraded existing windows	9.44	6.250	.592	.482	.792

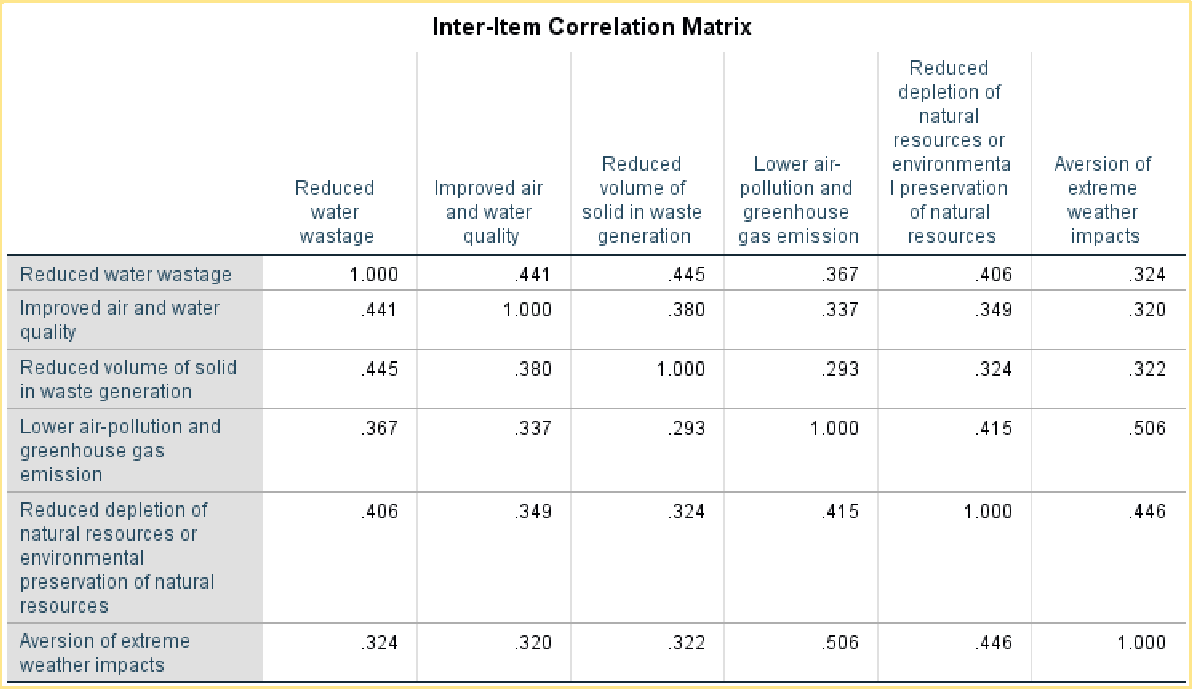
Appendix H: Item statistics for environmental benefits of sustainable building retrofits



Item Statistics

	Mean	Std. Deviation	N
Reduced water wastage	1.85	.712	86
Improved air and water quality	1.71	.571	86
Reduced volume of solid in waste generation	2.13	.878	86
Lower air-pollution and greenhouse gas emission	1.47	.588	86
Reduced depletion of natural resources or environmental preservation of natural resources	1.59	.639	86
Aversion of extreme weather impacts	1.90	.797	86

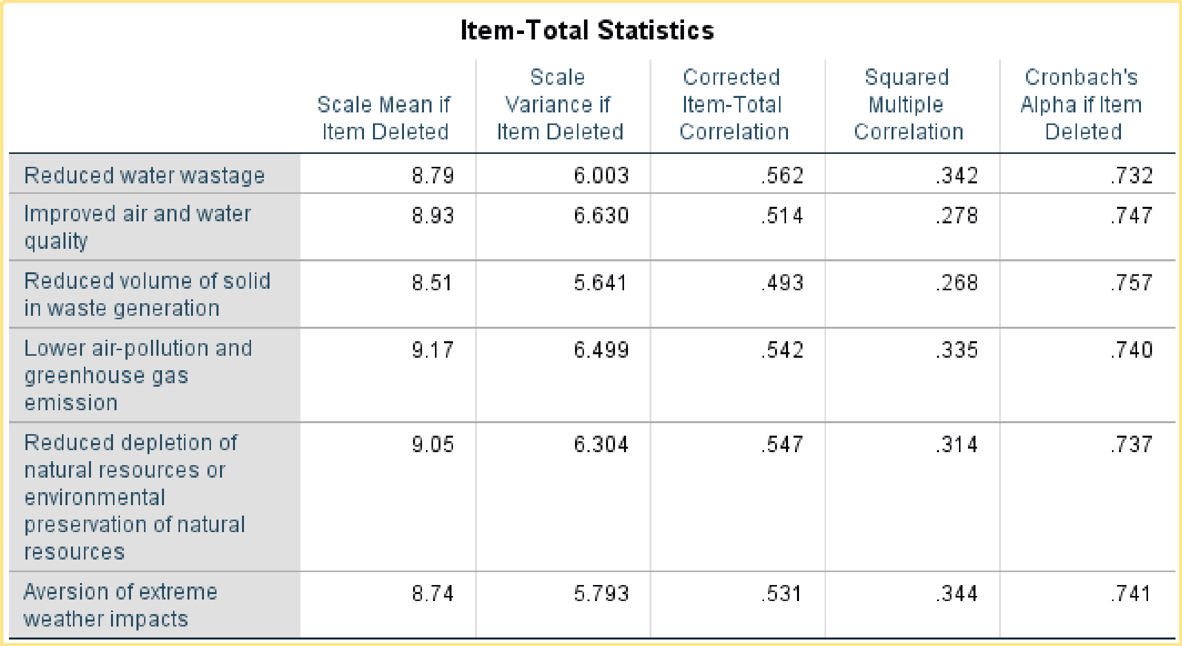
Appendix I: Inter-item correlation matrix for environmental benefits of sustainable building retrofits



Inter-Item Correlation Matrix

	Reduced water wastage	Improved air and water quality	Reduced volume of solid in waste generation	Lower air-pollution and greenhouse gas emission	Reduced depletion of natural resources or environmenta l preservation of natural resources	Aversion of extreme weather impacts
Reduced water wastage	1.000	.441	.445	.367	.406	.324
Improved air and water quality	.441	1.000	.380	.337	.349	.320
Reduced volume of solid in waste generation	.445	.380	1.000	.293	.324	.322
Lower air-pollution and greenhouse gas emission	.367	.337	.293	1.000	.415	.506
Reduced depletion of natural resources or environmental preservation of natural resources	.406	.349	.324	.415	1.000	.446
Aversion of extreme weather impacts	.324	.320	.322	.506	.446	1.000

Appendix J: Item-total statistics for environmental benefits of sustainable building retrofits



Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Reduced water wastage	8.79	6.003	.562	.342	.732
Improved air and water quality	8.93	6.630	.514	.278	.747
Reduced volume of solid in waste generation	8.51	5.641	.493	.268	.757
Lower air-pollution and greenhouse gas emission	9.17	6.499	.542	.335	.740
Reduced depletion of natural resources or environmental preservation of natural resources	9.05	6.304	.547	.314	.737
Aversion of extreme weather impacts	8.74	5.793	.531	.344	.741

Appendix K: Rotated component matrix[a] for barriers

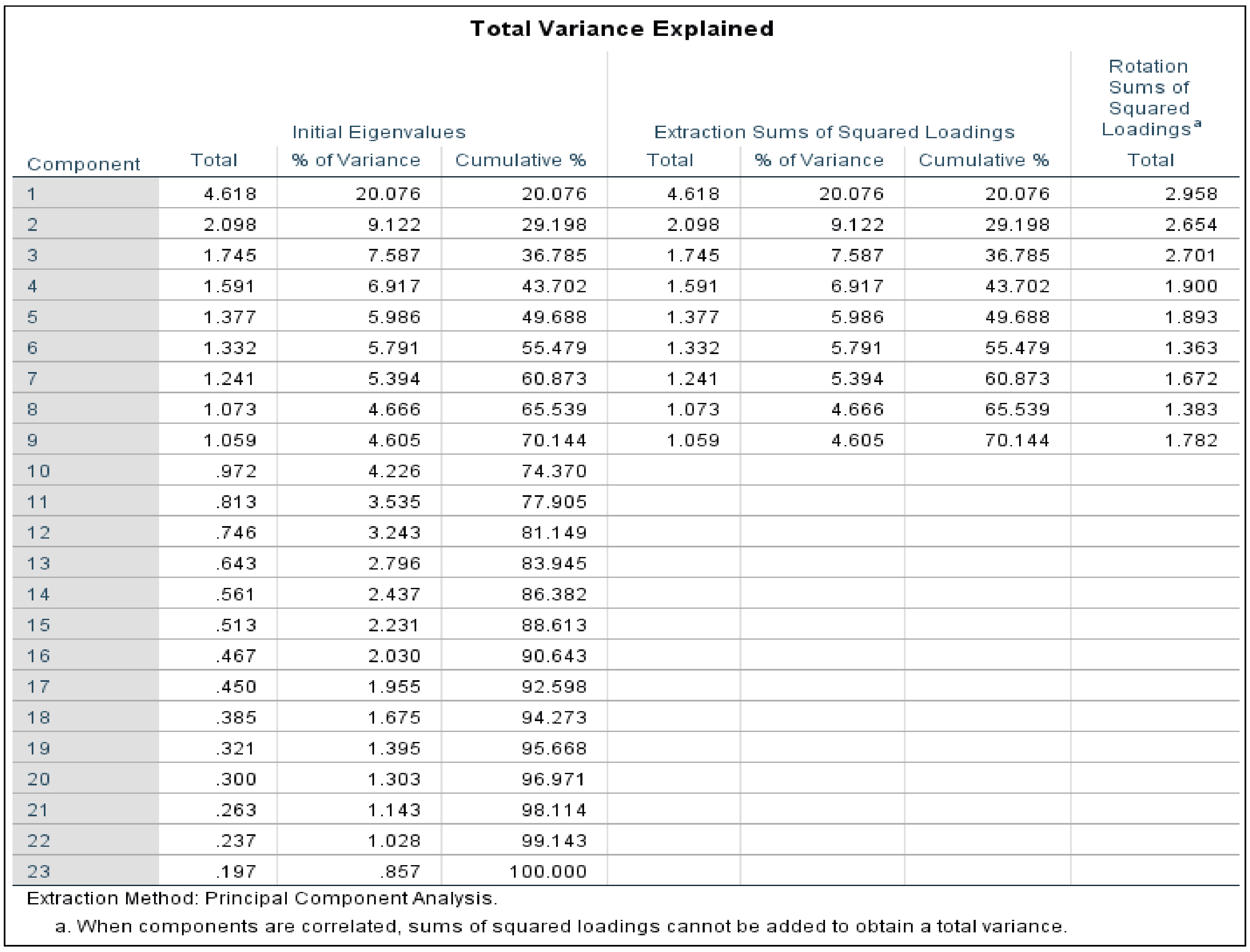
Rotated Component Matrix[a]

	Component								
	1	2	3	4	5	6	7	8	9
Lack of information on appropriate sustainable construction materials/technologies	.678								
Unclarity of information and information overload about sustainable retrofitting	.579								
Lack of capturing, documenting and reviewing mistakes and lesson learned in retrofitting	.570								
Inadequate sustainable retrofit data	.480								
Lack of strong enforcement by the government		.565							
Lack of legislation on sustainable retrofitting		.477							
Lack of legislation for penalties		.443							
Lack of proper government funding or grant			.629						
Inadequate engagement between lenders and finance providers			.621						
Awareness gaps of sustainable retrofitting				.443					
Lack of clarity, long-term plans and a roadmap from Government				.323					
Investor and user dilemma (Landlord and tenant)					.573				
Lack of appropriate decision-making due to stakeholders' different opinions/ideas					.478				
Low rate of returns on investment of low-carbon technologies					.330				
Lack of skilled installers and workforce						.615			
Lack of suitable materials						.558			
Perceived as an expensive project to embark							.593		
The hidden cost of retrofitting							.559		
Lack of collaboration amongst construction stakeholders								.595	
Tenant/property owner disagreements over rent increase after sustainable retrofit								.489	
High maintenance cost of low carbon technologies								.436	
Diminished aesthetics									.551
Resistance to change from traditional refurbishment practices									.448

Extraction Method: Principal Component Analysis.

9 components extracted.

Appendix L: Total variance explained for barriers to sustainable retrofit projects



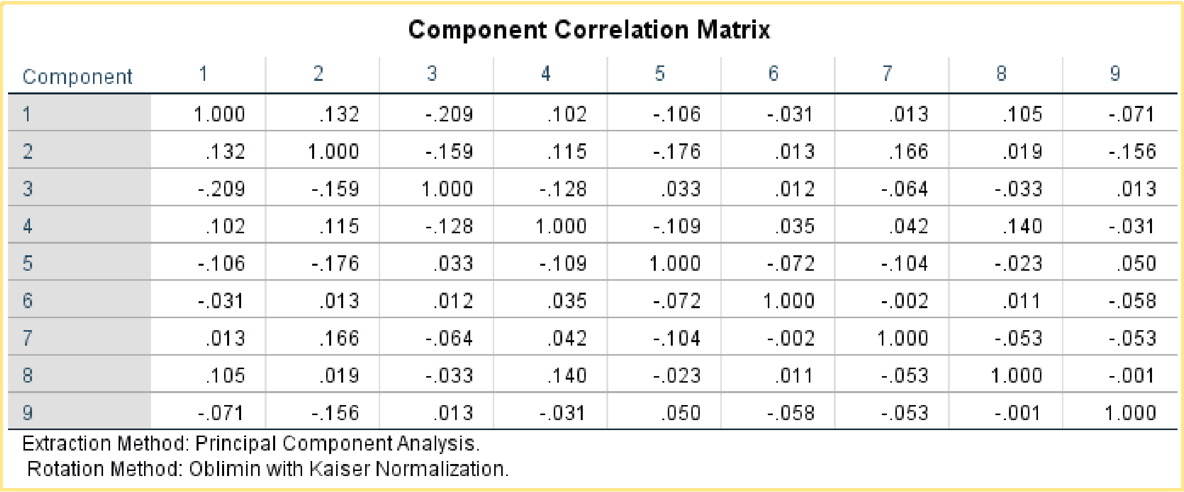
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings^a
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4.618	20.076	20.076	4.618	20.076	20.076	2.958
2	2.098	9.122	29.198	2.098	9.122	29.198	2.654
3	1.745	7.587	36.785	1.745	7.587	36.785	2.701
4	1.591	6.917	43.702	1.591	6.917	43.702	1.900
5	1.377	5.986	49.688	1.377	5.986	49.688	1.893
6	1.332	5.791	55.479	1.332	5.791	55.479	1.363
7	1.241	5.394	60.873	1.241	5.394	60.873	1.672
8	1.073	4.666	65.539	1.073	4.666	65.539	1.383
9	1.059	4.605	70.144	1.059	4.605	70.144	1.782
10	.972	4.226	74.370				
11	.813	3.535	77.905				
12	.746	3.243	81.149				
13	.643	2.796	83.945				
14	.561	2.437	86.382				
15	.513	2.231	88.613				
16	.467	2.030	90.643				
17	.450	1.955	92.598				
18	.385	1.675	94.273				
19	.321	1.395	95.668				
20	.300	1.303	96.971				
21	.263	1.143	98.114				
22	.237	1.028	99.143				
23	.197	.857	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Appendix M: Component correlation matrix for barriers to sustainable retrofit projects



Component Correlation Matrix

Component	1	2	3	4	5	6	7	8	9
1	1.000	.132	-.209	.102	-.106	-.031	.013	.105	-.071
2	.132	1.000	-.159	.115	-.176	.013	.166	.019	-.156
3	-.209	-.159	1.000	-.128	.033	.012	-.064	-.033	.013
4	.102	.115	-.128	1.000	-.109	.035	.042	.140	-.031
5	-.106	-.176	.033	-.109	1.000	-.072	-.104	-.023	.050
6	-.031	.013	.012	.035	-.072	1.000	-.002	.011	-.058
7	.013	.166	-.064	.042	-.104	-.002	1.000	-.053	-.053
8	.105	.019	-.033	.140	-.023	.011	-.053	1.000	-.001
9	-.071	-.156	.013	-.031	.050	-.058	-.053	-.001	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Appendix N: Communalities for barriers to sustainable retrofit projects

Communalities

	Initial	Extraction
Unclarity of information and information overload about sustainable retrofitting	1.000	.720
Inadequate data	1.000	.660
Lack of information on appropriate sustainable construction materials/technologies	1.000	.715
Lack of appropriate decision-making due to stakeholders' different opinions/ideas	1.000	.660
Proper awareness gaps of sustainable retrofitting	1.000	.742
Perceived as an expensive project to embark	1.000	.674
Lack of suitable materials	1.000	.778
Lack of skilled installers and workforce	1.000	.820
Lack of documenting and reviewing mistakes and lesson learned in retrofitting	1.000	.659
Tenant/property owner disagreements over rent increase after sustainable retrofit	1.000	.769
Lack of proper government funding or grant	1.000	.624

Inadequate engagement between lenders and finance providers	1.000	.703
Lack of strong enforcement by the government	1.000	.610
Lack of legislation for penalties	1.000	.700
Lack of legislation on sustainable retrofitting	1.000	.734
Resistance to change from traditional refurbishment practices	1.000	.744
High maintenance cost of low carbon technologies	1.000	.620
Diminished aesthetics	1.000	.658
Lack of clarity, long-term plans and a roadmap from Government	1.000	.739
Hidden cost of retrofitting	1.000	.761
Low rate of returns on investment of low-carbon technologies	1.000	.702
Investor and user dilemma (Landlord and tenant)	1.000	.651
Lack of collaboration amongst construction stakeholders	1.000	.688

Extraction Method: Principal Component Analysis.

Appendix O: Rotated component matrix for enablers to sustainable retrofit projects

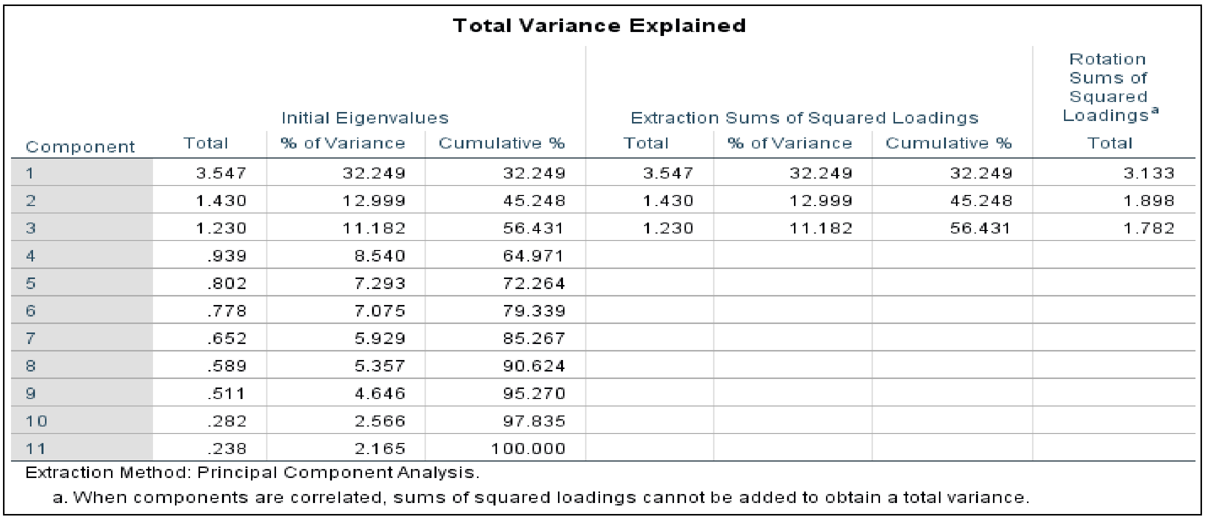
Rotated Component Matrix[a]

	Component		
	1	2	3
Client awareness	.662		
Increased building value	.617		
Better health improvement for building occupants	.538		
Sustainability brand reputation improvement	.372		
Energy cost-reduction		.790	
Lower operational costs and maintenance		.701	
Financial incentives		.65 2	
Higher profit or return on investment in long-term		.481	
Contributing to greenhouse gas emission reduction targets		.	.614
Positive public image associated with environmentally responsible practices			.333
Building Regulations and code			.320

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Appendix P: Total variance explained for enablers to sustainable retrofit projects



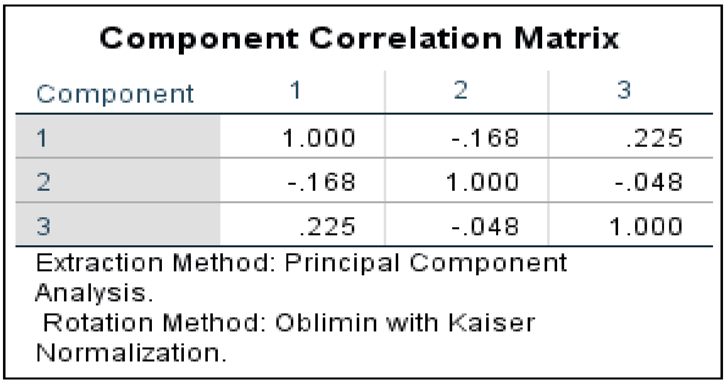
Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.547	32.249	32.249	3.547	32.249	32.249	3.133
2	1.430	12.999	45.248	1.430	12.999	45.248	1.898
3	1.230	11.182	56.431	1.230	11.182	56.431	1.782
4	.939	8.540	64.971				
5	.802	7.293	72.264				
6	.778	7.075	79.339				
7	.652	5.929	85.267				
8	.589	5.357	90.624				
9	.511	4.646	95.270				
10	.282	2.566	97.835				
11	.238	2.165	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Appendix Q: Component correlation matrix for enablers to sustainable retrofit projects



Component Correlation Matrix

Component	1	2	3
1	1.000	-.168	.225
2	-.168	1.000	-.048
3	.225	-.048	1.000

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

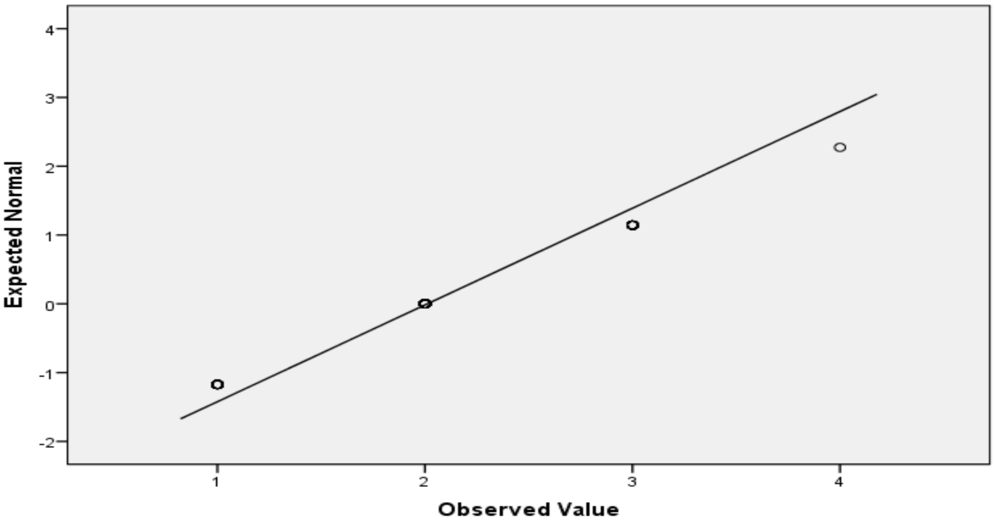
Appendix R: Communalities for enablers to sustainable retrofit projects

Communalities

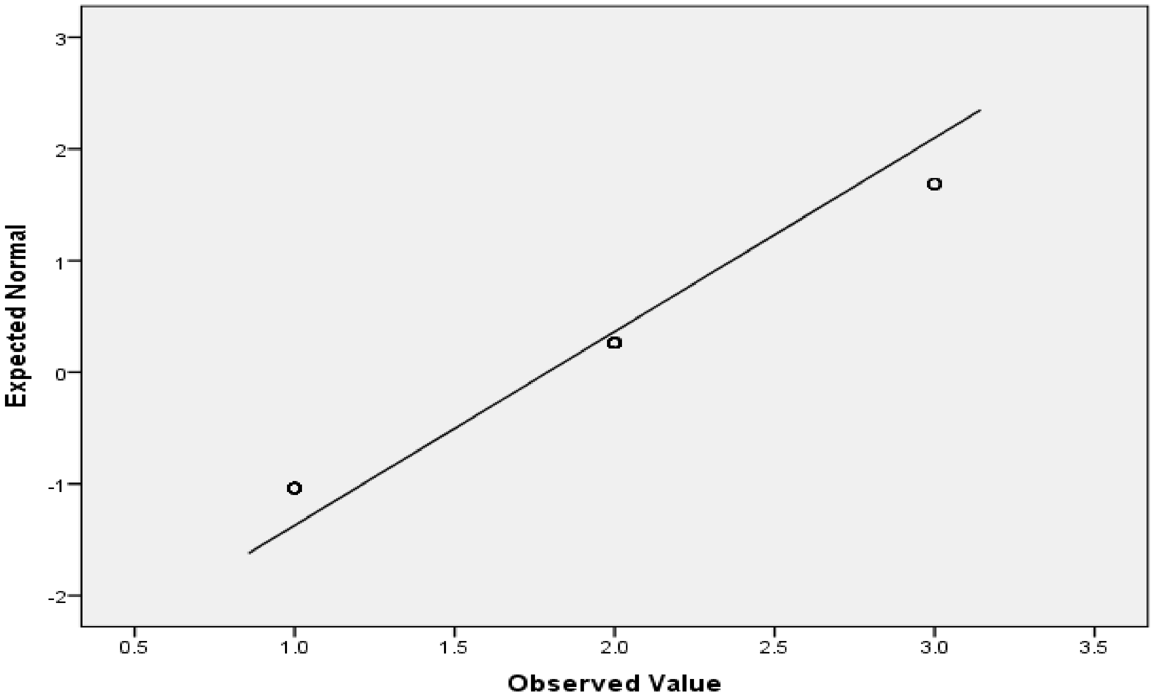
	Initial	Extraction
Higher profit in long-term	1.000	.694
Increased building value	1.000	.423
Lower operational costs and maintenance	1.000	.624
Financial incentives	1.000	.673
Client awareness	1.000	.467
Building Regulations and code	1.000	.529
Sustainability brand reputation improvement	1.000	.663
Energy cost-reduction	1.000	.688
Possitive public image associated with environmentally responsible practices	1.000	.449
contributing to greenhouse gas emmission reduction targets	1.000	.535
Better health improvenment for building occupants	1.000	.463

Extraction Method: Principal Component Analysis.

Appendix S: Direction of the variables running from downward left to right indicating positive correlation on options in making decision difficult



Appendix T: Direction of the variables running from downward left to right indicating positive correlation on options in making decision easy



Appendix U: Interview Questions

Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Section 1: Background information

1. How do you describe your organisation?
2. What is the size of the organisation you represent?
3. What is the age of your organisation?
4. Please indicate the size of your organisation's annual turnover
5. What your name?
6. What is your job title and position in the organisation?
7. What is your professional Background?
8. How many years of experience in the construction industry?
9. Your company involves in sustainable retrofit projects.

Section 2: Sustainable retrofit questions

1. Recall from the survey you measured provided enablers and barriers to sustainable retrofit with the options provided. Can you now identify the critical barriers and enablers to sustainable retrofitted building projects?
2. From the survey results some respondents suggested that the research investigates on the risks and complications involved in sustainable retrofitted building projects. Please, in delivering sustainable retrofit projects can you itemise the risks and complications involved?

Section 3: Knowledge management issues and decision-making

1. What do you understand by ‘knowledge’ and ‘knowledge management’ if we are to relate it to sustainable retrofitting with the key stakeholders?
2. What is the role of knowledge management in delivering sustainable retrofit? 3
3. How do you capture knowledge in the sustainable retrofit projects since knowledge exist in tacit and explicit?
4. How do you think that managing project knowledge can enhance decision making in sustainable retrofitting?
5. How do you think we can avoid information overload as relates to sustainable construction?
6. So what criteria are used to determine the relevance of new knowledge, for example in a retrofit project?
7. Do you still think (recall was asked in the survey) there is a need for decision support framework that will be developed with knowledge management principles and procedures to assist the key stakeholders in making informed and appropriate choices in delivering sustainable retrofitted building projects?
8. Please, will you like to be contacted to evaluate the relevance and applicability of a decision support framework that will be developed?

Many thanks for devoting your valuable time; your contribution to this research is greatly appreciated.

Appendix V: Confirmation and approval of interview transcription document

Hello Individual A (name anonymised),

Good day, please find the attached the transcription document of our interview. If you recall before the commencement of the interview I stated that confidentiality is part of the whole interview process. Hence, your responses to questions are anonymised.

Please, I will appreciate you check the transcript to ascertain that the sentences are from you. However, there are bound to be few grammatical errors that are bound to be noticed, do not be irritated by this because it is normal when semi-structured interviews are transcribed mainly because of the high volume of the interview.

I expect to receive a response to contest your statement. However, if I do not receive any contrast reply until August 10, 2016, I will assume or interpret that you accept the transcribed document to be used for my thesis.

Many thanks again for your participation and great contribution.

Kind Regards,
Nnamdi Maduka

Appendix W: Framework validation interview questions (Qualitative)

Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

FRAMEWORK VALIDATION

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Section 1: Background Information

1. How do you describe your organisation?
2. What is the size of the organisation you represent or number of employees?
3. What is the age of your organisation?
4. Please indicate the size of your organisation’s annual turnover
5. What your name?
6. What is your job title and position in the organisation?
7. What is your professional Background?
8. How many years of experience in the construction industry?
9. Does your company involve in sustainable retrofit projects?

Section 2

1. Is the framework comprehensive as regards sustainability and retrofitting?

2. Do you think it addresses the gap of knowledge management in the embarking, uptake and delivering of sustainable retrofitted building projects?
3. Is the framework relevant to embarking and delivering of sustainable retrofitted building projects and can be adopted by the industry?
4. Do you think the framework will assist key stakeholders to make an informed decision?
5. Is the framework unambiguous and user friendly?
6. Any criticism, suggestions and gaps?

Many thanks for devoting your valuable time; your contribution to this research is greatly appreciated.

Appendix X: Validation of framework through survey questionnaire (Quantitative) and responses

Developing Decision Support Framework and Process with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Section 1: Background Information

10. How do you describe your organisation?
11. What is the size of the organisation you represent or number of employees?
12. What is the age of your organisation?
13. Please indicate the size of your organisation’s annual turnover
14. What your name?
15. What is your job title and position in the organisation?
16. What is your professional Background?
17. How many years of experience in the construction industry?
18. Does your company involve in sustainable retrofit projects?

northumbria
UNIVERSITY NEWCASTLE

Developing Decision Support Framework and process with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Section 1: Background information

THE ONLY GOVERNMENT ENDORSED QUALITY

1. How do you describe your organisation? SCHEME FOR TRADES IN OR AROUND THE
2. What is the size of the organisation you represent or a number of employees? HOME
3. What is the age of your organisation? 13 YRS
4. Please indicate the size of your organisation's annual turnover? £2M
5. What your name? P. VAUGHAN
6. What is your job title and position in the organisation PROGRAMME MANAGER.
7. What is your professional Background? ENERGY + IT
8. How many years of experience in the construction industry? ALMOST 30
9. Does your company involve in sustainable retrofit projects? YES.

RETROFIT PROCESS VALIDATION

Validation Criteria	Scoring scale 1(Poor) 5(Excellent)	Feedback/comment
1. The retrofit process addresses the issue of lack of managing knowledge in the industry	3	MORE STANDARDISATION AN CENTRALISATION ABOVE LOCAL AUTHORITY WOULD HELP. OPEN
2. The retrofit process is relevant to the industry as regards retrofitting of buildings	4	
3. The retrofit process is relevant to your current practices in retrofit projects	4	SIMILAR IN ROLE + AMBITION TO PAS 2035
4. The retrofit process will benefit your organisation	3	PRINCIPLES WILL BE ADOPTED THROUGH PAS 2035.
5. The retrofit process is useful as a decision support tool	4	
6. The issues covered and overall content are comprehensive and relevant	4	KEY AREAS ADDRESSED -
7. The retrofit process is easy to read, understand and use, implement or apply	3	RETROFIT WILL BE DIFFICULT FOR SMALL BUSINESSES TO ADOPT.
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The retrofit process defined activities at an appropriate level	—	WOULD NEED TO REVIEW SUPPORTING DOCUMENTS.
10. The retrofit process specified appropriate roles and responsibilities for the activities	2	ROLES FOR ESTABLISHING BUSINESS CASE TO BE DEFINED AND FOR QUALIFICATIONS/SKILLS
11. The retrofit process is replicable	—	
12. Would you recommend the retrofit process to the key for use in retrofit projects?	Yes or No	THE KEY PRINCIPLES YES. (ALTHOUGH WE ARE BOUND TO PAS 2035
13. Is there anything missing that should be considered?	[✓ Yes] or No	STAGED DELIVERY FOR SOME PROJECTS. TO CONSIDER THE MASS MARKET WHERE WHOLE HOUSE RETROFIT IS NOT POSSIBLE.

More Feedback/Comments:

IT WOULD HAVE BEEN GOOD TO HAVE MORE TIME TO FULLY CONSIDER ANSWERS.

WORK REPRESENTS THE AIMS AND AMBITIONS OF THE WIDER RETROFIT AGENDA – WELL DONE -

RETROFIT DECISION-SUPPORT FRAMEWORK VALIDATION

Validation Criteria	Scoring scale 1 (Poor) 5(Excellent)	Feedback/Comment
1. The framework addresses the issue of lack of managing knowledge in the industry	3	Begins To, But Very Local. Needs To Define The Rules for Data Access Between Parties.
2. The framework is relevant to the industry as regards retrofitting of buildingS	3	
3. The framework is relevant to your current practices in retrofit projects	4	
4. The framework will benefit your organisation	3	Principles - Yes - We Are Bound To Pas 2035.
5. The framework is useful as a decision support tool	3	
6. The issues covered and overall content are comprehensive and relevant	3	Feedback Loop Could Be More Proactive in Obtaining. Building Performance Information.
7. The framework is easy to read, understand and use, implement or apply	3	Easy To Read And Understand.
8. The decision logic icons are adequately placed and helpful for decision-making	4	Auditor Could Have. More Proactive Role in Contractor Selection - Client May Need Help in Decision
9. The framework defined activities at an appropriate level	Probably. 4	Need To Read Summary Info.
10. The framework specified appropriate roles and responsibilities for the activities	3	Maybe Use Industry Language. For The Auditor. - Whats The Quals Where Does A Customer Find One.
11. The framework is replicable	4	With Standardisation of Quals / Competence + Knowledge Sharing
12. Would you recommend the framework to the key for use in retrofit projects?	Yes [✓] or No	We Have To Submit Pas 2035 - Without It - Yes -
13. Is there anything missing that should be considered?	Yes or No [illegible]	Some More Definition On Roles / Quals And Integration With Existing Building Practices Will Help.

More Feedback/Comments:

More Time To Read / Absorb
And Review Supporting Document
Would Be Good -
Comments Based on Brief Overview -.
Good Luck with it -

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Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

RETROFIT PROCESS AND FRAMEWORK VALIDATION

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Background information

1. How do you describe your organisation? Energy + environment consultancy
2. What is the size of the organisation you represent? Micro (2 people)
3. What is the age of your organisation? 14 yrs.
4. Please indicate the size of your organisation's annual turnover £150k
5. What your name? Liz Warren
6. What is your job title and position in the organisation? Director.
7. What is your professional Background? Engagement, marketing, training.
8. How many years of experience in the construction industry? 16
9. Your company involves in sustainable retrofit projects. Y.

' Training + guidance for industry
Policy development for Government.

RETROFIT PROCESS VALIDATION (page 1).

Validation Criteria	Scoring scale 1(Poor) 5(Excellent)	Feedback/comment
1. The retrofit process addresses the issue of lack of managing knowledge in the industry	4	
2. The rctrofit process is relevant to the industry as regards retrofitting of buildings	5	Definitely! It follows the typical retrofit process very well.
3. The retrofit process is relevant to your current practices in retrofit projects	4	
4. The retrofit process will benefit your organisation	4	
5. The retrofit process is useful as a decision support tool	5	Especially for thinking about the timing of key decisions.
6. The issues covered and overall content are comprehensive and relevant	5	Very!
7. The retrofit process is easy to read, understand and use, implement or apply	5	
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The retrofit process defined activities at an appropriate level	5	
10. The retrofit process specified appropriate roles and responsibilities for the activities	5	
11. The retrofit process is replicable	5	
12. Would you recommend the retrofit process to the key for use in retrofit projects?	[✓ Yes] or No	
13. Is there anything missing that should be considered?	Yes or [✓ No]	

More Feedback/Comments: It's a really helpful tool for bringing more structure into an unstructured sector with lots of participants in any one project.

RETROFIT DECISION-SUPPORT FRAMEWORK VALIDATION (page 2)

Validation Criteria	Scoring scale 1 (Poor) 5(Excellent)	Feedback/Comment
1. The framework addresses the issue of lack of managing knowledge in the industry	4.	
2. The framework is relevant to the industry as regards retrofitting of buildingS	5	It is thorough, comprehensive and well-structured around retrofit project processes.
3. The framework is relevant to your current practices in retrofit projects	4	
4. The framework will benefit your organisation	4	
5. The framework is useful as a decision support tool	4	
6. The issues covered and overall content are comprehensive and relevant	5	Definitely
7. The framework is easy to read, understand and use, implement or apply	5	One note: how can it be made easy to use for people who work on site? (ie, not at a desk).
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The framework defined activities at an appropriate level	4	
10. The framework specified appropriate roles and responsibilities for the activities	4	
11. The framework is replicable	5	
12. Would you recommend the framework to the key for use in retrofit projects?	[✓ Yes] or No	
13. Is there anything missing that should be considered?	Yes or [✓ No]	

More Feedback/Comments:

northumbria
UNIVERSITY NEWCASTLE

Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

RETROFIT PROCESS AND FRAMEWORK VALIDATION

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Background information

1. How do you describe your organisation? Building Science Centre
2. What is the size of the organisation you represent? 650+ employees
3. What is the age of your organisation? 98 years
4. Please indicate the size of your organisation's annual turnover
5. What your name? TIM WISEMAN
6. What is your job title and position in the organisation? BREEAM SCHEME MANAGER
7. What is your professional Background? DOMESTIC ENERGY EFFICIENCY
8. How many years of experience in the construction industry? 10 years
9. Your company involves in sustainable retrofit projects. Certification and consultancy

RETROFIT PROCESS VALIDATION

Validation Criteria	Scoring scale 1(Poor) 5(Excellent)	Feedback/comment
1. The retrofit process addresses the issue of lack of managing knowledge in the industry	4	
2. The retrofit process is relevant to the industry as regards retrofitting of buildings	5	
3. The retrofit process is relevant to your current practices in retrofit projects	4	In certification terms
4. The retrofit process will benefit your organisation	4	
5. The retrofit process is useful as a decision support tool	4	Integrates well with BREEAM
6. The issues covered and overall content are comprehensive and relevant	4	
7. The retrofit process is easy to read, understand and use, implement or apply	4	
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The retrofit process defined activities at an appropriate level	4	
10. The retrofit process specified appropriate roles and responsibilities for the activities	4	
11. The retrofit process is replicable	4	
12. Would you recommend the retrofit process to the key for use in retrofit projects?	[✓ Yes] or No	As a certification body we cannot recommend anything
13. Is there anything missing that should be considered?	Yes or [✓ No]	

More Feedback/Comments:

RETROFIT DECISION-SUPPORT FRAMEWORK VALIDATION

Validation Criteria	Scoring scale 1 (Poor) 5(Excellent)	Feedback/Comment
1. The framework addresses the issue of lack of managing knowledge in the industry	5	
2. The framework is relevant to the industry as regards retrofitting of buildingS	5	
3. The framework is relevant to your current practices in retrofit projects		we do not undertake retrofit projects
4. The framework will benefit your organisation	4	
5. The framework is useful as a decision support tool	4	
6. The issues covered and overall content are comprehensive and relevant	4	
7. The framework is easy to read, understand and use, implement or apply	4	
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The framework defined activities at an appropriate level	4	
10. The framework specified appropriate roles and responsibilities for the activities	4	
11. The framework is replicable	4	
12. Would you recommend the framework to the key for use in retrofit projects?	[✓ Yes] or No	
13. Is there anything missing that should be considered?	Yes or [✓ No]	

More Feedback/Comments:

Developing Decision Support Framework and process with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Section 1: Background information

1. How do you describe your organisation? **Innovate UK is the UK's innovation agency, part of UK Research and Innovation (UKRI)**
2. What is the size of the organisation you represent or number of employees? **350 in Innovate UK. Several thousand in UKRI**
3. What is the age of your organisation? **Innovate UK is eleven years old**
4. Please indicate the size of your organisation's annual turnover: **We don't have turnover per se. Our annual allocation for funding innovation is currently more than £600m**
5. What your name? **Dr Rick Holland**
6. What is your job title and position in the organisation? **Regional Manager, North West England. We are a team of regional manager in Innovate UK's Strategy directorate**

7. What is your professional Background? **Chartered mechanical engineer, building services (CIBSE) and professional sustainability consultant in the construction and real estate sector**
8. How many years of experience in the construction industry? **From 2006-2012 prior to joining Innovate UK's team for funding construction innovation projects up to 2016.**
9. Does your company involves in sustainable retrofit projects? **We have funded innovation projects on sustainable retrofit projects. I have evaluate the benefits of retrofit across dozens of homes and published good practice guidance reports.**

RETROFIT DECISION-SUPPORT FRAMEWORK VALIDATION

Validation Criteria	**Scoring scale** 1 (Poor) 5(Excellent)	**Feedback/Comment**
1. The framework addresses the issue of lack of managing knowledge in the industry	3	Seems a very robust general framework. There could be a lot of impact by applying the framework to one or two opportunities where improved knowledge management would solve a real construction issue.
2. The framework is relevant to the industry as regards retrofitting of buildingS	3	Seems relevant in a general sense and applying it to real scenario(s) would demonstrate its relevancy in practice.
3. The framework is relevant to your current practices in retrofit projects	4	Research on new methods to improve retrofit outcomes is very relevant. If the proposal was to develop the framework into an innovative product or service then this would be 5/5.
4. The framework will benefit your organisation	3	It is inspiring to see this approach applied to the industry. Though we do not do retrofits ourselves.
5. The framework is useful as a decision support tool	2 Or maybe n/a	I am not convinced the intent of the framework is to be a decision support tool. To be honest that sounds like something different, that would require a very much finer granularity of detail on individual decisions.
6. The issues covered and overall content are comprehensive and relevant	5	Applaud that the scope includes evaluation of real performance and feedback to benefit future projects.

7. The framework is easy to read, understand and use, implement or apply	3	Easy to read and understand. Applying it experimentally to real scenario(s) would improve its applicability and ease of use.
8. The decision logic icons are adequately placed and helpful for decision-making	n/a 2	As per answer #5
9. The framework defined activities at an appropriate level	3	As per answers 1 & 2
10. The framework specified appropriate roles and responsibilities for the activities	3	As per answers 1 & 2
11. The framework is replicable	3	As per answers 1 & 2
12. Would you recommend the framework to the key stakeholders for use in retrofit projects?	**No**	It is certainly ready for the next research project to move the framework into a phase of experimental development; i.e. to a higher Technology Readiness Level. Not ready to be applied by practitioners yet.
13. Is there anything missing that should be considered?	**Yes**	Who will ultimately deploy the framework on a retrofit project? Is it one person/organisation involved throughout from start to finish, or is it a platform (perhaps digitally based) that all decision makers across multiple organisations will be required to use as a matter of course of doing the retrofit? Required perhaps by the client or their advisors. What happens to the centrally collected lessons learned? They have commercial value. Who owns them? How can they enable the framework to be deployed at a cost effective price?

More Feedback/Comments:

RETROFIT PROCESS VALIDATION

Validation Criteria	Scoring scale 1(Poor) 5(Excellent)	Feedback/comment
1. The retrofit process addresses the issue of lack of managing knowledge in the industry	4	Comprehensive structure and flow to the process. Would score 5/5 if it had been applied to real scenarios to demonstrate impact and to further improve the process.
2. The retrofit process is relevant to the industry as regards retrofitting of buildings	5	Mapping the process from end-to-end is very valuable and especially applaud relating this back to the accepted processes of RICS & RIBA.
3. The retrofit process is relevant to your current practices in retrofit projects	n/a	We do not do retrofit ourselves
4. The retrofit process will benefit your organisation	3	Thought stimulating
5. The retrofit process is useful as a decision support tool	4	It highlights who to involve when, and what factors should be considered at each stage. Would score 5/5 if had been applied to some fully worked through example decisions that are typically made. i.e show that this process could change the outcome of decisions.
6. The issues covered and overall content are comprehensive and relevant	4	As per answer #1
7. The retrofit process is easy to read, understand and use, implement or apply	3	It is easy to read and understand, but requires a further research project at a higher TRL (experimental development) before it could become a product that can be applied.
8. The decision logic icons are adequately placed and helpful for decision-making	5	As per answer #2
9. The retrofit process defined activities at an appropriate level	4	As per answer #5
10. The retrofit process specified appropriate roles and responsibilities for the activities	4	As per answer #5
11. The retrofit process is replicable	3	Most retrofit project will have fairly unique aspects, whether the physical building, the stakeholders involved,

		or the ambitions of the finished specification. Deploying this process on case study projects will illustrate how flexible the tool would need to be and where the areas of consistency can be found. I scored 3 as the tool is presently replicable in theory, but it requires further research (experimental development) to show which elements are also replicable in practice.
12. Would you recommend the retrofit process to the key for use in retrofit projects?	**Yes**	As a basis for further research and development
13. Is there anything missing that should be considered?	**No**	

More Feedback/Comments:

Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

RETROFIT PROCESS AND FRAMEWORK VALIDATION

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Background information

1. How do you describe your organisation? Construction organisation/contractor/ Consultancy/
2. What is the size of the organisation you represent? Over 4,000 Staff
3. What is the age of your organisation? Over 100years.
4. Please indicate the size of your organisation's annual turnover Over £1·62 billion
5. What your name? Dr. Syeda Zainab Dangana
6. What is your job title and position in the organisation? Sustainability R&D Manager WATES SMART SPA
7. What is your professional Background? PhD in Sustainable Construction Managem
8. How many years of experience in the construction industry? 14 years.
9. Your company involves in sustainable retrofit projects. Yes

RETROFIT PROCESS VALIDATION

Validation Criteria	Scoring scale 1(Poor) 5(Excellent)	Feedback/comment
1. The retrofit process addresses the issue of lack of managing knowledge in the industry	5	
2. The retrofit process is relevant to the industry as regards retrofitting of buildings	5	
3. The retrofit process is relevant to your current practices in retrofit projects	5	
4. The retrofit process will benefit your organisation	4	
5. The retrofit process is useful as a decision support tool	4	
6. The issues covered and overall content are comprehensive and relevant	5	
7. The retrofit process is easy to read, understand and use, implement or apply	4	
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The retrofit process defined activities at an appropriate level	3	
10. The retrofit process specified appropriate roles and responsibilities for the activities	3	
11. The retrofit process is replicable	5	
12. Would you recommend the retrofit process to the key for use in retrofit projects?	[✓ Yes] or No	
13. Is there anything missing that should be considered?	[✓ Yes] or No	The feedback loop icon should connect to the business cas

More Feedback/Comments:

RETROFIT DECISION-SUPPORT FRAMEWORK VALIDATION

Validation Criteria	Scoring scale 1 (Poor) 5(Excellent)	Feedback/Comment
1. The framework addresses the issue of lack of managing knowledge in the industry	5	
2. The framework is relevant to the industry as regards retrofitting of buildingS	5	
3. The framework is relevant to your current practices in retrofit projects	5	
4. The framework will benefit your organisation	4	
5. The framework is useful as a decision support tool	5	
6. The issues covered and overall content are comprehensive and relevant	5	
7. The framework is easy to read, understand and use, implement or apply	4	
8. The decision logic icons are adequately placed and helpful for decision-making	4	
9. The framework defined activities at an appropriate level	4	To a large extent but not exactly
10. The framework specified appropriate roles and responsibilities for the activities	5	
11. The framework is replicable	4	
12. Would you recommend the framework to the key for use in retrofit projects?	**[✓ Yes] or No**	
13. Is there anything missing that should be considered?	**Yes or [✓ No]**	

More Feedback/Comments:

Developing Decision Support Framework with Knowledge Management Principles in Delivering Sustainable Retrofitted Building Projects

RETROFIT PROCESS AND FRAMEWORK VALIDATION

Brief Research Background: sustainable retrofit building presents important opportunities for reducing greenhouse gas emissions in the environment. Sustainable retrofitted buildings have been considered as one of the key approaches to achieving sustainable development in the construction industry. The research aims to develop a decision support framework to assist key stakeholders in delivering sustainable retrofitted building projects.

Confidentiality: It is important to state that all responses will be treated with absolute confidentiality and be used for academic purposes only. To this end, we would like to thank you immensely for your kind consideration.

Background information

1. How do you describe your organisation? COLLABORATIVE OF RETROFIT SPECIALISTS.
2. What is the size of the organisation you represent? 5 staff – 70 companies.
3. What is the age of your organisation? 5 yrs
4. Please indicate the size of your organisation's annual turnover £3m
5. What your name? Russell Smith. (DIRECTOR, RETROFIT PROJECTS)
6. What is your job title and position in the organisation?
7. What is your professional Background? CIVIL ENG/STRUCTURAL
8. How many years of experience in the construction industry? 23
9. Your company involves in sustainable retrofit projects. 100%.

RETROFIT PROCESS VALIDATION For FRAMEWORK

Validation Criteria	Scoring scale 1(Poor) 5(Excellent)	Feedback/comment
1. The retrofit process addresses the issue of lack of managing knowledge in the industry	4.	We need to find a way to pay for it; TrustMark will help.
2. The retrofit process is relevant to the industry as regards retrofitting of buildings	4.	Needs all of the elements there as discussed.
3. The retrofit process is relevant to your current practices in retrofit projects	5	
4. The retrofit process will benefit your organisation	5	We do a lot of this already
5. The retrofit process is useful as a decision support tool	5	
6. The issues covered and overall content are comprehensive and relevant	5	
7. The retrofit process is easy to read, understand and use, implement or apply	5	
8. The decision logic icons are adequately placed and helpful for decision-making	3	Suspect feedback loops within loops
9. The retrofit process defined activities at an appropriate level	4	Perhaps more detail needed for site based work.
10. The retrofit process specified appropriate roles and responsibilities for the activities	4.	The 'Retrofit Coordinator' is a v. important role + needs to be differentiated.
11. The retrofit process is replicable	5.	
12. Would you recommend the retrofit process to the key for use in retrofit projects?	[✓ Yes] or No	
13. Is there anything missing .that should be considered?	[✓ Yes] or No	Feeding into Local Authority databases to record progress.

More Feedback/Comments:

RETROFIT DECISION-SUPPORT FRAMEWORK VALIDATION For Process

Validation Criteria	Scoring scale 1 (Poor) 5(Excellent)	Feedback/Comment
1. The framework addresses the issue of lack of managing knowledge in the industry	3	It identifies it; solutions are the next level.
2. The framework is relevant to the industry as regards retrofitting of buildingS	5	
3. The framework is relevant to your current practices in retrofit projects	5	
4. The framework will benefit your organisation	5	We do a lot of this already.
5. The framework is useful as a decision support tool	4.	Needs to recognise feedback to earlier stages
6. The issues covered and overall content are comprehensive and relevant	5	
7. The framework is easy to read, understand and use, implement or apply	3	Feedback loops needed part-way.
8. The decision logic icons are adequately placed and helpful for decision-making	3	
9. The framework defined activities at an appropriate level	5	
10. The framework specified appropriate roles and responsibilities for the activities	4,	Retrofit Coordinator oversees a lot of other works.
11. The framework is replicable	5	
12. Would you recommend the framework to the key for use in retrofit projects?	[✓ Yes] or No	
13. Is there anything missing that should be considered?	Yes or [✓ No]	

More Feedback/Comments: