RETROFITTING TO REDUCE CARBON EMISSIONS FROM EXISTING BUILDINGS IN BLOEMFONTEIN, SOUTH AFRICA

BY

CHIKEZIRIM OKORAFOR

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE

DOCTOR OF ENGINEERING

IN

CIVIL ENGINEERING

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY AT THE

CENTRAL UNIVERSITY OF TECHNOLOGY, FREE STATE

PROMOTER: PROFESSOR F.A. EMUZE

CO-PROMOTER: PROFESSOR D.K. DAS

JUNE 2019

DECLARATION OF ORIGINAL AUTHORSHIP

I, CHIKEZIRIM OKORAFOR, on this 3rd day of June 2019 declare that

- The work in this thesis is my personal effort,
- Sources used or referred to have been acknowledged, and
- The thesis has not been submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification at any other recognised educational institution.

Signed

Chikezirim Okorafor

216005935

DEDICATION

This thesis is dedicated to my mother, Mrs Grace N. Okorafor.

ACKNOWLEDGEMENTS

All praise to God Almighty, the creator of the universe, and source of life, wisdom, energy, and strength. I am most grateful to Him for making this dream come true.

I would like to thank my promoters, Professor Fidelis Emuze and Professor Dilip Das, for their support, knowledge, enthusiasm, constructive criticism, patient, and cooperation, and for consistently guiding me through the doctoral path. I want to express formal gratitude to Dr B. Awuzie and Dr M. Oladokun for their insightful comments and contributions.

I would also like to thank the following people for their advice and goodwill before commencement of the project: Professor A.A. Thalukhaba, Dr J.Okumbe, Dr O. Nkwonta, Dr I. Anugwo, Dr E. Mwanumo, Dr C. Eke, Mr E.O. Nwamadi, and Mr D. Adedokun. I would like to thank the following people for their assistance during the course of the project: Dr R.B. Isa, Dr A. Aka, Dr E. Allu, Mr T.G. Monyane, Mr F. Aneke, Mr I. Kanu, Mr G. Mollo, Mr D. Adedeji, Mr S. Abejide, Mr I. Azege, Mrs Z. Uwah, Ms P. Atoro, Ms P. Moja, and Ms L. van Eeden.

Sincere thanks go to all those who participated in the research for their time and genuine interest. The financial support from Central University of Technology, Free State (CUT) is gratefully acknowledged.

This project would not have been completed without the unwavering support and encouragement of my family members Chief J.O. Okorafor, Mrs G.N. Okorafor, Reverend O. Okorafor, Mrs I. Okoroji, Engr O. Okorafor, and Mr E. Okorafor for their amazing support and selflessness.

Finally, I am thankful to the staff and students of the Department of Built Environment at CUT and other people who have supported me in various ways.

LIST OF PUBLICATIONS

Okorafor, C., Emuze, F.A. and Das, D.K. (2017). Low carbon building: Implementation strategies utilised in South Africa. In: Proceedings of the International Conference of the Sustainable Ecological Engineering Design for Society(SEEDS), Leeds, United Kingdom, pp. 516–524.

Okorafor, C., Emuze, F.A. and Das, D.K. (2018). Conceptualising a system framework for retrofitting existing buildings in South Africa. In: Proceedings of the International Conference of the Sustainable Ecological Engineering Design for Society (SEEDS), Dublin, United Kingdom.

Okorafor, C., Emuze, F.A. and Das, D.K. (2019). A South African Experience of Building Energy Retrofit Project Challenges and Solutions. In: Proceedings of the International Conference of the Sustainable Ecological Engineering Design for Society (SEEDS), Leeds, United Kingdom.

Okorafor, C., Emuze, F.A. and Das, D.K. (2019). Using Case Study Design to investigate the delivery of Building Energy Retrofit Projects. In: Proceedings of the Construction Industry Development Board Post graduate International Conference Johannesburg, South Africa.

Okorafor, C., Emuze, F.A. and Das, D.K. (In review). A Framework for Implementing Energy Retrofit Projects in Existing Buildings. Journal of Smart and Sustainable Built Environment.

Okorafor, C., Emuze, F.A. and Das, D.K. (In review). An Artefact for improving the delivery of building energy retrofit project in South Africa. Journal of Built Environment Project and Asset Management.

ABSTRACT

Designing energy-efficient retrofits for buildings will bring about environmental, economic, social and health benefits. However, selecting specific retrofit strategies is complex and requires careful planning. In its contribution to resolving these complexities, the study attempts to provide insights into how building energy retrofit (BER) can be understood and addressed within a socio-technical context. The study was situated in a pragmatist paradigm in which a mixed-methods research design was adopted. The quantitative data was statistically analysed, while the qualitative data was transcribed and thematically analysed. The study identified and highlights the key elements needed in implementation of BER projects, and offered solutions with respect to the challenges highlighted in the BERP delivery process. This gave rise to an artefact that serves as a guide for innovative and proactive tools to attain efficiency in the delivery of BER projects. It was discovered that the artefact has adequate robustness to engender change in the industry. The description of the developed artefact is followed by detailed steps on how to implement it, which is easily understandable by industry stakeholders.

Keywords: building, construction, complex adaptive system (CAS), energy, retrofit, South Africa

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AHU: air handling unit

BER: building energy retrofit

BERM: building energy retrofit measure

BERP: building energy retrofit project

CAS: complex adaptive system

CDM: clean development mechanism

CHP: combined heat and power

CIDB: construction industry development board

CO_2: carbon (IV) oxide

COP: conference of the parties

CSR: corporate social responsibility

DEA: department of environmental affairs

EBER: existing building energy retrofit

EE: energy efficiency

EPBD: energy performance of buildings directive

ERM: energy retrofits measure

ESCO: energy Service Company

FCU: fan coil unit

GBCSA: green building council of South Africa

GDP: gross domestic product

GNP: gross national product

GSHP: ground-source heat pump

HVAC: heating, ventilation and air conditioning

IEA: international energy agency

IET: international emissions trading

IPCC: intergovernmental Panel on climate change

JI: joint implementation

LCB: low-carbon building

LCE: low-carbon economy

LED: light-emitting diode

LEDs: low-emission development strategies

LEDSGP: low emission development strategies global partnership

M&V: measurement and verification

NCCC: national committee on climate change

NT: national treasury

RET: renewable energy target

SAPOA: South African property owners association

SHW: solar hot water

UNDP: united nation development programme

UNEP: united nation environment programme

UNFCCC: united nation framework convention on climate change

USD: united state dollars

VAV: variable air volume

WCED: world commission on environment and development

WGBC: world green building council

ZEB: zero-energy building

Central University of Technology, Free State

DEFINITIONS OF TERMS

A **framework** is a basic structure underlying a system or concept (Frodeman, Thompson Klein and Mitcham, 2010: 112).

A **system** can be defined as an entity, which is a coherent whole, such that a boundary is perceived around it in order to distinguish internal and external elements and to identify input and output relating to and emerging from the entity (Ng, Maull and Yip, 2009: 337).

An **artefact is** something observed in a scientific investigation or experiment that is not naturally present but occurs as a result of the preparative or investigative procedure (Hevner et al., 2004: 79).

The **built environment** is the human-made surroundings that provide the setting for human activity, ranging in scale from buildings and parks or green spaces to neighbourhoods and cities, which can often include their supporting infrastructure, such as water supply or energy networks (Milford, 2009: 49).

Carbon emission is the release of carbon gases and/or their precursors into the atmosphere over a specified area and period of time (Diakaki, Grigoroudis and Kolokotsa, 2008).

Chaos theory contends that not all systems obey randomness; some systems can be defined and bounded by mathematical functions, depending on the controllability of initial and subsequent conditions (Townsend, 1992: 29).

A **complex adaptive system** is a collection of individual systems with freedom to act in ways that are not always totally predictable, and whose actions are interconnected, so that one system's actions change the context for other systems (MacLennan, 2012: 3).

Geothermal energy is energy harnessed through the capture of heat, either in steam form or hot water form, from beneath the earth's surface (Mark, Tatum and Stallings, 2013: 4).

A **low-carbon building** is a building that emits significantly less GHG than regular buildings (Mauro, 2015: 16).

Renewable energy is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat (Diakaki, Grigoroudis and Kolokotsa, 2008).

Retrofitting is the installation of individual or multiple energy efficiency measures to an existing building (Winkler, 2017: 12).

Systems thinking theory consists of a set of distinct elements linked together to form a whole, showing, in the process, properties of the whole instead of properties of its component parts (Meadows, 2008: 13; Von Bertalanffy, 1968: 42).

CHAPTER 1 - RESEARCH ORIENTATION

1.1 INTRODUCTION

This chapter introduces the orientation of this study. It commences with the background to the research and the problem statement. The research aim is then stated. The chapter is structured to include the background; the central research question; the research sub question; the research aim; the research objective, the significance of the study, the research design, the scope of the study, the structure of the thesis and the conclusion.

It is expected that at the end of this chapter the reader will have an understanding of what the study is about.

1.2 BACKGROUND

Since existing buildings comprise the largest segment of the built environment, it is important to initiate energy retrofits to reduce consumption and the cost of heating, cooling, and lighting. The Construction Industry Development Board (cidb) in South Africa has advocated the need to retrofit the building stock in the country (Milford, 2009: 69). However, conserving energy is not the only reason for retrofitting existing buildings; retrofitting can also be used to create a high-performance building (Paradis, 2012:17). However, retrofitting as an option is still in its infancy in South Africa. Five indicators manifest this, namely a delivery system for retrofitting does not exist, the official schedule of rates of any government agency does not include energy retrofit, contractors and skilled artisans knowledgeable in this are scarce, professionals have limited knowledge of retrofitting options, and information on retrofitting is not adequate. As a result, the use of retrofitting as a tool for managing carbon emission is fraught with obstacles, putting it beyond the reach of the ordinary person (Milford, 2009: 69). This study focuses on proposing new ways to use retrofitting as a strategy in attaining carbon emission reduction in existing buildings in South Africa.

1.3 CENTRAL RESEARCH QUESTION

In the built environment, the phenomenon of global warming is turning out to be a key concern, due to fear of its repercussions. The United Nations Development Programme (UNDP, 2007) report titled *Energy development and climate change: decarbonising growth in South Africa* revealed that by international standards South Africa's economy is extremely energy intensive in terms of energy consumption in relation to its gross national product (GNP). The report further states that despite its relatively low gross domestic product (GDP) (52nd in the world) and low human development index (HDI) (121st in the world), South Africa has considerably high carbon emissions (37th in overall CO_2 emissions). The CO_2 emissions are as a result of energy-production activities, in which the building sector is in the forefront (CIDB, 2009: 23).

In particular, the CIDB (2009: 23) concludes that the operation of the building sector accounts for around 23% of total emissions. Based on historical trends and anticipated government investment programmes, it is likely that investment in the building sector will grow, on average, at around 2% per year between 2008 and 2050, which will result in the total building stock doubling by 2050. If CO_2 emissions are unchecked, this will result in a twofold increase in emissions (CIDB, 2009: 40; Milford, 2009). There is consensus that there is a need for more comprehensive work on artefacts to be scientifically developed and empirically verified for attaining major carbon emission reduction in the South African built environment. There is a need for a scientifically based framework for integration of retrofitting strategies. The main research question is *"What artefact would engender effective delivery of building energy retrofit projects among the existing building stock in South Africa?"* This main question leads to formulation of the research problem statement, which states that retrofitting of existing buildings remains a major challenge, which needs to be addressed to support emission reductions from the South African building stock (CIDB, 2009:69; Milford, 2009; Wafula and Thalukhaba, 2013: 7).

1.4 RESEARCH SUB-QUESTIONS

Based on the research problem statement, the study sought responses to the following research sub-questions:

- What are the current best practices in delivery of building energy retrofit projects?
- What are the key elements involved in energy retrofit of an existing building?
- What are the issues and challenges facing delivery of energy retrofit of an existing building?
- What are the solutions for delivery of energy retrofit to an existing building?
- How do we put forward a delivery system for energy retrofit of an existing building?

1.5 RESEARCH AIM

The purpose of the study is to develop an artefact that will engender effective delivery of building energy retrofit projects among the existing building stock in South Africa.

1.6 RESEARCH OBJECTIVES

In order to provide answers to the research questions and to achieve the aims of the research, the objectives of the study are the following:

- To assess the current best practices in delivery of building energy retrofit projects,
- To explore the key elements involved in energy retrofit of an existing building,
- To find out the issues and challenges facing management of energy retrofit of an existing building,
- To seek potential improvement for the delivery of energy retrofit of an existing building, and
- To develop an artefact that can be adopted for promoting the deployment of retrofits in existing buildings.

1.7 SIGNIFICANCE OF THE STUDY

Among the most common themes identified in building energy research, delivery of energy retrofit has been found to be a major factor (CIDB, 2009:69; Swan and Brown, 2013: 9). Despite this observation, current retrofitting measures have continued to downplay the level of consideration accorded to this factor. There is a need to evolve a framework by which industry stakeholders will be better informed about effective energy retrofit. There are a few ways to address this gap, such as understanding the variables/elements that makeup effective retrofitting, understanding the dynamics of the constituent elements, analysing the relationship between the elements, and adapting the elements in such a way as to facilitate effective retrofitting.

The significance of this study is to add to the existing knowledge in the area of sustainable building. Through critical reviews and evaluation and analysis of relevant projects, the study will evolve an artefact for promoting CO_2 emissions reduction from buildings in South Africa. It is expected that evaluation of these variables will contribute to learning, teaching, research and practice in the construction industry. The results of this research effort will also deepen the debate around building energy retrofit.

1.8 RESEARCH DESIGN

This research uses a mixed-methods research design drawn from the pragmatic philosophical view in order to achieve its objectives, as stated in section 1.6. Use of a mixed-methods research design was motivated by three main reasons, namely the nature of the research problem, the data and the methods of collecting this data, and the purpose of the research. The research problem involves answering questions relating to "what" and "how", which means that a single approach cannot be used. This, then, informed the decision to use a method that combines both the qualitative and the quantitative research strategies. The complex adaptive system, used as the artefact approach, on its own merit, is hinged on a pluralistic approach that considers both the qualitative and the quantitative approaches to artefact development. It is also evident that the nature of the research in this thesis entails capturing both qualitative and quantitative data, which, by implication, means triangulation of data. The research starts with a review of the literature in the area of energy consumption and carbon emissions in the building sector. This involves identification of the social and the technical variables influencing energy consumption and carbon emissions in the building sector. The review favours the complex adaptive system as the most suitable approach to capture the problem in the research. Developing an artefact using the complex adaptive system approach involves using both qualitative and quantitative data sources.

1.9 SCOPE OF THE STUDY

The research provides a framework for delivery of building energy retrofit in the South African construction industry. The study focuses on the existing government building stock in South Africa. The study was conducted among clients, contractors and subcontractors, and professionals who are experienced in this trade.

1.10 STRUCTURE OF THE THESIS

The research project is structured as follows:

Chapter 1: Research Orientation

The introduction chapter provides the background to the subject. It also communicates the significance of the study, a statement of the problem, and guiding questions that will be investigated. The research question and objectives and the importance of the study are also presented in this section.

Chapter 2: Literature review

This chapter presents a survey of related literature from books, journal articles, conference papers, and Internet searches. The literature review chapter is structured according to the guiding questions of the study.

Chapter 3: Theoretical framework

The theoretical framework chapter explains the rationale for adopting the complex adaptive system's thinking methodology as the most appropriate methodology for the conduct of the investigation into the energy retrofit of existing buildings. Furthermore, relevant theories are also highlighted and reviewed, particularly the theories of systems thinking and chaotic and complex systems.

Chapter 4: Research methodology

This chapter presents an outline of the way in which the research was designed and conducted. It describes the research tools and their design, the methods used in collecting the data, the treatment of the data, the research technique used, the population and the sampling design, and the interpretation of the results.

Chapter 5: Data collection and analysis

The data-collection chapter focuses on presenting the findings and analysing the data in the research study. Answers are also offered to the research questions.

Chapter 6: Artefact development

This chapter describes the development of the artefact and validation thereof.

Chapter 7: Summary, conclusions, and recommendations

The summary chapter presents a summary of all the findings, and it provides conclusions drawn from the study. Recommendations are also presented in this chapter.

1.11 CONCLUSION

Chapter 1 introduced the subject of the research study. It described the structure of the thesis, the background to the study, the significance of the study, and the methodology used, although not in detail. It conveyed information on how the research report is presented. The following chapter looks into the extant literature on carbon emission reduction research and other related literature in line with the objectives of the study.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Having introduced the context of this study in the previous chapter, albeit briefly, this chapter shall proceed to provide an in-depth description of the contexts within which this study is situated. This chapter presents the extant scholarship relating to energy efficiency in the built environment. In achieving this goal, the chapter is structured as follows:

- Carbon emission and its impact on sustainability,
- Low-carbon building,
- The drivers of low-carbon building,
- Barriers to low-carbon building, globally and in South Africa, and
- The low-carbon economy existing in South Africa.

Following the contexts, technical approaches to engender low-carbon building are explored, in the form of energy efficiency technologies, including a review of government policies in place to achieve a low-carbon economy. It is expected that at the end of the chapter, a comprehensive understanding of the existing relationship between the socio-technical elements of the study will have been established.

2.2 CARBON EMISSION IN A GLOBAL CONTEXT

While the phenomenon of global climate change is largely responsible for the current focus on carbon management, one must be mindful of the wider implications of CO_2 emission for sustainable development, and the role that the built environment plays in this interaction. In spite of all the attention on carbon management in recent years, the fact remains that global greenhouse gas emissions and global carbon intensity (measured as CO_2 emissions per unit of economic output) have continued to rise (Pielke, 2010: 17). The world emitted twice as much CO_2 per marginal unit of economic activity in the decade leading to 2008 than in the previous decade (Diakaki et. al, 2008:13). It seems that global economic output is unable to extricate itself from carbon dependency (99% of the variations in carbon emissions can be explained by the changes in the approximately USD 50 trillion global economy – Pielke, 2010: 17), and the trend is unlikely to reverse. This is made clear by the 'Kaya Identity' (Kaya, 1990, as cited in Emmanuel and Baker, 2012: 3; Peters et. al, 2017).), which is composed of two primary factors: economic growth, and technology changes.

(1) CO_2 emissions = population × per capita GDP × energy intensity × carbon intensity

(2) P = total population

(3) GDP/P = per capita GDP

GDP = economic growth (contraction)= P × GDP/P = GDP

(4) Energy intensity (EI) = TE/GDP = total energy (TE) consumption/GDP carbon intensity (CI) = C/TE = CO_2/total energy consumption

(5) EI × CI = ‘carbon intensity of the economy’ = TE/GDP × C/TE = C/GDP

Thus, according to the logic of these relationships, carbon accumulating in the atmosphere can be reduced only by reducing one or more of the following: population, per capita GDP, energy intensity, or the carbon intensity of the economy. It is at this point that the wider importance of ‘sustainable development’ comes into play. The definition of ‘sustainable development’ is by now well known: The Brundtland Commission Report (WCED, 1987) defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. It contains within it two key concepts:

1. The concept of ‘needs’, in particular the essential needs of the world’s poor, to which overriding priority should be given; and

2. The idea of limitations imposed by the state of technology and social organisation on the environment’s ability to meet present and future needs (WCED, 1987).

The built environment is critical to both of these concepts of ‘sustainable development’, and therefore the management of carbon in the built environment is central to our efforts to bequeath a ‘sustainable’ world to future generations. Buildings (especially housing, but also other infrastructure) contribute to fulfilling the need for sustainable development, especially for the poor; the state of technology in the built environment provides a quick win for the world to achieve a low-carbon (and therefore sustainable) future.

2.2.1 The built environment’s role in the global carbon cycle

The built environment is a major consumer of energy, and it is thus a significant contributor of CO_2. The United Nations estimates that buildings consume 30–40% of the total energy used worldwide (United Nations Environment Programme, 2007: 17). If we take into account cities, up to 90% of energy use occurs in and/or for cities (Svirejeva-Hopkins, Schellnhuber and Pomaz, 2004: 45). Given the rapid urbanisation and associated development in built infrastructure in both developed and developing nations, the role of the built environment in energy use, and therefore CO_2 emissions, is likely to be considerable (Emmanuel and Baker, 2012: 6). This is especially the case in Asia, but also in Latin America and, to a lesser extent, in sub-Saharan Africa. At the same time, the technical know-how needed to achieve substantial savings in energy use in the built environment (and therefore large reductions in CO_2 emissions) is largely well known. Therefore, in theory, at least, the expected boom in built infrastructure in the world could potentially offer huge opportunities to reduce emissions and wean the world away from its carbon-intensive ways. The Intergovernmental Panel on Climate Change (IPCC) has asserted that the built environment sector is not only the most technically feasible sector but also the most cost-effective sector for reducing carbon emissions (Rivers, 2010). The question now is “What, then, is preventing such huge and cost-effective potential from being realised?”

2.2.2 History of policies and protocols for carbon management

The policies and protocols for carbon management are a rich mosaic, varying from national-level legislation for energy and carbon management, best-practice guides, and regional carbon-trading mechanisms to global treaties and protocols. The global carbon-management protocols are largely governed by the Kyoto Protocol – an international treaty ratified by over 190 countries to reduce greenhouse gas (GHG) emissions that affect the global climate (Chenget al., 2008: 774). The Kyoto Protocol is the legal implementation mechanism for the United Nations Framework Convention on Climate Change (UNFCCC), adopted in May 1992. Opened for signature during the Earth Summit in Rio de Janeiro, Brazil, in June 1992, the UNFCCC came into force in March 1994, when 154 countries ratified it. The Kyoto Protocol itself came into force in February 2005 (Cheng et al., 2008: 774). The objective of the Convention is to stabilise atmospheric concentrations of CO_2 gases at 'safe' levels. To this end, all parties to the Convention have agreed to address climate change, adapt to its effects, and report their actions to implement the Convention (Fenhann and Hinostroza, 2011: 23).

The Convention divides countries into two groups: Annex I parties, which consist of developed countries and economies in transition, and non-Annex I parties, which include primarily developing countries (Fenhann and Hinostroza, 2011: 23). The governing body, with implementation as well as scientific and technical interpretative responsibilities to the Convention, is the Conference of the Parties (COP). Table 2.1 lists the key milestones achieved by the COP until2015. The main mechanisms to achieve the targeted emission reduction (both the legally binding targets for the Annex I countries and the non-binding agreements for the non-Annex I countries) are all 'market-based' and mostly revolve around three types: The Clean Development Mechanism (CDM), joint implementation (JI), and International Emissions Trading (IET). In summary, the Protocol's first commitment period started in 2008 and ended in 2012. The second commitment period began on 1 January 2013 and will end in 2020.

Table 2. 1 Key milestones in the UNFCCC process

Conference of the Parties(COP)	**Location, date**	**Relevant procedural milestone achieved**
COP3	Kyoto, Japan, 1997	Agreed to a legally binding set of obligations (Annex I countries to lower their emission by approximately 5.2% below that of 1990 levels). This is expected to be achieved in 2008–12 (Cheng et al., 2008). Non-Annex I countries agreed to non-binding obligations ("common but differentiated responsibilities"). Also known as the Kyoto Protocol.
COP5	Bonn, Germany, 1999	Guidelines for the preparation of national communications by parties included in Annex I to the Convention (annual inventories and national communications) – subsequently amended at several COP meetings.
COP7	Marrakech, Morocco, 2001	Finalised most of the Kyoto Protocol's operational details and set the stage for its ratification (also known as Marrakech Accords); sets forth the operational rules for the CDM, JI, and IET (Cheng et al., 2008).

COP8	New Delhi, India, 2002	Expressed linkages between climate change and sustainable development (the Delhi Ministerial Declaration on Climate Change and Sustainable Development). Highlighted the equal importance of adaptation measures and those that can be mitigated.
COP10	Buenos Aires, Argentina, 2004	Guidance on the CDM, including the designation of verification authorities.
COP11	Montreal, Canada, 2005	Establishment of an Adaptation Fund. Launch of JI. Official launch of the Kyoto Protocol.
COP13	Bali, Indonesia, 2007	The Bali Action Plan, consisting of recognition of the deeper cuts in emission needed to arrest climate change, and preparation of a measurable, reportable and verifiable nationally appropriate mitigation plan, including for developing countries (in the context of sustainable development).
COP15	Copenhagen, Denmark, 2009	Establishment of the Copenhagen Green Climate Fund as an operating entity of the financial mechanism of the Convention, to support projects, programmes, policies, and other activities in developing countries related to mitigation, including Reducing Emissions from Deforestation and Forest Degradation (REDD+), adaptation, capacity building, and technology development and transfer – approaching USD 100 billion a year by 2020.
COP16	Cancun, Mexico, 2010	Establishment of the Cancun Adaptation Framework, to enhance action on adaptation, including through international cooperation and coherent consideration of matters relating to adaptation under the Convention.
COP17	Durban, South Africa, 2011	All governments committed to a comprehensive plan that will come closer over time to delivering the ultimate objective of the Convention on Climate Change, namely to stabilise greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous interference with the climate system, and at the same time will preserve the right to sustainable development.
COP 18	Doha, Qatar,2012	At the 2012 UN climate change conference governments consolidated the gains of the last three years of international climate change negotiations and opened the way to necessary

		greater ambition and action on all levels. Among the many decisions taken, governments • Strengthened their resolve and set out a timetable to adopt a universal climate agreement by 2015, which will come into effect in 2020, • Streamlined the negotiations, completing the work under the Bali Action Plan, to concentrate on the new work towards a 2015 agreement under a single negotiating stream in the Ad hoc Working Group on the Durban Platform for Enhanced Action (ADP), • Emphasised the need to increase their ambition to cut greenhouse gases (GHGs) and to help vulnerable countries to adapt, • Launched a new commitment period under the Kyoto Protocol, thereby ensuring that this treaty's important legal and accounting models remain in place and underlining the principle that developed countries lead mandated action to cut greenhouse gas emissions, and • Made further progress towards establishing financial and technological support and new institutions to enable clean-energy investments and sustainable growth in developing countries.
COP 19	Warsaw, Poland, 2013	Key decisions adopted at this conference include decisions on further advancing the Durban Platform, the Green Climate Fund and Long-Term Finance, the Warsaw Framework for REDD+, the Warsaw International Mechanism for Loss and Damage, and other decisions.
COP 20	Lima, Peru, 2014	At the twentieth Conference of the Parties, world governments had the opportunity to make a last collective push towards a new and meaningful universal agreement in 2015.
COP 21	Paris, France, 2015	Negotiations resulted in the adoption of the Paris Agreement on 12 December, governing climate change-reduction measures from 2020. The adoption of this agreement ended the work of the Durban Platform, established during COP17.

Source: (Emmanuel and Baker, 2012: 10; UNFCCC, 2014)

1. The CDM, which was established under Article 12 of the Kyoto Protocol, enables Annex I parties to implement projects that reduce GHG emissions in non-Annex I parties in return for certified emission reductions (CERs). CDM projects also assist host parties in achieving sustainable development and in contributing to the ultimate objective of the Convention.
2. The JI mechanism is defined in Article 6 of the Kyoto Protocol, where an Annex I party with an emission reduction and limitation commitment under the Kyoto Protocol may implement an emission-reduction or emission-removal project in the territory of another Annex I party with an emission reduction and limitation commitment under the Protocol. The party implementing the project may count the resulting emission reduction units (ERUs) towards meeting its own Kyoto target. This country-to-country initiative has little direct bearing on the management of carbon in the built environment.
3. IET, which is set out in Article 17, provides for Annex I parties to acquire emission units from other Annex I parties and to use those units towards meeting a part of their targets. These units may be in the form of the initial allocation, assigned amount units (AAUs), removal units (RMUs), units issued for the amount generated from domestic sink activities, CERs under the CDM, or ERUs generated through JI. Apart from the units generated by the CDM-based CERs, little direct link to the built environment is seen.

Given the possibility for technology transfer, the worldwide search for lowest-cost opportunities for reducing emissions, and the possibility for small-scale and private-sector organisations to play a part in these, the CDM offers potential for the built environment sector to reduce emissions, especially in the developing world (Williams, 2010: 7604).

2.3 LOW-CARBON BUILDING

In recent years, a great effort has been made at international level to reduce the energy consumption of buildings. The construction sector represents one of the main challenges to deal with in order to guarantee sustainable development. Globally, starting in2002 with the Energy Performance of Building Directive (EPBD)(2002/91/CE), for the first time in history all member states of an entire continent decided to establish common guidelines for improving the energy performance of buildings, for both new and existing architecture (Mauro, 2015: 16). In this regard, at national level, several laws have been promulgated to enforce the mandatory trends, by taking into account the local peculiarities of the building stock, technology, and construction activities. This challenge requires an urgent and coordinated global response.

Importantly, buildings account for a higher proportion of CO_2 emissions than any other economic sector, and emissions attributable to building construction and operations have been increasing in recent decades. These emissions can primarily be traced back to heating, cooling and lighting systems, although emissions from embodied materials are also significant. This has led to development of new strategies to reduce the amount of energy consumed by buildings, but numerous technical, economic and policy barriers will have to be overcome. The strategies utilised to achieve a low-carbon building vary depending on the type and the location of the building. Mark et al. (2013: 3) reported research carried out in the United States and Europe. The projects were studied based on the carbon output of the building and the strategy used to achieve a low-carbon building. The first type of strategy is known as geothermal energy, and it is relatively new to the construction industry. Geothermal energy is energy harnessed through the capture of heat, either in steam form or hot water form, from beneath the earth's surface (Mark et al., 2013: 4). This type of energy is harnessed by digging deep wells and using pumps to bring the steam or hot water to the surface and using it to heat or cool a building. Geothermal energy can also be used to provide electricity for a building. Geothermal heat is found mainly at plate boundaries, so it all depends on the location of the site as to whether or not this form of renewable energy is available (Mark et al., 2013: 4). The United States is the largest producer and user of geothermal energy in the world. This is because the US has the technology, and geothermal energy is located mainly along the Ring of Fire, which is the area surrounding the Pacific Ocean.

All of the United States' geothermal power plants are located in the western part of the country (EIA Geothermal, 2012: 17). An innovative design that is used in Europe is a building technology called energy piles. The construction company Skanska came to the conclusion that if you are going to dig a deep hole for foundation piles, why not go ahead and make that foundation pile be a geothermal energy system as well? That is how the energy pile was conceived, and it is a relatively simple approach. The engineer accounts for the extra depth needed to reach geothermal level, and they adjust pile depth accordingly. Pipes are laid out through the pile, and the hot water or steam is pumped up through them, just like in any other geothermal system (EIA Geothermal, 2012: 17; Mark et al., 2013: 4).

Another type of renewable energy, one of the oldest forms of renewable energy, since fire was first discovered, is called biomass energy. Biomass energy is created using the waste from plants and animals (International Energy Agency, 2011). Biomass is a very resourceful type of renewable energy; biomass will diminish landfills and eliminate unwanted waste. A common misconception when discussing biomass is that when biomass is burnt, it creates CO_2 emissions. This is true, but the CO_2 captured during its own growth balances out the carbon emitted during its use, therefore it is still classified as renewable. The only time biomass would not be environmentally beneficial would be if forests were cleared to grow biomass, which is why most biomass companies try and use previously cleared land, such as under-utilised farmland (National Renewable Energy Laboratory (NREL), 2012: 7).

Another strategy, which has been adopted in Europe, is called allowable solutions. The theory of allowable solutions suggests that if you get your building as carbon-efficient as possible, and then, through your renewable energy source, provide renewable energy for another development, your building is then seen as zero-carbon, due to the carbon that you saved the other development (Mark et al., 2013: 4; NREL, 2012: 7).

Yet another strategy, which is used mainly in the United States, is called carbon offsetting. Carbon offsetting can be done in two ways. The first way is becoming less and less prevalent in the construction industry, because of the lack of honesty on the part of the company providing the offsets, and the lack of control on the part of the developer. The first method is done by paying a company, hopefully one that is reputable, a varying amount of money to replenish a site. For example, a developer can purchase a plot of land in the African jungle to save it from deforestation, thereby offsetting the carbon they created on their project.

The problem with this way of offsetting is the fact that companies that are being paid by these developers may or may not sell the same plot of land to multiple developers, so the fact is that even though developers are paying, they are not truly offsetting the carbon they are creating. So it is a lose-lose situation, as the developer is creating carbon that has not been offset (and paying for it), and the land that was paid for is not being protected. The other method of offsetting a project's carbon, which is more controllable, is done within the United States, and the developer can actually see what has been paid for. Through this method, a developer will pay a company, which will invest the money in a renewable power company or in re-growing deforested lands or marine life (NREL, 2012: 7). A good example of where this is used is the Cliff House in San Francisco, California. The Cliff House is a zero-carbon project, but not by design. The Cliff House became zero-carbon through a company called Planktos. Planktos takes Cliff House's money and invests it in re-growing forests and regenerating plankton populations all around the world, both of which reduce carbon, thereby offsetting the CO_2 emissions created on the project. These two strategies may seem unorthodox, but they both are a great way for a previously built building, or one that simply could not achieve zero-carbon status, to become zero-carbon, while regenerating what has already been destroyed.

In the European Union (EU) there is a scheme called the Carbon Trading Scheme, which is very similar in nature to offsetting in the United States, just on a much larger scale. By paying money to the EU, companies can offset their carbon created on-site. The money is then put into developing and researching renewable energy sources. The methods described to achieve a low-carbon project have been used throughout Europe and the United States. Both regions have particular technologies they have focused on and perfected. The main difference, other than a few building technologies, is the strategic methods that are used in each region. In Europe they utilise the system of allowable solutions and carbon trading and in the United States they use carbon offsetting and, in some places, a tactical strategy of providing power back to the grid.

Arguably, there is one thing that has kept arising in both the United States and Europe, and that is the fact that not one person/company/organisation could provide one answer as to what implementation strategies are best used to achieve a low-carbon building. The NREL (2012: 7) posited that achieving a zero-carbon building all depends on the location and the type of the project. For instance, one of the most innovative strategies discovered was the use of Skanska's energy piles. However, geothermal energy is not available everywhere on the planet, so it is all site-dependent. Since there is no definite strategy to achieving a low-carbon building, the following list shows some methods that were discovered during research (EIA Biomass, 2012: 13; EIA Geothermal, 2012: 17; Mark et al., 2013: 4; NREL, 2012: 7), there must be an on-site source of renewable energy, such as geothermal, biomass, hydroelectric, wind or solar energy. Not all of these are required, but a combination of two or more of these sources is not an uncommon practice. The orientation of the building can have a crucial impact on the building's ability to achieve maximum natural daylight and ventilation. By providing shading and glazing on the windows, the building will be able to alter the amount of sunlight let into the building. Using recycled materials when possible is a good way to reduce the building's carbon footprint.

By having an ultra-tight building envelope, the building requires less insulation, and less power is required to heat and cool the building. Also by utilising natural ventilation when possible, a building can have zero energy required for ventilation. Natural air can be captured and treated within the building and then dispersed safely and with no operating cost. By utilising natural rainwater, there is no need to purchase water. The rainwater can be treated and used for washing, flushing toilets, and site irrigation. By recycling the building after its useful life, it is insured that there will not be any CO_2 emissions created by the building's waste. By increasing the thermal insulation of the building, the energy needed to heat and cool the building may be reduced significantly.

In South Africa, Okorafor, Emuze and Das (2017: 5) reported that South Africa has shown some remarkable improvement in curbing the effect of carbon emission in its buildings with the use of regenerative lift drives, geothermal ground loops, the Intelligent Building Management System, purchasing carbon credits and offsetting through the Kariba REDD+Project, and power-generating gym equipment.

2.3.1 Drivers of low-carbon building

Drivers for low-carbon building have been identified by Pitt, Tucker, Riley and Longden (2009: 207) that focus on policy, financial, knowledge and client demand factors, although these vary depending on their position within the supply chain (Häkkinen and Belloni, 2011: 240). Swan, Ruddock and Smith (2013: 527) in their study found that government policy and targets, organisational commitment, available finance, resident demand, climate change, fuel poverty, maintaining asset value/stock condition, maintaining let-ability of property, reduced fuel bills, and running costs for tenants are factors that influence drivers for low-carbon building. Despite these factors, multiple drivers exist for the development of low-carbon housing globally. These are broadly clustered under three categories: business drivers, cultural drivers, and legislative drivers. They are examined below.

2.3.1.1 Business drivers

According to Osmani and O'Reilly (2009: 2), there is a growing culture of corporate social responsibility (CSR) within the building industry. The importance attached to CSR was strongly illustrated in the World Wide Fund (WWF) report titled *Building a sustainable future*, where a survey of 20 of the UK's largest housing developers revealed that 70% report publicly on their approach to sustainability, and that 65% have a corporate sustainability policy in place (Osmani and O'Reilly, 2009: 2). Consequently, CSR has the potential to be a powerful driver for zero-carbon homes, as companies strive to improve their environmental performance. Furthermore, Carter (2006: 13) stated that in exceeding minimum sustainability standards, house builders can benefit from enhanced brand recognition and reputation. Similarly, the WWF (2007) report as cited in (Osmani and O'Reilly, 2009: 2) added that *investing in sustainability* also indicated that achieving high standards of environmental and social performance can be used to a developer's advantage to attract customers and high-calibre employees. However, the construction supply chain could have a more profound impact on the zero-carbon agenda. A study by Keeping and Shiers (2004: 17) found that the construction supply chain is more motivated to develop green products and practices, due to its marketing objectives and the market differentiation it can benefit from. Even in South Africa, notable multinational organisations have used low-carbon building as a marketing strategy to garner business opportunities (Okorafor et al, 2017: 7).

2.3.1.2 Cultural drivers

Globally, customer demand for low-carbon housing is currently limited, especially in sub-Saharan Africa. Low-carbon housing is recognised as a growing market and area of interest. A study carried out by Sponge Sustainability Network (2006: 17) reveals that there is a growing desire amongst the public to adopt sustainable lifestyles. The growth in customer demand is likely to encourage house builders to voluntarily integrate sustainable features into future developments. It is suggested that this growing low-carbon culture could be built upon by government initiatives, either through the provision of fiscal incentives, as recommended by Dobson (2007: 283), or the integration of sustainability factors in property valuations, as explained by Sponge Sustainability Network (2006: 17). Favourable planning policies, such as the Planning Policy Statement, and existing government policies, such as the Energy White Paper, which are aimed at promoting sustainability in the built environment, are likely to further enhance integration of such features and the promotion of a low-carbon culture. Moreover, these policies pave the way for new legislation, which stakeholders in the building industry have been shown to respond best to.

2.3.1.3 Legislative drivers

The prospect of future legislation itself should prove to be a major driver in achieving zero-carbon homes in the near future (Dobson, 2007: 283; Lutzendorf and Lorenz, 2007: 654). It is anticipated that with the global clarion call for CO_2 emissions abatement at present, legislation enforcing this is likely to be the most influential driver for house builders to build zero-carbon homes, and those who adopt a proactive attitude will gain extensive and practical knowledge of low-carbon house building, from which they will benefit financially by being able to meet the enhanced building requirements more cost-effectively.

2.4 BARRIERS TO LOW-CARBON BUILDING

Globally, barriers to low-carbon building stand in the way of designing and building energy-efficient buildings. Swan, Ruddock and Smith (2013: 531) in their study posited these barriers to be lack of funding support, lack of technical knowledge, lack of an equipment supply chain, lack of an installation skills supply chain, resident resistance, too much long-term risk, e.g. defects or non-performance, lack of a repairs and maintenance supply chain, lack of policy and government intervention, and commercial difficulties, e.g. failure to establish a business case. The main barriers that will be discussed in this study include technical and design barriers, cultural barriers, legislative barriers, and financial barriers.

2.4.1Technical and design barriers

Technical and design barriers are one of the main considerations when looking at the feasibility of low-carbon homes in the world, as a step to change in the housing construction process. One of the primary issues with the construction of low-carbon homes is the integration of renewable technologies into small-scale developments, as it is widely perceived that such technologies are currently unreliable (Dobson, 2007: 283; Lutzendorf and Lorenz, 2007: 654; Osmani and O’Reilly, 2009: 5) and are believed to be installed to the detriment of profit, outside space, and aesthetics (Sullivan, Mark and Parnell, 2006: 567). A further design barrier revolves around the fact that a greater percentage of house builders in the Western world tend to use a range of standard house sets across their developments, to help reduce costs and defects, and as a result, they are reluctant to adopt policies which require excessive design changes (Williams and Adair, 2007: 139). As Stafford, Gorse and Shao (2011: 5) put it, each house is unique, so there is no one-size-fits-all solution, and, as such, installers and tradesmen do not have all the necessary skills to fit more advanced energy efficiency and renewable energy measures.

2.4.2 Cultural barriers

Globally, cultural barriers are seriously impeding the successful construction of low-carbon building in the world. For example, in the UK building sector, an unwillingness to implement untested or new sustainable materials and products has been recently recorded in a study by Williams and Adair (2011: 141). This is as a result of the traditional attitudes maintained within the house-building sector, which restrict the uptake of innovations (Nelson, Peterhansi and Sampat, 2014: 681; Poyton, 2013: 13). Compounding this unwillingness to stray from tradition is a lack of sustainability requirements by clients, as identified in a study by Sponge Sustainability Network (2006: 17), and the widespread perception that there is currently a lack of demand for sustainable properties amongst the general public (Williams and Adair, 2011: 144).

2.4.3 Financial barriers

The perceived increased costs of achieving a low-carbon building are yet another hurdle constraining house builder from attempting to overcome the existing cultural, design and technical challenges (Nelson et al., 2014: 681; Williams and Adair, 2011: 144).

Several studies have revealed that housing developers are reluctant to instigate innovation and achieve high sustainability standards due to the costs associated with the implementation of such standards (Nelson et al., 2014: 681; Poyton, 2013; Williams and Adair, 2011: 144). Cato (2008: 26) and Williams and Adair (2011: 145) concur that the high cost of certain sustainable measures is a major barrier to low-carbon building when compared to traditional building. Moreover, this issue is exacerbated by the uncertainty surrounding the actual cost of achieving the different levels of low-carbon building. Several studies undertaken to date have shown that the cost of achieving the different levels of low-carbon building will vary depending on factors such as the construction methods employed (Maunsell and Capener, 2007: 4). Taking into consideration the lack of cost and financial data associated with the construction of low-carbon building, coupled with current cultural and technical concerns regarding sustainability, it is clear that in light of the current financial climate of the world, governments are likely to face several challenges and hurdles in achieving their low-carbon building objective.

2.5APPROACHES TO ENGENDER LOW-CARBON BUILDING

Buildings account for a higher proportion of CO_2 emissions than any other economic sector, and emissions attributable to building construction and operation have been increasing in recent decades. These emissions can primarily be traced back to heating, cooling and lighting systems, although emissions from embodied materials are also significant. The Intergovernmental Panel on Climate Change has identified buildings as the sector with the greatest potential for carbon reductions, particularly because reductions that result from improved building performance also yield substantial economic benefits (IPCC, 2007: 14). The World Business Council for Sustainable Development has concluded that the energy use of buildings worldwide could be reduced by 60% by 2050 if innovative technologies are used (WBCSD, 2009: 12).

Owing to the range of financial incentives for different technologies that are available around the world, and the frequency with which they change, any summary of these would be extensive and would quickly be out of date. However, understanding the types and levels of incentives that apply to each technology, as well as any relevant local, national and international legislation and regulations, is essential in selecting the most appropriate technology (or technologies) for each individual need. Geography also has a huge role to play, both locally and globally. In the case of renewable energy, solar energy is obviously most efficient at lower latitudes, while wind and wave energy tend to favour more exposed locations at higher latitudes. However, solar energy is perfectly viable even at high latitudes, while exploiting manufactured wind tunnels in the built environment may provide new sources of wind power. Similarly, the viability of combined heat and power (CHP) depends significantly on the local built environment, but there also needs to be a reliable fuel supply, and the selection of any large-scale technology has to consider the local availability of the resource and the carbon cost (and other impacts) of any fuel imports. This problem has prompted the development of new strategies to reduce the amount of carbon dissipated by buildings. The study will now review various approaches to engender low carbon in the built environment.

2.5.1 Solar thermal panels

Solar thermal or solar hot water (SHW) panels are probably the most commonly installed building integrated renewable technology (Allen, Hammond and McManus, 2008: 529). Solar thermal panels (also known as "collectors") can be fitted at optimal angles on rooftops, and they contain a liquid, usually an anti-freeze, which is heated by the sun and is pumped to heat water in a boiler (Allen et al., 2008: 529; Emmanuel and Baker, 2012: 43). Although output is dependent on weather conditions, the technology can provide hot water all year round, even in higher latitudes. For example, in temperate countries, such as the UK, building-mounted solar thermal panels currently have the potential to meet up to 70% of an average household's hot water needs, with the additional benefits of being low-maintenance and low-cost in comparison to other micro renewable technologies (UK Department of Energy and Climate Change (DECC), 2011). The availability of unused roof space in urban areas means that both solar thermal panels and solar photovoltaic cells have significant potential to reduce carbon emissions from the built environment (Emmanuel and Baker, 2012: 43).

2.5.2 Solar photovoltaic cells

Solar photovoltaic cells (PVs) convert energy from the sun directly into electricity, and are a proven and highly popular renewable technology, which is still rapidly advancing. As for solar thermal systems, PV panels can be installed on any roof with an appropriate aspect, but they can also be integrated into roofing tiles and walls, and new thin film designs can be affixed to windows (Weber and Shah, 2011: 431). One of the most common places to find a panel is on top of transport infrastructure such as parking meters, and trials of PVs integrated into road surfaces are being conducted in Oregon, USA (OIPAF, 2008). Historically, PVs have suffered from a lack of investment, and this helps explain why costs remain a barrier to wider installation, as high costs mean long payback periods for investors. As the efficiency of solar cells continues to improve and the costs of manufacture continue to fall, along with an increasing range of applications in the built environment (including powering other renewable technologies), PVs are set to be one of the most important technologies for reducing GHG emissions from the built environment (Emmanuel and Baker, 2012: 43; Weber and Shah, 2011: 431).

2.5.3 Micro wind turbines

According to Carbon Trust (2011a: 3) and Emmanuel and Baker (2012: 43), micro wind turbines come in a wide range of designs and sizes, which maximises their ability to generate electricity from any available wind resource. Micro wind turbines include both building-mounted turbines, typically capable of generating anything up to 2kW, and the smaller stand-alone turbines, commonly used by off-grid buildings. Most designs are horizontally mounted, and many share the three-blade design used for many larger turbines, but various blade configurations are available, and vertically mounted turbines are suitable for smaller stand-alone installations. A key problem for micro wind turbines in urban environments is that the complexity and variation in local air flows can result in higher intermittency in supply than for other micro renewable technologies (Carbon Trust, 2011a: 3; Weber and Shah, 2011: 431). Noise and vibration may also pose problems for mounting turbines on existing buildings, and so, as with any micro renewable technologies, they may be subject to local planning laws. Nevertheless, the flexibility of micro wind turbines makes them another valuable option for reducing CO_2 emissions.

2.5.4 Ground-source heat pumps

Ground-source heat pumps (GSHPs) use heat pumps to utilise the stable temperature of the ground to provide heating and/or cooling for both space and water. They are distinct from geothermal systems in that they are not limited by the need to identify and exploit geothermal 'hot spots' (the heat comes from the sun, not the earth), and the thermal stability of the ground makes them more efficient than their air-source equivalents. Heat (or cooling) is delivered by pumping a fluid with a high thermal capacity and a low freezing point around a 'loop' installed below ground and through a heat exchanger on the surface. Although they require electricity for powering the pump, this can be delivered by solar PVs (creating 'geo-solar' systems), and, once installed, they are low-maintenance and have long life spans, typically 25 years for the pump and 50 or more years for the loop, and they also offer lower payback periods than some other renewable technologies (U.S. Department of Energy, 2011). However, GSHPs are not without their disadvantages, particularly for applications in urban areas. Although loops can be installed under existing buildings, this entails significant disruption of construction; for example, installing a loop under a domestic property may require digging up any garden area, and higher concentrations of GSHPs can change ground temperatures, leading to reduced system efficiencies. GSHPs are also not suitable for use in the colder climates found towards the poles (Carbon Trust, 2011a: 3). Although less flexible in application than most other renewable technologies, GSHPs provide consistent and long-term supplies of heat and cooling, and when combined with solar PVs, they provide an important source of zero-carbon energy generation.

2.5.5 Air-source heat pumps

Air-source heat pumps (ASHPs) operate on the same principle as GSHPs, but use air as a heat exchanger, instead of the ground (Carbon Trust, 2011a: 3; Emmanuel and Baker, 2012: 43). The use of air, with its lower thermal capacity and much higher temperature instability, means that ASHPs are less efficient than GSHPs (GSHPs being more than twice as efficient on cold days in temperate climates), although performance is improving. Also, like GSHPs, they require an electricity supply, which can be met from solar PVs, and in suitable locations they can also be combined with GSHPs, for greater efficiencies at lower marginal costs (U.S. Department of Energy, 2011). The greater flexibility of ASHPs, particularly for applications in densely populated areas and on high-rise buildings, means that they are expected to become an increasingly common sight in urban environments (Carbon Trust, 2011a: 3; Emmanuel and Baker, 2012: 43).

2.5.6 Hydropower

Hydroelectric dams are humanity's great monuments to the early days of renewable energy, although originally motivated by the need to generate large amounts of power without the need to transport fuel, rather than for their emissions credentials (Suzuki, Dastur, Moffatt and Yabuki, 2010). The controversies that surround hydropower dams usually relate to their impacts on landscapes, local human and animal populations, and the flow and quality of water downstream – the latter being particularly controversial when a river crosses state or national borders (Emmanuel and Baker, 2012: 45). An excellent case study of these debates can be gleaned from the volumes of work published on the Colorado River Compact in the USA. From an emissions perspective, it is debatable whether hydropower at this scale is 100% renewable, as flooding land produces significant amounts of emissions, particularly methane. Hydropower is also highly location-dependent, and new dams are often subject to a wide range of legislation and other limiting factors, with some countries already having exploited much of their available potential (Emmanuel and Baker, 2012: 45).

2.5.7Wind farms

After hydro, by far the most widely installed centralised renewable technology is wind power, either onshore or offshore (Suzuki et al., 2010). The tendency for the onshore resource potential to be greatest in exposed and picturesque rural areas has generated significant public opposition in some parts of the world, but those in favour of greater expansion argue that the immediate visual impacts are far outweighed by the long-term impacts of climate change (REN, 2011; Wang, 2011: 177). Offshore wind farms use larger turbines and produce much higher outputs of electricity. However, the difficulties of constructing farms far out to sea mean that at present most farms are still visible from the shore (Emmanuel and Baker, 2012: 45; REN, 2011; Wang, 2011: 177). One solution to this, as used in countries such as Germany, is to locate wind farms alongside existing transport networks. Both onshore and offshore farms produce intermittent supplies of electricity and usually require new electricity infrastructure. Nevertheless, they form an essential component of the collection of renewable technologies that can meet existing energy demands using proven and commercially viable technologies (REN, 2011; Wang, 2011: 177).

2.5.8 Solar farms

When installed at large scales, both solar thermal panels and solar PVs can be used to generate electricity. Solar farms consist of either large arrays of PV panels or vast thermal plants that use mirrors to focus energy from the sun onto a heat transfer fluid (REN, 2011; Wang, 2011: 177). Most commonly the latter is achieved by using parabolic mirrors to focus energy on a tube containing the fluid, but more recent designs contain the fluid in a tower surrounded by a circular array of mirrors that focus the energy on its tip (REN, 2011). Such installations are also termed "concentrating solar power (CSP) farms", and the same principle can be applied to improve the output from PVs, in what are termed "concentrating photovoltaic (CPV) farms". Although some CSP farms have existed for many years, particularly in the USA, it is only recently that the technology has really taken off. Farms now being developed will significantly ramp up global capacity, from around just over 1.1GW to more than 17GW. Almost half of this expansion is in the USA (8.7GW), followed by Spain (4.5GW) and China (2.5GW). Although solar farms are relatively uncommon at present, both forms of the technology are expected to play an increasingly significant role in reducing emissions, and are a cornerstone of major infrastructure projects, such as the European super grid (REN, 2011; Wang, 2011: 177).

2.5.9 Biomass

Biomass systems generate heat from the combustion of organic materials, most commonly wood or wood-based materials (Carbon Trust, 2011g: 3). Biomass is organic matter such as wood, straw, energy crops, sewage sludge, waste organic materials, and animal litter (Bahaj et al., 2017: 155). It is often viewed as a form of stored solar energy, captured by the plants as they grow. Of course, the plants also absorb CO_2 as they grow, so using biomass fuels completes the carbon cycle. This is low-carbon compared to traditional fuels, which release CO_2 but do not absorb it in their production. Biomass heating can offer material carbon savings over traditional heating fuels and can, in some cases, reduce the cost of heating. Bahaj, Myers and James (2017:155) and the Carbon Trust (2011g: 4) confirm that the main motivation for using biomass in their case study projects was to reduce the carbon emissions of the buildings. Using solid biomass for heating typically gives reductions in net CO_2 emissions of around 90% relative to using fossil fuel heating systems. Other motivations were security of fuel supply, price stability, and lower cost when compared to fossil fuels. Biomass fuel should be sourced locally to reduce the transport costs and associated carbon emissions (Bahaj et al., 2017: 155; Carbon Trust, 2011a: 4).

2.6 RETROFITTING

The term "retrofitting" has a multifaceted definition based on context. For the purposes of this research, the term "retrofitting" is simply defined as the installation of individual or multiple energy efficiency measures to an existing building (Winkler, 2017: 12). An energy efficiency measure is any technology that improves the energy performance of the building, such as loft insulation, advanced heating controls, and renewable energy-generation technologies (Unruh, 2002: 321; Winkler, 2017: 12). Due to global warming and depletion of natural resources, the world has recognised the impact of CO_2 emission and its attendant consequences at large. It has been asserted that the built environment is a major contributor to this CO_2 emission. Consistent with the above view, Lombard (2012: 2) posits that existing buildings are responsible for 3.5% of final energy consumption, with the majority of the energy being used to power heating, ventilation and air conditioning (HVAC) systems, lighting, and office equipment. Energy is the primary component contributing towards the operating costs of buildings.

There are a number of ways in which one can reduce energy consumption within a building. The simplest way to ensure that buildings consume less energy is to build new sustainable buildings. In the context of the built environment one can focus on "retrofitting" existing buildings, in order to improve the energy efficiency of the buildings. As highlighted by Ma, Cooper, Daly and Ledo (2012: 810), Unruh (2010: 821), and Winkler and Marquard (2009: 53), building energy retrofitting (BER) offers many challenges and opportunities. The substantial challenges, in any sustainable retrofit project, are due to the presence of several uncertainties, such as climate change, human behaviour, and state policy, which have a large impact on project success. Furthermore, a building is a very complex system, consisting of highly interactive components. Therefore, evaluation of the effects induced by building energy retrofit measures (BERMs) on building behaviour is critical, and selection of the best retrofit strategy becomes very complex. A research study by Ma et al. (2012: 891) proposed a detailed review and analysis of the main methodologies adopted for designing an efficient energy retrofit, thereby identifying some key elements influencing building energy retrofit. Figure 2.1 below depicts such elements.

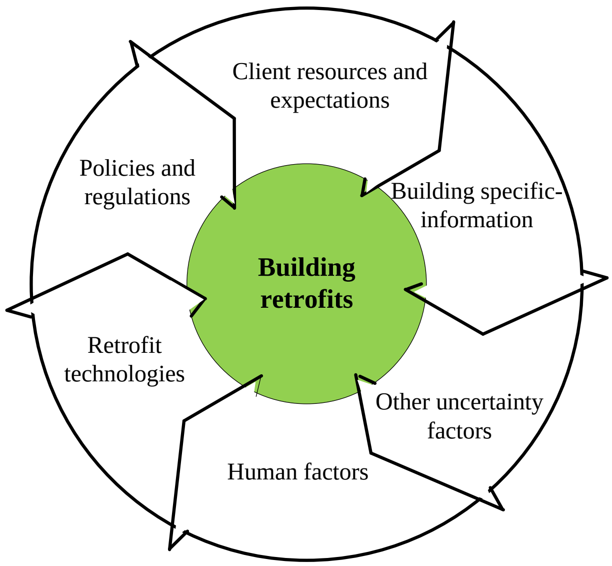


Figure 2. 1 : Key factors influencing building retrofit (Source: Ma et al., 2012: 892)

The elements are policies and regulations, client resources and expectations, building-specific information, human factors, retrofit technologies, and other uncertainty factors. Policies and regulations impose the minimum levels of energy performance that should be achieved in the case of BER from the government. Furthermore, they can also offer financial support, namely incentives, for implementing efficient BERMs. Baek and Park (2012: 492) presented an interesting review on the impact of such regulations on the promotion of housing renovation. The most recent public policies addressed to energy retrofit are the EPBD Recast in the EU and the Standard 189.1 in the US, as summarised in Tobias and Vavaroutsos (2009: 14). Client resources and expectations define the main goals to pursue by the retrofit project, as well as the available economic budget. Therefore, this element is crucial, because it substantially affects objective functions and constraints of the multi-objective optimisation problem represented by the finding of the best retrofit delivery strategy.

A further key element (Ma et al., 2012: 892) for an effective retrofit is the exploitation of building-specific information, such as geographical location, geometry, size, age, intended use, occupancy profiles, operation schedules, energy sources, type of HVAC system, and so on. This information should be considered in order to propose the most appropriate BERMs. Human factors constitute another relevant element for the success of energy retrofit. They involve occupant behaviour, in terms of comfort needs, activity schedules, and access to controls, thereby implying a deep influence, characterised by a significant uncertainty, on the final outcomes of a retrofit project (Fulford, 2011: 17; Hoes et al., 2009: 297). Several studies have showed that proper and smart occupant behaviour can produce substantial energy savings, with no or low investment and without penalising thermal comfort. For instance, Owens and Wilhite (1988: 854) demonstrated, for Nordic countries, that an energy saving of 20% can be achieved in domestic energy use, while Santin, Itard and Visscher (2009: 1224) showed that the impact of people behaviour on the energy use for heating is close to 5% in the Netherlands.

Retrofit technologies correspond to energy retrofit measures (ERMs). They represent renovation actions aimed at reduction of building primary energy consumption. In their paper, Ma et al. (2012: 895) proposed a possible classification of retrofit measures in three categories, depicted in Figure 2.2 (taken from the mentioned study), consisting of(a) supply-side management (b) demand-side management, and(c) a change in energy-consumption patterns. Category A includes implementation of efficient primary heating/cooling systems, as well as of renewable energy sources (RESes), such as thermal solar collectors, photovoltaic (PV) generators, wind turbines, biomass systems, and so on. The purpose is to provide the building with innovative and efficient energy-supply systems.

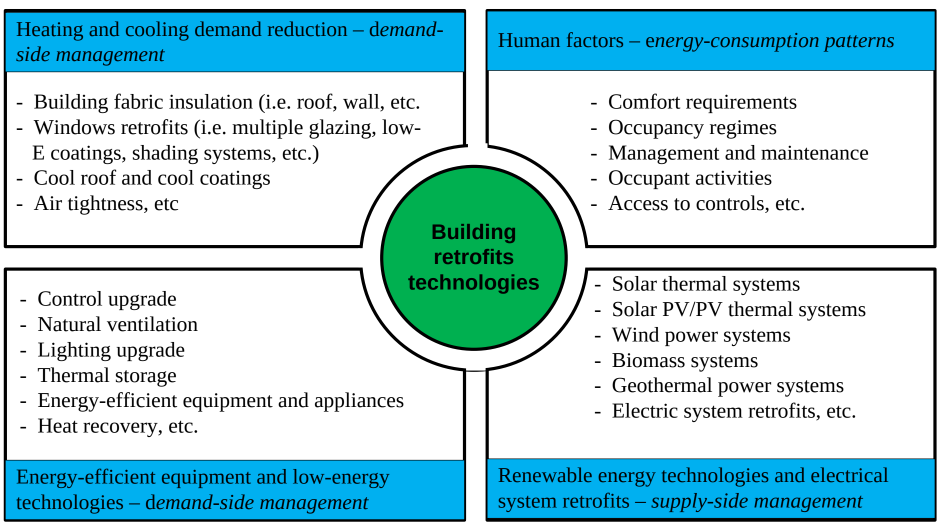


Figure 2. 2 : Main categories of building retrofit technologies (Source: Ma et al., 2012: 892)

Category B (demand-side management) collects different energy measures for reduction of heating and cooling demand, such as renovation of the building fabric, efficient windows, solar shading systems, natural ventilation, heat recovery, thermal storage systems, and many other efficient technologies. Category C (energy-consumption patterns) considers the ERMs, generally with no or low investment cost, that point to properly addressing the human factors. In fact, as already mentioned, smart and appropriate occupant behaviour can induce high energy savings, up to 20%.

2.6.1 Motivation for retrofitting

According to Hills (2009: 11), Unruh (2002: 321; 2010: 821), Winkler (2017), and Winkler and Marquard (2009: 53), retrofitting of a building involves any upgrade that improves the building's energy efficiency and environmental performance. The aim of adapting and retrofitting an existing building is to reduce water use, improve spatial comfort and quality in terms of natural light and ventilation, and reduce the total energy consumption of the building. For the purpose of this study, an energy retrofit means adapting the electrical, mechanical, and structural components of existing buildings with new green energy-efficient technologies. Through an integrated design process, so as to create a high-energy performance building that will significantly contribute to mitigation of climate change.

Retrofitting of existing buildings has internationally been identified as a strategy for improving the financial, environmental and social performance of buildings (Langston, Wong, Hui and Shen, 2008: 18). Kurul (2007: 2) suggests that adopting this process could significantly contribute to mitigation of climate change, by reducing CO_2 emissions. Hills (2009: 12) reports that China Resources Property Ltd, a leading development company that initiated retrofitting of the 50-storey China Resources Building constructed in Wan Chai, Hong Kong, in 1983, believes that retrofitting existing buildings is more cost-effective than redevelopment. Amber Marie Beard explains that costs are a significant issue when considering whether to retrofit or to redevelop. Project investigations have indicated that retrofit of the China Resources Building would cost HK$600 million, but that demolition and reconstruction would cost twice as much (Hills, 2009: 12). The costs indicate that constructing a new energy-efficient building would cost US$1,282per square metre more on initial building costs alone.

Love et al (2011: 33) suggest that the costs of refurbishing an existing building to meet new sustainable standards only represent a cost premium of 12% of conventional refurbishment and maintenance costs. Milne (2012: 11) states that the cost premium in the US was estimated by professionals at 17%, while the actual cost premium of retrofitting an existing building represents only a 1.5% increase on conventional refurbishment and maintenance costs (Milne, 2012: 11). Additionally, demolition and redevelopment costs represent a considerable saving, which influences the financial bottom line. In most cases, reusing existing building assets can lower material and transport costs, energy consumption, and pollution.

Various authors, such as Shipley, Utz and Parsons (2006: 2), Unruh(2002: 321,2010: 821), and Winkler and Marquard(2009: 53), suggest that it is potentially less expensive to adapt and retrofit than to demolish and rebuild, as the structural components already exist, which typically shortens the contract periods. From a financial perspective, retrofitting can be more cost-effective if planned well, and landlords can continue to generate income from their properties during the retrofitting stage, as opposed to losing on rental income during redevelopment.

2.6.2 Process of retrofitting an existing building

In order to effectively carry out an energy retrofitting, it is important that the following guidelines be adhered to in order to achieve maximum results. Hoes et al. (2009: 297) posited that the following are paramount:

Assessment of the building: This can also be referred to as an “energy audit”. This involves baselining the building’s performance. This is done in order to understand the starting point; Planning: A proper understanding of the asset/building is required. One should ascertain what the intended primary use of the building going forward is and Implementation of the change; and measurement of performance: It is important that the improved results be measured, so that the market executives or internal stakeholders are able to understand that the initial capital outlay did result in the objective of a reduction in operating costs being achieved. Although it is important to identify the process of retrofitting, one needs to be aware that simply retrofitting a building will not result in the most effective reduction in energy consumption. The most effective reduction in energy consumption will only be achieved if and when the behaviour of the occupants of that building changes. Behaviour change, although an intangible measurable can have a significant impact on the ultimate success of an energy retrofit (Fulford, 2011: 17; Ma et al., 2012: 89). Fulford (2011: 17) pointed out that there are three elements that one will need to address when implementing an energy retrofit: firstly, gain an understanding of the issues and the behaviour of the occupants of the building; communicate the impact of changes to the occupants of the building; focus on collaboration, that is, "a carbon reduction programme is an opportunity to create a positive partnership between property managers and occupants where all parties are helping to achieve a common goal".

2.6.3 Benefits of retrofitting

The Green Building Council of South Africa published *The rands and sense of green building* in South Africa (Milne, 2012: 56), which presents the economic business case that supports green buildings from international experiences and local projects. The benefits and the barriers of green building across both new building and existing building retrofits are presented below for a sustainable business case that is based on three international studies. Milne (2012: 56), as cited in Steyn (2014: 23), states that no comparable research has been undertaken in South Africa, due to the relative immaturity of the South African green building industry.

Study 1: *Greening our built world: costs, benefits, and strategies* (2010) – Greg Kats. Study 2: *Sustainability and the dynamics of green building - new evidence on the financial performance of green office buildings in the USA* (research reported by the Royal Institution of Chartered Surveyors (RICS)) (2010) –Eicholtz, Kok and Quigley. Study 3: *Building better returns – a study of the financial performance of green office buildings in Australia* (research reported by the University of Western Sydney, Australia, and the University of Maastricht, Netherlands, in conjunction with Jones Lang LaSalle and the CBRE) (2011). The results of the above studies on the benefits and the challenges of green building are presented below.

Lower operating costs

According to the RICS report (Eicholtz et al., 2010), energy is the largest operating expense of a commercial building, representing 30% of operating expenses. A dramatic decrease in monthly operating costs can be achieved by reducing energy consumption by way of energy-efficient technologies. According to Bernstein and Russo (2011: 59), an average of 25–30% more energy efficiency and an average of 39% more water efficiency are achieved through green building. The projects in the GBCSA's *The rands and sense of green building* (Milne, 2012) report that Green Star SA-rated buildings achieve energy savings of 25–50% compared to buildings designed according to SANS 204 recommendations. Energy efficiency in commercial buildings can be achieved by way of efficient lighting, heating ventilation, HVAC control, elevators, and efficient appliances. The monthly operating costs of the building can be cut dramatically by reducing the energy consumption with these energy-efficient elements.

This change is evident in the retrofit of the Empire State Building in New York City, where implementation of energy-efficient technologies has achieved energy savings of 38–40%, reducing energy bills by US$4 million (R40,360,000) per year (Hills, 2009: 11; Milne, 2012:

73). Reduced energy consumption in green buildings is directly linked to the ratio of decreased operating costs. By implementing green energy-efficient technologies in buildings, the operating costs per year are reduced, saving on energy bills. This cost saving reduces the payback years of the initial green-initiative capital investment, as evident from the study by Bernstein and Mandyck (2013: 35).

Higher return on investment (ROI)

A number of studies conducted in the United States (US), Australia, and the United Kingdom (UK) aim to establish a link between green building and an improved ROI. According to Milne (2012: 62), these studies are only possible in international markets, where green building has a more mature database. In South Africa, the green-building market is still relatively young, and a true representation of the benefits of ROI, presented by green building, has not yet been established. The study by Bernstein and Russo (2011: 5) shows that 82% of green buildings in the US provide a better ROI than conventional buildings. In 2010, a study by Arup and Davis Langdon for the Property Council of Australia found that green building retrofits achieve a 10% better ROI from energy savings, as well as higher rental rates than conventional commercial buildings.

The study analyses a city-centre office tower, a peripheral-city high-rise, and a suburban office, all built in the 1980s. The findings provide clear evidence that retrofitting an existing building with green energy-efficient technologies – to achieve a minimum 4.5 stars NABERS (Australian Green Star) – provides a positive ROI (Hills, 2009: 11). The RICS report (Eichholtz et al., 2010) analyses 21,000 rentals and 6,000 sales buildings certified by the US Green Star rating system, known as the LEED (Leadership in Energy and Environmental Design) environmental assessment method. It concludes that the rental rates as well as the market value of commercial buildings are a great deal higher in green retrofitted buildings. The report also finds that a large number of green retrofitted buildings were built between 2007 and 2009. The ROI on green buildings has not been affected by the recent downturn in property markets (Milne, 2012: 62).

According to Steyn (2014: 25), green retrofitted buildings tend to achieve higher rental incomes than conventional buildings in Johannesburg. Green retrofitted buildings currently obtain average rental rates of R180/m² per month compared to conventional buildings in the same area, which realise an average rental of R140/m² per month. This trend may be attributed to the enhanced marketability and reduced risks that green retrofitted buildings offer, in addition to the mentioned benefits that green buildings have over conventional buildings (Steyn (2014: 25).

Enhanced marketability

Steyn (2014: 25) posited that increased media coverage on green retrofitted building initiatives in Green Star SA-rated buildings and a growing awareness of climate change initiatives in green building have resulted in a corporate trend. This is evident from reports by Frank Berkeley, Managing Executive of Ned bank Corporate Finance, and Albert Geldenhuys, Managing Director of Aurecon South Africa, who both maintain that the media coverage received in terms of their green retrofitted building offices has been substantial in marketing the companies' environmentally sustainable capabilities (Milne, 2012: 68). Bernstein and Mandyck (2013: 13) state that green retrofitted building is a market-driven initiative, and that tenants are seeking green buildings to enhance their corporate profile.

Reduced viability and risk

Electricity tariffs in South Africa have risen dramatically over the last five years (Bernstein and Mandyck, 2013: 13). Retrofitted buildings reduce the risks associated with the effects of these tariff hikes, because both energy consumption and the monthly overall costs are reduced. Government is increasing environmental sustainability within the built environment by implementing SANS 10400 part XA and initiating other climate change strategies. Further efforts are raised through the voluntary GBCSA rating. Retrofitted buildings are future-proofed against the planned carbon taxes and increased rates from policymakers and corporations, which demand energy efficiency in buildings (Beattie, 2011: 28; Milne, 2012: 69).

2.6.4 Barriers to retrofitting

The complexity of adapting an existing building for new uses poses a major challenge to retrofitting projects (Kurul, 2007: 2).: 4; Kurul, 2007: 2). Hence it is necessary to test the viability of adaptive reuse and retrofitting in existing buildings and to develop tools that will facilitate understanding and management of its complexity. Langston, Wong, Hui, and Shen, 2008), argue that "the promotion of adaptive reuse" will require government and prime candidates to implement financial incentives, as well as to broaden the experience of adaptive reuse and retrofitting of individuals in the market sector. Milne (2012: 94–117) identifies the factors discussed below as barriers to retrofitting.

2.6.4.1 Direct capital costs

The main barrier and focus of the property industry of retrofitted building is the perception that retrofitted building adds significantly to the capital costs. Morris (2013: 55) states that "the most common reason cited in studies for not implementing building energy retrofit designs is first cost". Frost and Sullivan (2014) reported in their study that South Africans share this perception of increased direct capital cost on implementing green retrofit.

2.6.4.2 Lack of knowledge

The Green Building Council of South Africa acknowledges that there is still a lack of understanding of the sustainability principles specific to green retrofit building (Milne, 2012: 107). Over the last three years, various courses offered by GBCSA have attracted over 3,000participants, which clearly indicates that there is a keen interest in obtaining green building knowledge (Milne, 2012: 107). The Green Building Council of Australia supports this view in the report *the dollars and sense of green buildings* (2016), which states that developers and building owners are aware of green building and the benefits that it poses. However, they lack the knowledge and skills to implement green building principles. In a US study, *breaking through the barriers to sustainable building*, by Miriam Landman (1999: 31), cited in Steyn (2014: 32), the findings indicate that only 8% of professionals in the built environment are frequently educated and updated on green building principles. The figure will be less in the South African context.

2.6.4.3 Lack of evidence to inform valuations

The global built environment valuation sector and prospective buyers have yet to recognise the benefits presented by retrofitted buildings. According to Steyn (2014: 34), retrofitted building benefits in terms of financial calculations have not yet been quantified, and therefore the value of these buildings has not yet been established. Milne (2012: 108) reports on an interview with Trevor King, property valuation manager of Old Mutual Property, where he states that "the valuation of retrofitted buildings will be evidence based. A greater pool of rated green retrofitted buildings in South Africa is required to have been bought and sold to establish the true value of green building".

2.6.4.4 Lack of research

Due to the relatively immature nature of South Africa's green building industry, there is a lack of studies to provide evidence of the costs and financial benefits of retrofitted building in South Africa, and especially the advantages of retrofitting existing buildings. The GBCSA emphasises the need for relevant research on green buildings in South Africa, as well as on capital cost impacts and the income and valuation impacts of retrofitted buildings, to make a good business case for future retrofitted building.

The following recommendations for the implementation of green building initiatives are made by the Green Building Council of Australia in *The dollars and sense of green buildings* (2006), as well as by the GBCSA in *The rand and sense of green building* (Milne, 2012): firstly, increasing the commitment to national green building rating tools and coordination with building regulations, principles, standards and targets to provide clarity for the industry, especially related to the existing building stock, increasing government policy and regulations to ensure that consistent minimum green standards are applied across all building codes. Establish a range of green building educational programmes within tertiary institutions to increase the uptake of green building practices and improve the understanding of the skills and technologies of green building practices. Confirm government's leadership in and partnership with the industry to support the industry's uptake of green building practices, and attach financial incentives to improving the environmental performance of existing buildings and using green building technology to accelerate the transition of the industry (state and local planning incentives and concessions, as well as special tax deductions for green building practices, should be encouraged).

2.6.4.5 Commercial risk and uncertainty

Retrofits can pose a complex challenge, which contractors are hesitant to take on, as difficult renovations may decrease profit margins (Steyn, 2014: 34). This is often a result of the risks associated with reuse, which include unknown work and scope changes, compatibility and stability of materials, and design constraints. Reuse projects therefore require skilled specialists with experience in existing building renovations (Roth, Eklund and Simonsson, 2002). In some cases, the lack of accurate information and drawings of older existing buildings can thwart the reuse and retrofit of the building before the process has even begun (Love et al, 2011: 40). Even with the existing plans in hand; there is always uncertainty about what could be found, e.g. there could be pipes and wires in walls that weren't indicated on the plans (Hills, 2011: 13). Retrofit projects present with limitations on what can be done with the existing structure. Amber Marie Beard, project architect for China Resources Property Ltd, explains that "a major challenge around retrofits as opposed to redevelopment is the lack of freedom and the fact that you are stuck in an existing environment and layout" (Hills, 2009: 13).

2.6.4.6 Financial and technical barriers

Developers are of the opinion that retrofitting of existing buildings is not cost-effective, and that demolition and reconstruction is a better way to acquire a reasonable profit. Unfortunately, this has led to hundreds of older buildings being prematurely demolished (Shipley et al., 2006: 17). The Green Building Council of South Africa (Milne, 2012) and the Green Building Council of Australia (2006) suggest in their publications *the rand and sense of green building* and *the dollars and sense of green buildings*, respectively, that there is a perceived lack of value attached to the long-term benefits of green building initiatives. The extent of technical resources needed to solve the complexity of some existing retrofit projects hampers the adoption of retrofitting, which makes demolition an attractive, viable solution (Steyn, 2014: 35).

2.7 CONCLUSION

This chapter has provided an overview of extant research surrounding CO_2 emission abatement and the challenges that affect successful delivery of existing building energy retrofit. By exploring building energy management and its complexities, it is understood that managing such projects requires a set of unique skills and abilities, which requires new learning to be acquired and new methods to be adapted. Having successfully established the relationship between the various themes mentioned earlier, this study shall proceed to discuss the components of the theoretical framework.

CHAPTER 3: THEORETICAL FRAMEWORK

3.1 INTRODUCTION

This chapter discusses the central issues that relate to the conduct of this research. It presents the components of the research and the general framework for data collection and analysis. According to Anfara (2008: 872), a theoretical framework has the capability to reveal the significance and the understanding of a phenomenon, and it guides the research by allowing for prediction and increased understanding of the boundary criteria for the discipline. Green (2014: 34) concludes that adoption of a theoretical and a conceptual framework is a useful technique in developing an understandable research structure. This postulation is supported by Anfara (2008: 872), who believes that theory assists a researcher in development of a conceptual framework, and it shows them how to make logical sense of the interconnectedness of all the identified variables that are important in investigating a problem. Green (2014: 35) maintains that researchers build theoretical and conceptual frameworks to enhance integration of research findings into a more meaningful and coherent structure. Therefore, the focus of this chapter is to present and discuss the theoretical and conceptual frameworks on effective energy retrofit for existing government buildings.

3.2 NEED FOR THE STUDY

As a result of global warming and limited natural resources, countries around the world are keen on reducing their carbon footprint (National Refurbishment Centre, 2012: 13). The clamour for the built environment to contribute to reducing energy consumption has necessitated that researchers explore various ways of reducing the rate of carbon emission through effective energy retrofit. Due to its many constraints and limitations, retrofitting buildings for energy efficiency is considered an interdisciplinary process where several factors need to be involved (Godwin, 2011: 14). These factors together influence the type and the extent of the project, making each retrofitting project a unique and complex optimisation problem.

The term "energy retrofit" is defined as the installation of individual or multiple energy efficiency measures to an existing building (Langston et al., 2008: 18). According to Lombard (2012: 2), existing buildings in South Africa are responsible for 3.5% of final energy consumption, with the majority of the energy being used to power heating, ventilation and air conditioning (HVAC) systems, lighting, and office equipment. The South African Property Owners Association (SAPOA) (2010: 3) posits that electricity is the primary component contributing to the running costs of buildings, and the cost of electricity will inherently have an impact on the overall profitability of their companies. There are a number of ways in which one could reduce energy consumption within a building. The simplest way to ensure that buildings consume less energy is to build new sustainable buildings. However, for existing buildings, retrofitting is the way forward. Energy retrofitting is a fairly new concept, which needs to be understood and further explored within the South African context.

The historical availability of relatively cheap electricity within South Africa is felt to be one of the primary reasons why existing buildings have been designed and built in such a way that they have performed poorly regarding energy consumption (Lombard, 2012: 5). It is generally accepted by the property industry that retrofitting of a building will result in a number of associated benefits (Clinch and Healy, 2010: 115). Kurul (2007: 2) posits that adopting this process could significantly contribute to mitigation of climate change, by reducing CO_2 emissions. But the challenges due to its complexities need to be overcome. In addition, various attempts at energy retrofitting have been documented across the globe, in the form of working documents, guidelines, and academic publications. Yet some gaps have been established after a review of these documents pertaining to energy retrofit. The gaps identified form the basis of this research. Table 3.1 summarises the gaps for effective retrofitting.

Table 3. 1: Gaps identified for effective retrofitting of existing buildings

Gap	Author(s)
Non-interaction of the social elements of the socio-technical system with the technical aspects	A study by Swan and Brown (2013: 181) reveals that the successful retrofitting of buildings to improve energy performance is not simply a technological challenge. It is a complex socio-technical problem that needs to be addressed in a coordinated way, utilising skills and knowledge from a range of industrial, technical and social backgrounds (Swan and Brown, 2013: 183). Amongst the complex socio-technical challenges are retrofit technologies, human factors, building-specific information, client resources and expectations, and other uncertainty factors, as observed by Ma et al. (2012: 891).
	Performance gap issues in housing retrofit projects are a major challenge in the field. Closing the gap in such projects could potentially make a novel contribution to major reduction in energy consumption, by delivering design predictions (Bayat, 2014: 1).
	Inadequacy of retrofit measures is identified as one of the major retrofit challenges, as the effectiveness of technological measures is unreliable (Davies and Osmani, 2011: 294). Swan, Ruddock, Smith and Fitton (2013: 181) conducted a detailed investigation assessing the effectiveness of retrofit measures, which validates such perceptions. Dowson, Poole, Harrison and Susman (2012: 295) share the same view, suggesting that retrofit measures using technology "may only be half as effective as anticipated". This indicates that the retrofit measures (technology alone) are to a certain extent unreliable, which effectively has a direct impact on the efficiency of retrofit design integration.
Organisational culture/behavioural problem	Koshman and Ulyanova (2014: 38) opined that human beings are an integral part of the energy-management system, but many energy-saving measures focus only on technologies and appliances. Karvonen (2013: 564)

	concluded that effective energy efficiency upgrades can be achieved through the development and realisation of customised solutions to each house, through facilitated engagement between occupants, housing providers, and construction professionals.
	A study conducted by Hermelink (2005: 437) reveals that technical measures alone in retrofitting do not lead to attainment of the forecasted results. The author argues that human factors should be considered during retrofitting, to bring about the desired levels of effectiveness.
The problem of change management	A significant impediment to implementation of long-term energy retrofitting plans is the inability to cater for the behaviour of building occupants (Natural Resources Canada, 2015: 4). Behaviour change, although an intangible measurable, can have a significant impact on the ultimate success of an energy retrofit (Fulford, 2011: 12).
	According to Natural Resources Canada (2015: 5), energy retrofit management is more about change management than engineering, and buildings are dynamic environments that must evolve to maintain the value they provide to their owners and occupants. According to Karvonen (2013: 564), to realise significant reductions in energy demand, it is imperative to incorporate changes in stakeholders' understanding and social practices (habits, perceptions, and motivations), coupled with physical interventions.

Source: (Researcher, 2018)

Among the most common themes identified in building energy research, human factors have been found to be the most important factor (Swan and Brown, 2013: 183). Despite this observation, current retrofitting measures have continued to downplay the level of consideration accorded to this factor. There is a need to evolve a mechanism by which industry stakeholders will be better informed about effective energy retrofit. There are a few ways to address this gap, such as understanding the variables/elements that make up effective retrofitting, understanding the dynamics of the constituent elements, analysing the relationship between the elements, and adapting the elements in such a way as to facilitate effective retrofitting.

Consistent with research by other scholars, there is empirical evidence to support a positive link between complex elements that influence effective retrofitting (Ma et al., 2012: 891). The relationship has been well established in building energy research, and its consequences are recognised as crucial indicators for improved building energy retrofit. Analysis and integration of these key elements of retrofitting (socio-technical aspects) has been shown to be generally predictive of effective retrofitting (Ma et al., 2012: 891), but more research is needed to identify and integrate the elements that are associated with effectiveness of building retrofit (Karvonen, 2013: 564). This research gap is depicted in Figure 3.1.

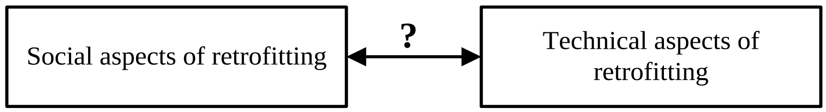


Figure 3. 1 : The missing link between the social aspects of retrofitting and the technical aspects of retrofitting (Source: Researcher, 2018)

The mechanism of effective retrofitting within existing buildings is not well understood, especially when it concerns integration of socio-technical components (Karvonen, 2013: 564). In this context, this research seeks to make an attempt at understanding the retrofitting phenomenon through a socio-technical systems perspective. Pertaining to the social aspects of this socio-technical systems perspective, this study seeks to explore the influence of human factors associated with building occupants on the design and delivery of building energy projects.

3.3THEORETICAL LENS

A growing trend in the social, technical and behavioural science research is to think about and attempt to understand specific research problems from an interdisciplinary view (Frodeman et al., 2010: 112; Jaccard and Jacoby, 2009: 73). A theoretical framework is the 'blueprint' for an inquiry (Frodeman et al., 2010: 112). As such, this section briefly highlights the theories influencing the study.

3.3.1 Systems thinking theory

Systems thinking can be used in solving complex problems that are not solvable using conventional reductionist thinking (Mele, Pels and Polese, 2010: 126). Since Aristotle's posit that knowledge is derived from the understanding of the whole, and not that of the single parts, researchers have been struggling with systems and parts in terms of their contents and their relative dynamics (Mele et al., 2010: 126). This historical effort evolved during the last century into "systems theory" (Bogdanov, 1922: ii; 1980: 182; Laszlo, 1996: 32; Meadows, 2008: 13; Von Bertalanffy, 1968: 42). In the same vein, Checkland (1981: 117; 1999: 145) confirmed that systems thinking theory usually consists of a set of distinct elements linked together to form a whole, showing, in the process, properties of the whole, instead of properties of its component parts. A system can be defined as an entity, which is a coherent whole (Ng et al., 2009: 337), such that a boundary is perceived around it in order to distinguish internal and external elements and to identify input and output relating to and emerging from the entity.

Generally, retrofitting exercises are complex, contradictory, and iterative. Yet their constituent elements are considered in relative isolation. The creative response is to identify the key elements and their interrelationships, which helps explains building energy retrofit. It has also helped in providing a new approach that allows synergetic interaction between different elements, thus increasing the possibility of innovative, trans-disciplinary solutions to retrofitting issues. The concept of the systems thinking perspective was reviewed based on the premise of associated elements and the complexity construct involved in the delivery of effective building retrofit, especially as it concerns those projects being delivered through the government.

3.3.2Chaos theory

Various scholars in diverse fields (Ayers, 1997: 373; Elbert et al. 2014: 234; Eve, Horsfall and Lee, 2011: 13) have contended that instability, dynamicity, evolution, and change from the very nature of every system. This thesis argues that such traits are embedded in the system characteristics. Systems are always subject to constraints, threats, dynamics, imposed changes, and voluntary changes (Ayers, 1997: 373). The proposition of chaos theory is that systems are located in the hub of a chaotic galaxy. This notion applies to systems that have a greater degree of complexity and dynamicity.

The theory contends that not all systems obey randomness; some systems can be defined and bounded by mathematical functions, depending on the controllability of initial and subsequent conditions (Townsend, 1992: 29).

Chaos theory and its concepts are being used by researchers from across different disciplines, ranging from information technology to engineering to economics to social sciences to cognitive, developmental and clinical psychology (Bonting, 2005: 77; Eve et al., 2011: 14;Guastello, Koopmans and Pincus, 2009: 77).Consideration of chaos theory involves understanding the interdependencies, interrelationships and interconnections between technology (e.g. tools and equipment), work tasks and processes, and human factors (Challenger and Clegg, 2011: 343).

An important implication of this approach to retrofitting systems is the understanding that changes to one aspect will undoubtedly affect other aspects (Challenger and Clegg, 2011: 344). The series of concepts guiding retrofitting includes simple design informed by the end user, congruence between all parts of the system and with organisational behaviourism, integrated task perspectives, and the enabling of local experts to problem-solve and adapt systems appropriately (Clegg, 2010: 464). Using a chaos theory perspective to understand existing systems in the energy management space helps to identify disconnects between technology and human factors that are systemically supported by the retrofitting design (Tucker and Topi, 2013). A research study by Tucker and Topi (2013: 4) concurred that chaos theory is premised on the interdependent and inextricably linked relationships among the features of any technological object or system and the social norms, rules of use and participation by a broad range of human stakeholders. The review of chaos theory in this study was informed to probe deeper into the interaction between human factors and technology, and using such knowledge to bring about synergy in the whole system.

3.3.3Complex adaptive systems theory

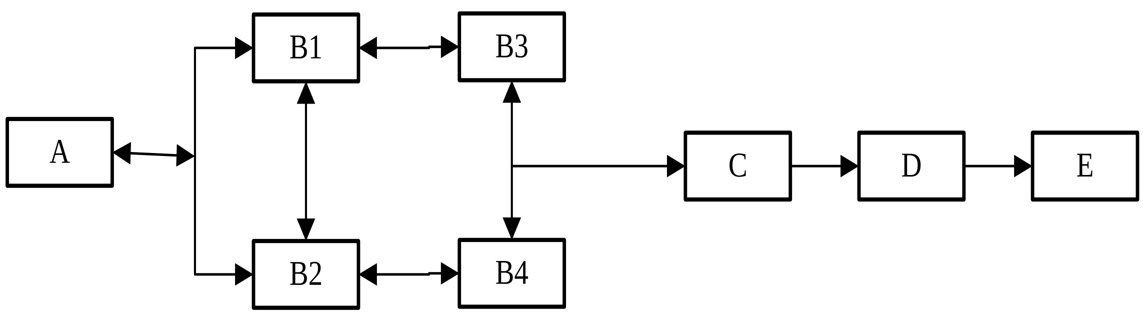
Retrofit addresses issues from the simple (with well-known cause-effect links) to the highly complex (webs and loops of cause-effect with unpredictable, emergent properties). Yet there is no conceptual framework within its theory base to help identify approaches appropriate to the level of complexity. The default approach favours reductionism (the assumption that reducing a system to its parts will inform whole-system behaviour). Such an approach can yield useful knowledge, but it is inadequate where issues have multiple interacting causes, such as social and technical determinants of effective energy retrofit. To address the complexities of retrofitting, there is a need for a conceptual framework that helps choose action that is appropriate to context. These problems prompt the use of complexity science – the study of complex adaptive systems (CAS). Complexity results from the interrelationship, the interaction and the interconnectivity of elements within a system and between a system and its environment (Chan, 2001: 11). According to MacLennan (2012: 3), a complex adaptive system is a collection of individual systems with freedom to act in ways that are not always totally predictable, and whose actions are interconnected, so that one system's actions change the context for other systems.

The CAS model is complex in that it is a dynamic network of interactions, and the relationships are not aggregations of the individual static entities, i.e., the behaviour of the ensemble is not predicted by the behaviour of the components. They are adaptive in that the individual and collective behaviour mutate and self-organise corresponding to the change, initiating micro-events or a collection of events (Gupta and Anish, 2012: 17; Millerand Page, 2007: 6; Mitleton-Kelly, 2012: 13).

The CAS model is a complex macroscopic collection of relatively similar and partially connected micro-structures formed in order to adapt to the changing environment and increase their survivability as a macro-structure(Gupta and Anish, 2012: 17; MacLennan, 2012: 3; Mitleton-Kelly, 2012: 13).The urgency to address critical issues such as carbon emission, which involves the social and technical determinants of building energy retrofit, calls for this study to engage with complexity science. Thovhakale, McKay and Meeuwis (2013: 57) make it clear that retrofitting is an example par excellence of a chaotic and complex system. To resolve these traps, this means the following variables in the chaotic and complexity domain in the context of effective retrofitting must be identified and resolved. In the study of Ma et al. (2012: 892), they concur that effective retrofitting can be influenced by the following complex elements: human factors; the retrofit programme; end user energy management; material culture; and best practice of retrofitting.

Therefore, maximising the potential for carbon emission reduction requires much deeper understanding of how different factors interact in existing buildings. A study by Kelly (2011: 2) indicates that human factors are as important as the physical characteristics of a building in influencing energy use, and that carbon emission from buildings are most sensitive to internal temperature changes, which are largely dependent on human behaviour. By understanding the interaction between socio-technical variables, the complexities of retrofitting and the relationships affecting energy use will be untangled (Kelly, 2011: 2; Shipworth, 2000: 26). The phenomenon of building energy retrofitting can be understood as the phenomena of complex adaptive systems. For the purposes of this study, the approach to industry innovation and learning adopted for the delivery of building energy retrofit is arguably situated in the CAS.

The CAS model provides the platform for unravelling the complexities, chaotic nature, relationships, cooperation, continuous improvement, dynamism, opportunities and adaptability for further innovation in all critical segments of energy retrofitting processes. The entire system of retrofitting can be seen as a network of relationships and interactions, in which the whole is very much more than the sum of the parts. A change in any part of the system, even in a single element, can result in reactions and changes in associated elements and the environment. Therefore, the effects of any one intervention in the system cannot be predicted with complete accuracy, because the system is always responding and adapting to changes and to the actions of individual elements. In practice, this idea urges recognition of the multiplicity of associations that shape effective retrofit. A complex adaptive systems framework for effective retrofitting would encompass energy retrofit best practice, human factors, end user energy management, the retrofit programme, and material culture. Furthermore, these relationships are non-linear, and causation is multidirectional, so that simple causal relations between dependent and independent factors are difficult to isolate. Causes are also outcomes. For example, people's adoption of technology will be as a result of end user energy management, which will, in turn, help in reducing dissipation of energy in the building. The study focused on the way in which interventions in the system affect effective building energy retrofit. In the proposed conceptual framework provided in Figure 3.2, a detailed mapping of such linkages, in order to explore, understand, resolve and adapt the complexities of retrofit systems, is shown.



Where
A = Identification of key elements involved in energy retrofit of an existing building
B1 = human factor
B2 = retrofit programme
B3 = material culture
B4 = best practice for building energy retrofit/end-user energy management
C = complex adaptive system
D = improved delivery for BERP
E = carbon emission reduction

Figure 3. 2 : Conceptual framework (Source: Researcher, 2018)

The conceptual framework was adapted to theoretically represent components of an effective energy retrofit. Specifically, the frameworkplaces effective energy retrofit and carbon emission reduction at the centre as it is, internally influenced by five broad areas: human factors (social viewpoints and attitudes towards energy), material culture (retrofit technologies and building fabric), retrofitting programme, end user energy management, and energy retrofit best practices. The framework illustrates how a holistic approach can be adopted to address optimal reduction of carbon in an existing building, as opposed to simply targeting one area. By investigating and improving the areas outlined in the framework, the study helped in improving delivery of BER in South Africa.

3.4 CONCLUSION

In this chapter, the justification for adopting the CAS model was stated. It provides the platform for unravelling the complexities, continuous improvement, and adaptability for further innovation in all critical segments of energy retrofitting processes. In the following chapter, the research methodology adopted for the study is discussed.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 INTRODUCTION

In this chapter, details of the procedure and the step-by-step method used to conduct the study are presented. The chapter also explains the research philosophy, research approach, research strategy, research choice, time horizon, techniques and procedures. The justifications for the choices made at each point are stated explicitly. It is expected that at the end of the chapter, the methodology applied in the collection of data, the subsequent analysis of the data, and the justification for the adoption of such a methodology will have been presented clearly. This chapter also discusses the ethical approval sought from and granted by CUT, which indicates the researcher's stance on matters of ethical concern.

Research is an organised way of exploring a problem to get the best solution (Gray, 2014: 3). A researcher's chosen research methodology provides the foundation for utilisation of a particular research philosophy, approach, strategy and choice. Leedy and Ormrod (2013: 2) posit that research methodology involves three processes, namely data collection, data analysis, and data interpretation, which are aimed at offering a better understanding of a phenomenon. Research methodology is a general approach to an inquiry. To some extent, this approach dictates which research method and tools are appropriate to use.

There is various conflicting terminology within the research methodology literature. This has resulted in the use of different terminology by different scholars to describe the same concept, thus making it imperative for authors to elucidate the particular nomenclature applied in their studies, so as to maintain consistency. For instance, while Saunders, Lewis and Thornhill (2012: 138) classify deduction, induction, and abduction as research approaches, Blaikie (2009: 44) describes them as research strategies. To maintain clarity and consistency in the study, this research relies solely on the terminology used by Saunders et al. (2012: 138).

4.2 RESEARCH PHILOSOPHY

According to Denzin and Lincoln (2011: 12), a research philosophy is a conviction of how data on a phenomenon should be gathered, analysed and presented. The research philosophy forms the basis for the choice of research design. Use of the appropriate research philosophy ensures a form of reference or standpoint of argument and leads to a smooth research process and reliable findings (Easterby-Smith, Thorpe and Jackson, 2012: 73). Easterby-Smith et al. (2012: 74) further explain that the research philosophy clarifies the research design and enables the researcher to understand what a more suitable design is to achieve the research objectives. The research design empowers the researcher to choose a research method that suits the type of investigation the study requires (Schensul, 2008: 516). Leedy and Ormrod (2013: 74) explain that the research design provides possible resolution of an identified research problem, by providing the researcher with an explicit strategy that suits the philosophical position adopted for the study. According to Tashakkori and Creswell (2008: 77), research methods are classified into three categories,namely qualitative research, quantitative research, and mixed-methods research.

Collis and Hussey (2013: 34) and Saunders et al. (2012: 138) assert that a research philosophy contains important assumptions about the way in which the researcher views the world and the assumptions that underpin their adopted strategies and methods.

4.2.1 Positivism –a deductive approach leading to quantitative methods

The research philosophy of positivism places emphasis on the generalisability of the research findings beyond the sample of a piece of research. It requires having a representation of the data from a defined population, and it will generally involve a statistical test of significance, to accord some measure of confidence in the results and the conclusions that are drawn from them (Tan, 2004: 38). Saunders et al. (2012: 138) explain that if a researcher's research reflects the philosophy of positivism, they will prefer working with an observable social reality, and that the end product of such research can be law-like generalisations similar to those produced by the physical and natural scientists. To generate a research strategy to collect the data, you are likely to use existing theory to develop hypotheses. These hypotheses will be tested and confirmed, in whole or in part, or refuted, leading to further development of theory, which may be tested by future research (Saunders et al., 2012: 138). Positivism asserts that a theory, phenomenon or law is only regarded as knowledge if, and only if, it is observable and measurable (Collis and Hussey, 2013: 77). In terms of research strategy, Essa (2008: 77) and Punch (2015: 55) contend that positivism adopts methodologies that are purely quantitative, and which, by implication, align with data collection and analysis that portrays quantitative methods.

This type of research method emphasises the significance of systematic techniques and procedures, which are employed in the natural sciences, where collection and analysis of data in numerical form is involved (Leedy and Ormrod, 2010: 121), as it focuses on the process of testing hypotheses (Leedy and Ormrod, 2010: 121). Leedy and Ormrod (2010: 121) view the quantitative research method as an attempt to seek and collect factual data, and to study the relationships between them. The information derived is usually in the form of numbers, which are quantified and summarised. The analysis of data produces empirical results and conclusions, which are drawn from the observations. According to Sutrisna (2009: 57–58), the quantitative researcher formulates a list of behaviours to be checked or rated by an observer, using a predetermined schedule or number scale as an instrument. As such, the quantitative researcher needs to construct an instrument to be administered in a standardised manner and according to the predetermined procedures. In doing this, the researcher must ensure that the instrument measures what it is supposed to measure. Sutrisna (2009: 57–58) argues that quantitative research emphasises measurement and analysis of causal relationships between variables, and it utilises charts and graphs to illustrate the results.

Briefly, quantitative research entails the use of standardised measures, such as structured questionnaires, to accommodate the perspectives of people in a limited number of predetermined response categories, to which number scales are assigned (Sutrisna, 2009: 57). In so doing, the researcher must ensure that the instrument measures what it is intended to measure. The significance of this test is to ensure reliability, or repeatability, of the results. In this view, positivists support quantitative research, or scientific paradigms that refer to the world as made up of observable and measurable facts (Patton, 2012: 48).

4.2.2 Interpretivism – an inductive approach leading to qualitative methods

Interpretivism-informed research is focused on understanding the phenomenon as it is, because interpretivism advocates and supports the idea that reality depends on the perceptions of the person (Fellows and Liu, 2015: 223). Various researchers (Creswell, 2013b: 71; Crotty, 1998: 77; Lincoln and Guba, 2010; Neuman, 2006: 23) view the interpretivist research philosophy and paradigm as an approach to qualitative research that, according to Blaikie (2009) and Bryman (2008), holds a sharp contrasting epistemology to positivism. This research paradigm seeks the understanding or meaning of phenomena subjectively through participants that make up this paradigm (Creswell, 2013b: 71). Interpretivism usually adopts qualitative research methods, which enables the researcher to carry out extensive discussions with a group of participants to examine issues (Creswell, 2013b: 71).

Qualitative research methods use a naturalistic approach to uncover and understand phenomena in their framework of specific settings. Qualitative research is commonly employed in studying complex situations, particularly research involving human perceptions, opinions and experiences (Guest, Namey and Mitchell, 2013: 2; Sutrisna, 2009: 57). According to Marshall and Rossman (2011:3), qualitative research is a broad approach for investigating social phenomena. Qualitative research, however, highlights the qualities of the phenomenon under study, rather than the numerical measurement aspects of the research. In using qualitative research methods, the researcher conceptualises ideas from the viewpoint that real-world phenomena need to be assessed within the context of that social reality. In broad terms, any kind of research that produces findings that are not obtained from statistical procedures or other quantitative means can be regarded as qualitative research (Marshall and Rossman, 2011: 3).

Guest et al. (2013: 2) explainthat qualitative research methods are often employed to answer the "why" and the "how" of human behaviour, opinion and experience. It is usually where useful and in-depth information seems difficult to obtain through a quantitative-oriented method of data collection that aqualitative research method would be more appropriate to be used. Qualitative research involves multiple methods of research inquiry, such as naturalistic inquiry, interpretive inquiry, and critical reflection. Leedy and Ormrod (2013:152) explainthat qualitative methods involve different designs, such as case study, ethnography, phenomenological study, grounded theory, content analysis, and in-depth interviewing.

4.2.3 Pragmatism

Pragmatism is founded on the assumption of finding a solution to a research problem. Creswell (2013b: 77) contends that pragmatist researchers mainly focus on the "what" and the "how" of the research problem, by applying all the methods based on the criterion they think will work best in answering their research questions, utilising both qualitative and quantitative approaches. Following on from this, pragmatic researchers realise that research methods have some shortcomings, and that they can use different research techniques at the same time.

This study has adopted the research philosophy of pragmatism, for three main reasons, namely the nature of the research problem, the data and the methods of collecting this data, and the purpose of the research. The research problem, as discussed in chapter 1of this thesis, entails answering a number of research questions in order to fulfil the aim and the objectives of the research. This includes answering questions relating to “what” and “how”, and, as such; it means that no single approach can be used to answer those questions. This informed the decision to use a method that combines both the qualitative and the quantitative research strategies.

“Mixed-methods approach” is the general term for the use of both quantitative and qualitative data-collection techniques and analysis procedures in a research design. For example, the researcher collects and analyses the data, integrates the findings, and draws inferences using textual and statistical data in a single study. The mixed-methods approach is recognised as an approach that addresses the weaknesses of both the qualitative and the quantitative methods, by conducting these methods separately, and by balancing the weaknesses of one method with the relative strengths of the other method (Creswell, 2008: 529). Based on the pragmatic philosophical stance of the research, mixed-methods research was chosen as the most appropriate research approach. The choice of this approach was necessitated by the nature of the research questions and the objectives.

4.3 RESEARCH STRATEGY

Saunders et al. (2012: 138) define research strategy as the strategy that the researcher intends to apply in providing answers to the research questions. The research strategy provides a framework for understanding the research. A number of factors govern the choice of research strategy, including the research objectives, the research questions, the research philosophy, and the time and resources available for the research (Saunders et al., 2012: 144). A brief description of selected strategies is presented in the following subsections.

4.3.1 Survey

The survey strategy is usually associated with the deductive approach and is most used to answer “who”, “what”, “where”, “how much” and “how many” questions (Saunders et al., 2012: 144). It tends to be used for exploratory and descriptive research. Surveys are popular, as they allow the collection of a large amount of data from a sizeable population in a highly economical way (Cooper and Emory, 1991: 11; Sutrisna, 2009: 57). Often obtained by using a questionnaire administered to a sample, this data is standardised, allowing easy comparison. In addition, the survey strategy is perceived as authoritative by people in general, and is comparatively easy both to explain and to understand (Marshall and Rossman, 2011: 3). The survey strategy allows you to collect quantitative data, which you can analyse quantitatively, using descriptive and inferential statistics.

4.3.2 Archival research

The archival research strategy allows research questions which focus on the past and changes over time to be answered, be they exploratory, descriptive, or explanatory. However, your ability to answer such questions will inevitably be constrained by the nature of the administrative records and documents, which Tan (2004: 17) considers as a limitation. Even where these records exist, they may not contain the exact information needed to answer your research question(s) or to meet your objectives.

4.3.3 Case study

The research strategy of case study involves an empirical investigation of a contemporary phenomenon within its real-life context, using multiple sources of evidence (Robson, 2002: 178). Yin (2014: 77) also highlights the importance of context, adding that within a case study, the boundaries between the phenomenon being studied and the context within which it is being studied are not evident. The case study strategy will be of particular interest to you if you wish to gain a rich understanding of the context of the research and the processes being enacted (Morris and Wood, 2011: 260). According to Robson (2002: 178) and Saunders et al. (2012: 178), the case study strategy has considerable ability to generate answers to the question “why?”, as well as the questions “what?” and “how?.” For this reason, data-collection techniques employed may be diverse and are likely to be used in combination. They may include, for example, interviews, observation, document analysis, and questionnaires, which are triangulated.

4.3.4 Phenomenology

Phenomenology is a qualitative research method that is used to describe how human beings experience a certain phenomenon (Giorgi, 2012: 12). A phenomenological study attempts to set aside biases and preconceived assumptions about human experiences, feelings and responses to a particular situation. It allows the researcher to delve into the perceptions, perspectives, understandings and feelings of those people who have actually experienced or lived the phenomenon or situation of interest (Moustakas, 1994: 33; Starks and Brown Trinidad, 2017: 1372). Therefore, phenomenology can be defined as the direct investigation and description of phenomena as consciously experienced by people living those experiences (Polkinghorne, 1989: 41). Phenomenological research is typically conducted through the use of in-depth interviews of small samples of participants. By studying the perspectives of multiple participants, a researcher can begin to make generalisations regarding what it is like to experience a certain phenomenon from the perspective of those that have lived the experience.

4.3.5 Research strategies suitable for this study

A combination of phenomenology, case study, archival research, and survey was appropriate for realising the research objectives, given the mixed-methods nature of the inquiry. Two stages of qualitative and quantitative data-collection approaches were adopted. In order to provide insights into the central question and the sub-questions of the study, a semi-structured interview, archival research in the form of document analysis, and the case study research method were adopted during the first phase of the study, to obtain information on the different workings of energy retrofit and how building energy retrofit has been carried out across the globe. The case study method was deemed to be appropriate because it enabled observations in order to obtain data for theory building, without the strict requirement of representative sampling of the project data.

During the second phase of the study, the data was triangulated through the feedback from respondents’ responses to the questionnaire survey. The essence at this stage was to test the theories developed from the first phase of the qualitative data gathering. This helped to improve the reliability and the validity of the findings.

4.4 RESEARCH TIME HORIZON

The research is situated in a cross-sectional time horizon, as it studies a particular phenomenon, and most research projects undertaken for academic purposes are time-constrained (Saunders et al., 2012: 155).

4.5 RESEARCH TECHNIQUES AND PROCEDURES

The research techniques can be used to depict the research process used in a study. As illustrated in Figure 4.1, the framework shows the various stages in the research process, which are discussed in the following subsections.

The results of the literature review led to understanding of the research problem, and the information therein responded to the research questions and also helped in formulation and refining of the research instruments. This was necessary because it allowed the study to select the most appropriate approach for unravelling various complexities in the retrofit domain.

4.5.1 Data-collection procedures

According to Leedy and Ormrod (2009: 9), data is information in an unorganised manner. Data contains a finite set of information that must be sorted, processed and presented in a recognised format to draw a valid conclusion (Leedy and Ormrod, 2009: 93). A study of this nature requires a mixed-methods design, which requires a combination of quantitative and qualitative research data in a single study. According to Yin (2014: 106), there are six sources of data commonly used in mixed-methods research (see Table 4.1). Table 4.1 illustrates the strengths and weaknesses of the various sources of data available for use in mixed-methods research.

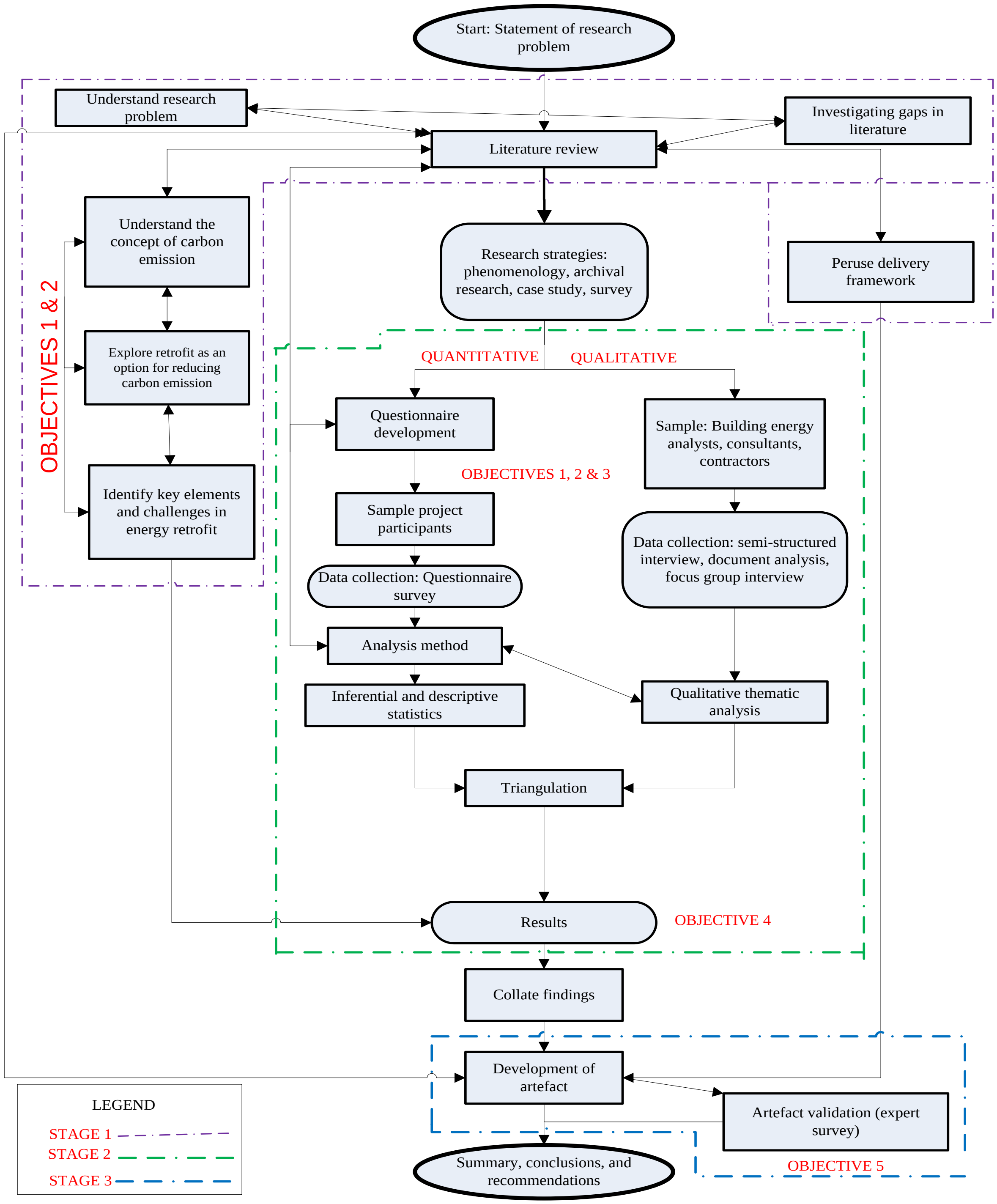


Figure 4. 1 : The methodological framework for the research

Table 4. 1 : The strengths and weaknesses of sources of data

Source	**Strengths**	**Weaknesses**
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of a case study • Specific – can contain the exact names, references, and details • Broad – can cover a long span of time and many events	• Irretrievability – can be difficult to find • Biased selectivity if collection is incomplete • Reporting bias – reflects • Access – deliberately withheld
Archival records	• [Same as in documentation] • Precise and usually quantitative	• [Same as in documentation] • Accessibility due to privacy reasons
Interviews	• Targeted – focuses directly on case study topics • Insightful – provides explanations as well as personal views (e.g. perceptions, attitudes, and meanings)	• Bias due to poorly articulated questions • Response bias • Inaccuracies due to poor recall • Reflexivity – interviewee gives what interviewer wants to hear
Direct observations	• Immediacy – covers actions in real time • Contextual – can cover the case's context	• Time-consuming • Selectivity – broad coverage difficult without a team of observers • Reflexivity – actions may proceed differently because they are being observed • Cost – hours needed by human observers
Participant observation	• [Same as in direct observations] • Insightful into interpersonal behaviour and motives	• [Same as in direct observations] • Bias due to observer's manipulation of events
Physical artefacts	• Insightful into cultural features • Insightful into technical	• Selectivity • Availability

	operation	

Source: (Yin, 2014: 106)

The researcher is cognisant of the aforementioned strengths and weaknesses of the various tools in the study. The highlighted weaknesses were addressed through complementarities of mixed methods.

4.5.2 Qualitative data collection

The research techniques used in the qualitative data collection seek to gain in-depth understanding of the research problem. The qualitative strategy gathered textual data, which tends to be detailed and rich in content and scope (Fellows and Liu, 2015: 29). This data was systematically gathered, keeping in mind the analytical procedure, which would reveal patterns and insights (Yin, 2014: 135). Furthermore, Miles, Huberman and Saldaña (2014:10)indicate that the strength of qualitative research data is that it focuses on natural occurrence, for instance ordinary events in natural settings (close proximity to a specific situation). Supporting this view, Guest et al. (2013: 21) assert that the strength of utilising the qualitative method is that it creates an advantageous avenue to adopt open-ended questions.This has the capability to provide vital information that the researcher did not anticipate to emerge. As such, this method yielded useful and credibleinformation regarding the study. Interviews, document analysis, and observations are the most common tools employed by qualitative researchers. Based on this, the research tools deployed in the data collection in this study were interviews, document analysis, and direct observation.

Interviews

In qualitative interviews, the researcher seeks more depth and plans interview questions in advance, organising them so that they are linked to one another, so as to obtain the information needed to complete the whole picture (Rubin and Rubin, 2005: 47; Minichielle, Aroni, and Hays, 2008: 89). Through such interviews, the researcher explores and learns to see the world from perspectives other than their own (Rubin and Rubin, 2005: 4; Wengraf, 2001: 114). To get such depth and detail, Rubin and Rubin (2005: 51) advocated that the interviewer must structure the interview around three types of linked questions: main questions, probe questions, and follow-up questions. Hesse-Biber and Leavy (2011: 102–103) identified three categories of interview: structured interviews, semi-structured interviews, and open-ended interviews.

Semi-structured interview variants were deployed for the interview sessions in this stage of the research, with the adoption of both closed and open-ended predetermined questions (see Appendix 1). The semi-structured interview approach enhances research reliability through process standardisation and replicability (Hesse-Biber and Leavy, 2011: 102; Minichielle, Aroni, and Hays, 2008: 89). The predetermined questions were answered by the selected practitioners in the project teams. Purposive sampling was also used to determine the views of the interviewees. Prior to the main interview session, a pilot study interview was carried out among academics and experienced role players in the retrofit trade to test and refine the interview protocol. This refinement was necessary in order to obtain the input of experts in the research instrument. This protocol was then sent to the participants of the selected live cases before obtaining invitations for the interview session.

The interviews lasted an average of 45 minutes and were recorded, and notes were taken. The permission of the interviewees was sought and obtained for recording before commencement of the interviews. In addition, focus group interviews were also employed in the study. Carson, Gilmore, Perry and Grønhaug (2001: 23) define a focus group interview as a group interview that focuses clearly on a particular issue, product, service or topic and includes the need for interactive discussion amongst participants. Other scholars define a focus group as" a group of interacting individuals having some common interest or characteristics, brought together by a moderator, who uses the group and its interaction as a way to gain information about a specific or focused issue" (Kvale and Brinkmann, 2009: 37; Minichielle, Aroni, and Hays, 2008: 89).This means that, in comparison with other forms of group interview, individual group members' interactions and responses are both encouraged and more closely controlled to maintain the focus. Participants are selected because they have certain characteristics in common that relate to the topic being discussed, and they are encouraged to discuss and share their points of view without any pressure to reach consensus (Krueger and Casey, 2015: 111). Use of focus group interviews in this study was premised on the need to elucidate the perceptions of respondents to the study, so that consensus and differences would have credible explanations.

Document analysis

The use of archival records provided information, which helped in drafting the interview guide, as well as in resolving any biases established from the interviews (Saunders et al., 2012: 155). The study examined retrofitted case-study building projects undertaken across the globe where useful information pertaining to the study was gathered.

Direct observation

The selected live cases were physically observed through a visit to the facilities. The purpose was to help confirm the various claims made about the building, using the observation protocol developed based on the claims by the interviewees. Physical observation allowed the researcher the ability to physically see the energy retrofit features and design concepts, and to ask relevant questions about the effectiveness of the deployed technologies. This qualitative evidence would be deployed to make sense of the thread of narratives observed in the mixed data sources emanating from the eight selected live cases in this study (Gray, 2014: 9).

4.5.3 Quantitative data collection

According to Creswell (2009: 145), quantitative data collection (the survey) is one of the acclaimed best strategies often adopted in the collection of data, where the objective is to reach a larger portion of society, which would have been difficult to attain using other strategies. The research technique used in the quantitative data procedure is the administration of questionnaires attained through survey design. Survey design collects numerical descriptions of phenomena, such as trends, attitudes or opinions of selected samples that can be generalised to the population (Collis and Hussey 2013: 66; Creswell 2009: 145). The study adopted a questionnaire survey when the need arose to complement the qualitative strands of the data collection; a purposive questionnaire survey was developed in order to provide more insight into the subject matter. The respondents were identified from the South African National Energy Development Institute database and previous participants of the study. A mail survey was used, through administration of questionnaires to the practitioners.

4.6 DATA ANALYSIS

For a meaningful analytical strategy, Yin (2014: 168) contends that there are four principles underlying high-quality data analysis in good social science research: attend to all evidence, address all plausible rival interpretations if possible, address the most significant aspect of the case study, and adopt prior expert knowledge.

4.6.1Analysis of qualitative data

Qualitative data analysis involves the process of data reduction to reveal its characteristic elements and structure, by gaining new insights into the data. There are various analytical strategies for analysing qualitative data, with different data mechanics. The mechanics are not limited to content analysis, grounded theory, narrative analysis, and thematic analysis, among others (Gray, 2014: 607–622). This research adopts the pattern matching and thematic approach to data analysis.

4.6.2 Quantitative data analysis

The quantitative data was analysed statistically, adopting both descriptive and inferential analytical tools. The study deployed statistical tests such as mean percentage (MP) and mean score (MS) to reduce the data to reasonable units for gaining meaningful insight. The MS was used to rank the variables according to the participants' perception within the variables identified.

4.6.3 Data triangulation

The qualitative analysis adopted the pattern matching and thematic approach to data analysis. The triangulation process was aligned with this approach for mixing qualitative and quantitative data. The emerging themes from the qualitative analysed data and the conclusions from the quantitative strands were adopted for the artefact development.

4.7 VALIDITY AND RELIABILITY OF THE RESEARCH FINDINGS

Research validity is a key issue in the conduct of any research. According to Saunders et al. (2012: 197), validity within the body of research implies that the research findings confirm what the researcher actually set out to achieve. Research reliability is defined as the ability of collected data and the interpretation or the analysis to be dependable, trustworthy, uniform, and repeatable (Miller, 2008: 754). The extent to which the results are consistent over time and are an accurate representation of the total population under study is referred to as reliability, and if the results of a study can be reproduced using a similar methodology, then the research instrument is considered reliable (Golafshani, 2003: 598). Miller (2008: 754) argues that the understanding of reliability in qualitative research differs from the understanding in quantitative research. Therefore, in the field of quantitative research, reliability deals with the degree to which many researchers of the same problem/study using identical procedures arrive at similar results. This means that variation in results is regarded as measurement error.

In this study, all information presented in this research is factual and is substantiated by semi-structured interviews, stakeholder opinions expressed in the questionnaire, and feedback as incorporated in the research interview guide used in this study. The selection of participants was purposive, and therefore only relevant participants were involved. This exercise ensured that all results emanating from the research are evidence-based, leading to conclusions and recommendations.

4.8 ETHICAL CONSIDERATIONS

Ethical principles of informed consent were abided by and complied with at all times in the course of both the interviews and the questionnaire administration. The consent form and the letter of identification were shown to the questionnaire respondents before they were handed out. The cover page of the questionnaire also explicitly stated the purpose of the survey, and it promised to protect participants' identity. Regarding the telephone interviews, the participants were informed before the interview that the conversation would be recorded using an audio device, and that the recordings would be used solely for research purposes. Those participants who were interviewed face to face were shown the letter of consent and the written statement from CUT indicating the researcher's stance on matters of ethical concern and his commitment to the privacy and the protection of all respondents. The participants were assured that all the information provided would be held in strict confidence and would be used in a way that would not identify them.

4.9 CONCLUSION

This chapter has discussed the methodology adopted in this study. It commenced with a description of the study's methodological framework, namely the research philosophy, research approach, research strategy, research choice, time horizon and techniques and procedures, and the justifications for these. The following chapter presents an analysis of the results for this research.

CHAPTER 5: DATA ANALYSIS

5.1 INTRODUCTION

The aim of this chapter is to present the analysis of the research findings. The chapter is broadly divided into five sections, namely the pilot study data collection, in the form of semi-structured interviews with experts, desktop projects on how energy retrofit of an existing building has been carried out, interviews to obtain insight into the actual running of a building energy retrofit project, focus group interviews, and an expert survey, to provide credible explanations of the problem.

5.2 PILOT STUDY

The pilot study data collection was to obtain opinions from experts in the field of building energy retrofit regarding current practices in managing and delivering a retrofit project. The interviewees in the pilot study were building energy retrofit experts who were selected based on their profession, their willingness to participate in the study, their experience, and their interest in improving the field of research.

All participants were provided with an information guide about the study, and they consented to the interview by completing and signing a consent form. The interview was conducted with the intention of contributing to the following research objectives:

- To assess the current best practices in delivery of energy retrofit projects,
- To explore the key elements of energy retrofit of an existing building,
- To understand the issues and challenges facing management of energy retrofit of an existing building, and
- To seek potential improvement for the delivery of energy retrofit of an existing building.

To realise the above objectives, themes, questions, and gaps were identified in the review of the literature. Information from the interviewees was gathered through the use of a digital recording device, which was clearly identified to them prior to the start of the interview, to confirm their consent to be recorded. The recording device allowed the researcher the opportunity to concentrate fully on the responses, although notes were also taken during and after the recording. These notes were taken into account during data analysis. Each interview was transcribed and underwent a series of coding exercises related to themes, relationships, and differences regarding the subject matter for the observation stage of the data analysis. Extensive reading on the research topic was done to ensure understanding of the context and to capture perspectives from the participants. This included revisiting and reviewing the interview transcripts to ensure that the emphasis on the topic was accurately captured.

5.2.1 RESULTS OF THE PILOT STUDY

The participation of professionals from building energy retrofit projects (BERPs) in this interview is paramount for obtaining in-depth knowledge on the study. This sample of interviewees comes from various countries. The participants also hold various positions, which ensure that diverse views are provided.

The balance of thought from the variety of organisations, countries and levels of experience was intentional. With an average of 15.6 years of experience in BER projects, these skilled professionals are not only able to highlight the complex issues for managing BER projects but also to demonstrate with their expertise the complexity of the profession itself, and to inform on gaps which need to be filled in order to deliver projects more successfully. Table 5.1 provides a profile of the interviewees.

Table 5. 1 : Profile of the interviewees

Interviewee	Organisation type	Position	Experience in years	Country
1	Research institute	Director	22	United Kingdom
2	Research institute	Director	17	United Kingdom
3	Consultant	Senior manager	14	South Africa
4	Municipal government	Energy manager	26	South Africa
5	Municipal government	Energy manager	17	Singapore
6	Consultant	Energy manager	19	United States
7	Consultant	Energy manager	12	United States
8	Consultant	Energy manager	16	United Kingdom
9	Research institute	Senior research fellow	7	South Africa
10	N/A	Research fellow	14	Nigeria
11	Consultant	Building energy use expert/ analyst	17	Australia
12	Consultant	Manager	15	Singapore
13	Research	Research fellow	7	South Africa

	institute

Source: (Researcher, 2018)

The interviewees reported on a number of common practices in the retrofit domain. They highlighted the way energy retrofit for an existing building is being procured and delivered. Table 5.2 shows the current best practices suggested by the interviewees when they work on energy retrofit projects within interdisciplinary and collaborative teams for government and private organisations.

Table 5. 2 : Reported energy retrofit project delivery best practices

Interviewee	**Response**
1	According to the interviewee, in any BERP delivery process the following are prerequisites that need to be followed: an internal assessment of the building, a detailed energy survey, a technical analysis, a cost-benefit analysis, an implementation plan, operation and maintenance procedures, and training of the occupants who will use the facility moving forward.
2	The respondent posited that building energy retrofit is one of the main approaches to realistically achieving a reduction in carbon emission and energy consumption in existing buildings. In order to maximise the benefits, the following practices must be borne in mind: establishing the current condition of the building, determining process needs, gathering baseline data, developing potential energy efficiency measures, implementing the measures, gathering verification data, and continuing to monitor and assess the system.
3	The respondent did not speak generally and was of the opinion that there are a great number of best practices in building retrofit technologies that are readily available. However, the decision as to which retrofit technology (or measure) should be used for a particular project is a multi-objective optimisation problem subject to many constraints and limitations, such as specific building characteristics, the total budget available, the project target, building service types and efficiency, the building fabric, and whether it is a minor, major or deep retrofit, etc.
4	Same as no. 3 above.
5	According to this interviewee, there is no best practice. Because each building is unique, the optimal solution is a trade-off between a range of energy-related and non-energy-related factors, such as energy and economic, technical, environmental and social factors, regulations, etc. It is incumbent upon the

	design team to innovate a process that will maximise the benefits of building energy retrofit in each building.
6	The sixth interviewee posited a state of practice procedure for the improvement of a building's energy efficiency which comprises five steps: step 1: a building analysis: the main purpose of this step is to evaluate the characteristics of the energy system; step 2: a walk-through survey: potential energy-saving measures are identified in this step; step 3: creation of a reference building: the main purpose of this step is to develop a base-case model, using energy analysis and simulation tools, that represents the existing energy use and operating conditions of the building; step 4: evaluation of energy-saving measures: in this step, a list of cost-effective energy-conservation measures is determined, using both energy-saving and economic analysis; step 5: the energy efficiency drive is implemented.
7	The seventh interviewee prescribed a sequence of activities to follow when carrying out existing building energy retrofit. First, determine if the existing systems are operating at optimum levels before considering replacing existing equipment with new higher-efficiency equipment. Second, if the building is metered, review utility bills from the last two years to determine if consumption (not cost) has risen. Third, determine air tightness of the building envelope, by examining the building envelope and looking for leaky windows, gaps around vents and pipe penetrations, and moisture intrusion. Fourth, aggregate the data and develop measures. Fifth, implement measures. Sixth, monitor and evaluate measures.
8	The respondent was of the view that assessment of the building is paramount, and that it is done in order to understand the starting point. Proper understanding of the asset/building is required, and the primary use of the building going forward. Implement the changes and measure performance. It is important that the improved results be measured, so that the stakeholders are able to understand that the initial capital outlay did result in the objective of a reduction in operating costs being achieved.
9	The respondent offered the following as the best practice for existing building energy retrofit: energy-efficient lighting; light-movement sensors; insulation; shading.
10	The tenth interviewee stated that the current best building energy retrofit practices revolve around the issues of building energy standards, building energy labels, and building energy incentives, as they pertain to the following

	when carrying out retrofit: combustion safety; mechanical equipment and air distribution; ventilation; infiltration; ceiling insulation; knee walls; water heating; appliances; lighting and fans.
11	The interviewee was of the opinion that there is no best practice for existing building energy retrofit (EBER), that EBER is complex, contradictory, and in a continual state of increasingly rapid flux, that the optimal solution lies in integrating social and technical aspects of EBER, and, above all, that EBER is complex, flexible, and adaptable.
12	The twelfth interviewee added that an energy analysis of the building under study is carried out, and that several alternative scenarios, predefined by the energy expert, are developed and evaluated. These specific scenarios, which may vary according to the characteristics, type and use of the building, climatic conditions, etc., are pinpointed by the building expert and are then evaluated mainly through simulation. Selection of the alternative scenarios, energy efficiency measures, and actions that will finally be employed is based largely on the energy expert's experience. In the aforementioned approach, the whole process and the final decisions are significantly affected by the experience and the knowledge of the corresponding building expert.
13	The view of the interviewee was that the stakeholders need to first define the scope of the work and set project targets based on what they want to achieve; the second phase comprises building energy diagnostics; the third phase is identification of retrofit options; the fourth phase is implementation of retrofit measures; the final phase is monitoring and verification of energy savings.

Source: (Researcher, 2018)

From Table 5.2 above, it can be deduced that there are recurring themes that arose from the study. For instance, interviewees 1, 2, 6, 7, 8 and 12 were of the opinion that a building analysis, developing energy efficiency measures, implementation of measures, and monitoring and verification are paramount to efficient delivery of retrofit projects. Interviewees 3,4and 5 argued in favour of a multi-objective optimisation model, where many factors are considered to get the best solution. The emerging theme that came from the view of interviewee 11 was that existing building energy retrofit (EBER) is complex, flexible, and adaptable. The optimal solution lies in integrating social and technical aspects of EBER.

5.2.2 Elements of retrofitting existing buildings

The interviewees were asked to discuss the major elements of a typical retrofit project. Table 5.3 shows the key elements that were suggested by the interviewees, who stated that they are prerequisites.

Table 5. 3 : Key elements involved in delivery of energy retrofit projects

Interviewee	Response
1	The interviewee stated that they consider on-site testing, implementation and commissioning, weather conditions of the area, the cost of energy in that area, the need to reduce carbon emissions, the geographical location, the building type, size, age and functionality, and operation and maintenance of energy sources of the building (service systems) as key elements in the process of retrofitting an existing building.
2	The second interviewee also stated that geographical location (for temperate regions the focus is often on heating and use of hot water in the building; the opposite is the case for warmer climates), the type of dwelling, the age of the dwelling, the building type, i.e., whether a bungalow, flats, or semi-detached houses, etc., the façade and cladding type, the area, the number of rooms, and the number of occupants are all key practical considerations in retrofitting works. They stated that some buildings allow certain modifications and can limit the available options presented to the adopter and the installers. Also, the age of the dwelling can be a deterrent, as some building owners will not want to invest in modern energy-saving retrofitting schemes on an old building.
3	The third interviewee did not give much detail. They stated that the elements involved are considering building components and structural elements, and that redirection of the internal building envelop function towards passive actions can also help.
4	According to this interviewee, these issues are usually addressed through a market study that involves consultation with stakeholders, such as government departments, schools, and hospitals that own or operate the buildings that are to be retrofitted, as well as with energy service providers and potential financiers. The choice of which retrofit option to pursue is based on detailed energy audits, which are usually performed by the entities who undertake the retrofits, such as energy service companies (ESCOs).
5	The fifth interviewee postulated that the following elements will lead to maximum benefits: determining occupant behaviour and needs and services required by the occupants, understanding the existing building structure and systems, understanding the scope and the costs of planned or needed installation, understanding what systems or components require replacement or renovation for non-energy reasons, reducing loads, selecting measures to reduce loads, and selecting appropriate and efficient HVAC systems. After

	reducing loads as much as possible, this interviewee posited that one must consider what HVAC system types and sizes are most appropriate to handle the reduced loads and find synergies between systems and measures, and that one must seek synergies across disciplines and find opportunities to recover and reuse waste streams. After the most appropriate and efficient technologies have been selected, the focus should shift to optimising the control strategies, and that one must realise the intended design and conduct initial and ongoing commissioning to ensure continued realisation of the intended design and its benefits. This step-by-step approach shows the critical elements of a deep retrofit design process, as posited by the interviewee.
6	According to the sixth interviewee, retrofitting in this context should involve applying an integrated, whole-building process. However, there are a number of basic techniques that can be used for key elements of a building: walls: cavity wall insulation, internal or external insulation, and cladding of external and internal surfaces; roofs: insulation and ventilation systems; doors: draught-proofing or replacement with high-performance doors; windows: installation of double or triple glazing, or draught-proofing of existing glazing; floors: installation of insulation; tanks and pipes: lagging; lighting: new controls, occupancy sensors, light-emitting diode (LED) lighting, and other low-energy technologies; boilers: installation of high-efficiency condensing boilers or micro combined heat and power (CHP), new controls, or connection to low-carbon community heating systems; chiller plant improvements: plant, pump, piping and controls upgrade; controls: installation of smart controls and building management systems; air conditioning: upgrade, or replacement with air- or ground-source heat pumps or passive cooling; renewable energy systems: installation of photovoltaic cells, solar thermal heating, passive solar heating, wind energy, wood and organic waste power-sourced heating or power plant, micro-hydro power, and so on; water conservation: installation of low-flow equipment, such as water fittings, shower heads, dual-flush WCs, rainwater harvesting, and so on; electricity: peak saving through thermal energy storage, on-site electricity generation, CHP, and so on.
7	Same as no. 6 above.
8	The interviewee postulated that the various members of the design and operations team should work together to design each system and assembly in consideration of its impact on the building as a whole. Deep retrofit projects usually involve whole-building energy simulation, to help determine which options will result in the lowest energy usage while still meeting other project

	goals. When delivering deep retrofit projects, the following elements should be considered: human factors, such as occupant behaviour, etc., retrofit technology, client resources and expectations, and building information.
9	The respondent offered the following as the key elements to be considered in deep energy retrofit for existing buildings: energy-efficient lighting; light-movement sensors; insulation; shading.
10	The interviewee simply suggested the following as the key elements to be considered in energy retrofit of an existing building: the retrofit programme; current best practices; understanding how occupants use energy; the contractors performing the retrofit.
11	The interviewee was of the opinion that to maximise the benefits of a deep energy retrofit project, socio-technical elements must be considered. For example, deep retrofit projects are especially suited for buildings that have a significant number of systems and assemblies near the end of their useful lives. Rather than just replacing these systems and assemblies with similar items, deep retrofit projects are a great opportunity to re-evaluate the types of systems and assemblies in the building, considering the current needs of the building and new technologies that have become available over the years. If a building's usage has changed significantly since it was originally constructed, the systems and assemblies in the building are likely not optimised to suit the current needs of the building. A deep retrofit project presents a perfect opportunity to evaluate the current systems and assembly types in a building and to present options for alternative systems and assemblies that may be more suited to the building's needs. Deep retrofits typically include major renovations to building systems and assemblies. Impact on the occupants must be considered, and this aspect can limit the scope and impact of a deep retrofit. If the occupants can be relocated for the deep retrofit construction period, or if there is a known upcoming break in occupancy, the level of retrofit can likely be deeper than if the occupants remained in the building during the deep retrofit construction period. Commissioning is highly recommended for deep retrofits. It provides assurance to building owners that the project was designed and constructed to meet the owner's requirements. Commissioning can start during a deep retrofit's pre-design phase and proceed through construction, to help the project team match the design with the needs of the building, and to help ensure the long-term maintainability of the facility. The participation of a commissioning agent is often most useful at the start of a project, when it can have the biggest impact on design and construction activities.

12	The process of retrofitting involves the careful balancing of different elements and their effects on the overall performance of a building. A change in one part of a building can affect another. Therefore, it is incumbent on those who want to retrofit their building to carefully consider the following elements: occupant behaviour, retrofit technologies, the people that will use the technology going forward, the scope of the retrofit project, financial resources, post-occupancy evaluation, etc. Above all, there is a need for a knowledge-management retrofit framework for informed decision-making while delivering the project.
13	There was no clear-cut view from the respondent.

Source: (Researcher, 2018)

In Table 5.3 above, the summary of key elements involved in delivery of BERPs mentioned by the interviewees clearly demonstrates agreement on the strong need to integrate social and technical aspects of building energy retrofit. The social aspects pertain to the behaviour of users of a facility regarding how they accept and use the retrofit technology. The technical aspects include retrofit technology, the building fabric, and how the technology will fit into the building. Even client resources and the payback period are paramount in determining the overall success of building energy retrofit project delivery processes.

5.2.3 Challenges of retrofitting buildings

The interviewees were requested to outline and explain the challenges encountered when retrofitting buildings. In their individual responses, several challenges were highlighted. The challenges that top the list range from insufficient communication to insufficient consultation. They all stated that the activities of stakeholders are insufficient and inadequate. A lack of stakeholder agreement, the piecemeal fashion of doing things, and the lack of social data incorporated in the project were also highlighted. These were closely followed by a lack of collaboration and cooperation, which revolves around a lack of stakeholder activities to obtain buy-in into the project, and experts operating randomly, which makes work move haphazardly. Lack of flexibility/adaptability is another serious challenge in building energy retrofit projects. This ability in times of unpredictability and complexity requires a trade-off between adherence to a process and adaptability/flexibility. They advocated that experts dealing in BER projects should obtain substantial benefits from being flexible, by applying learning through continuous improvement and administrative innovation, because no two BER projects are the same.

In the same argument, the interviewees posited that lack of technical know-how is equally a challenge. The absence of suitably qualified and experienced retrofit technicians can result in poorly installed systems. This can then lead to project failures and disappointment, making the client sceptical of the benefits of such initiatives. Such failures are damaging to the retrofit sector and the construction industry in general. Therefore, it becomes vital that contractors make use of engineers and installers that understand the importance of getting it right, and the implications of not following procedures and standards, which often results in failed projects.

Other challenges include the following: the capital cost of such investments, uncertainty about the payback period, and limited access to finance. This can be linked to the income of the potential investor; most clients (building owners) prefer a shorter payback time, so when the cost of investing in retrofit works is seen as one that will take over five years to recoup, many withdraw from such schemes, as the interviewees suggest. Education level can impact how receptive the potential adopter will be towards retrofitting an existing building. Low levels of education contribute to low awareness of the direct and indirect benefits of such systems to the individual and society at large; homeowners also fear disruption or damage to the building.

Location places certain constraints on the type and the nature of technologies that can be applied. Some interviewees went further to say that lack of building science/energy efficiency awareness among contractors, subcontractors, buyers, and others and lack of awareness seems to be a challenge, because some of them cannot differentiate between renovation and energy retrofit of buildings. The worst of it all is that contractors, subcontractors, and others lack the requisite experience to carry out the task, thereby creating more problems for the building after the retrofit. This may be in terms of technical know-how of some issues, such as air tightness, ducting, etc. of the dwellings. Uncertainties such as weather conditions (climate change), human behaviour factors, government policy change in terms of funding the project, selection of retrofit technologies, operational challenges (interruption of operations), resistance from building owners and investors, the specific nature and characteristics of the building, and the project budget and targets all present huge challenges.

The economic, technical, environmental and social dynamics of energy retrofit are challenging. Investment decisions for energy efficiency on retrofits are quite complex in nature. Other challenges relate to end users' awareness, attitudes and behaviours in relation to energy use and clients' requirements and experience (in most cases they have limited knowledge). Comprehensive and concrete weighted evaluation of the social, cultural and economic benefits of retrofitting an existing building can be a daunting task. There is always an element of uncertainty regarding the technical, financial and operational benefits of implementing BERPs, as suggested by the interviewees.

Finally, most of the interviewees concurred that the success of a retrofit depends firstly on understanding the building and its context in sufficient detail and depth. The professionals also need to understand that some of the formal standards and methods used by government and industry are incorrect or incomplete. Finally, it is important to understand the interactions between all these different elements and how different aims for retrofit may conflict with each other.

5.2.4 Potential solutions to retrofitting challenges

When asked to consider how best to overcome these retrofitting challenges and what was needed to improve the delivery of BERPs, most of the interviewees suggested improvement in the area of communication and consultation with all stakeholders, especially in affected buildings. They stated that information sessions are needed to receive and communicate details of activities, in order to deliver what is actually needed in the BERP. Collaboration and coordination are elements that must be improved upon.

Although it takes more time, money and effort to make decisions collaboratively, the potential gains of doing so outweigh the costs involved. Collaboration and coordination happen on the assumption that the resulting decisions will be superior to decisions made individually regarding BERPs. The interviewees went onto say that training provision for contractors, subcontractors and installers is of the utmost importance. Other potential solutions offered were provision of grants and low-interest loans for such retrofitting schemes, to serve as incentives, and awareness creation through targeted education, so that homeowners and occupants can see the energy and cost-saving potential of such retrofit practices. Yet other solutions offered were targeting owners of buildings in dire need of retrofit and pointing out how such retrofit works can improve comfort levels in a building, emphasising the importance of environmental and climate protection, and increased awareness through special campaigns by the government and professional bodies on issues relating to energy efficiency in buildings. Also, training, in the form of certification for contractors and subcontractors, and post-retrofit assessment of the building in order to detect issues with the retrofit will equally add value, as suggested by the interviewees.

They concurred that managing the different parties involved in the BERP delivery process in order to streamline implementation will also prevent or at least minimise fragmentation of the retrofit sector. They postulated that this can be achieved by better customer service provision, through changes to the level of marketing and an increase in the size of the target group, which will result in more awareness creation, preventing the rebound effect, i.e., a situation where savings from retrofitting lead to increased demand for other energy-consuming goods and services, thereby offsetting the initial gains. Where this happens, the client may dispute the needs and savings.

5.2.5 Summary of results of the pilot study

Table 5. 4 : A summary of the findings thematically

Theme	Summary of the findings
Assessing the current best practices in delivery of energy retrofit projects	• The results of the study suggest that a building assessment, a detailed energy survey, a technical analysis, a cost-benefit analysis, an implementation plan, operation and maintenance procedures, and training of the occupants are prerequisites for delivery of an energy retrofit project. • Other prerequisites include a building analysis, which is geared towards evaluating the characteristics of the energy systems, a walk-through survey, where potential energy-saving measures are identified, using energy analysis and simulation tools, which serves to establish energy use and operating conditions of the building, evaluation of energy-saving measures, and, finally, implementation of the energy efficiency
Exploring the key elements involved in energy retrofit of an existing building	• The study highlighted the need to determine occupant behaviour and needs and services required by the occupants, to understand the existing building structure and systems, to understand the scope and the costs of planned or needed installation and what systems or components require replacement, to identify and select measures to reduce loads, and to select appropriate and efficient HVAC systems. • Other features, such as the socio-technical elements of BER, must be considered. For example, deep retrofit projects are especially suited for buildings that have a significant number of systems and assemblies near the end of their useful lives. So it is a great

	opportunity to re-evaluate the types of systems and assemblies in the building, considering the current needs of the building and new technologies that have become available over the years. • The findings suggest that geographical location, the type of dwelling, the age of the dwelling, the building type, i.e., whether a bungalow, flats, or semi-detached houses, the façade and cladding type, the area, the number of rooms, and the number of occupants are all key practical considerations in retrofitting works. • Other elements that can be considered include appropriate design solutions and technologies that can engender effective and efficient energy management, namely walls, e.g. cavity wall insulation, internal or external insulation, and cladding of external and internal surfaces, roofs, e.g. insulation and ventilation systems, doors, e.g. draught-proofing or replacement with high-performance doors, windows, e.g. installation of double or triple glazing, or draught-proofing of existing glazing, lighting, e.g. new controls, occupancy sensors, light-emitting diode (LED) lighting, and other low-energy technologies.
Understanding the issues and challenges facing management of energy retrofit of an existing building	• The study reveals that communication and consultation are key challenges facing the BERP delivery process. • Other challenges include the following: insufficient and inadequate activities of stakeholders, a lack of stakeholder agreement, the piecemeal fashion of delivering BERPs, and the lack of social data incorporated in the project. • The study highlighted lack of flexibility/adaptability as another serious challenge in BER projects. • The study also reveals that lack of

	technical know-how is equally a challenge. The absence of suitably qualified and experienced retrofit technicians can result in poorly installed systems, which can then lead to project failures and disappointment, making the client sceptical of the benefits of such initiatives. • Other challenges include the following: the capital cost of such investments, uncertainty about the payback period, and limited access to finance. • Education level can impact how receptive the potential adopter will be towards retrofitting an existing building. • Human behaviour factors, government policy change in terms of funding the project, selection of retrofit technologies, operational challenges, and the specific nature and characteristics of the building all present huge challenges to the BERP delivery process.
Improvements in the delivery of energy retrofit of an existing building	• The study suggested improvement in the area of communication and consultation with all stakeholders, especially in affected buildings. • The study suggested the need for training provision for contractors, subcontractors, and installers. • Education awareness for owners of buildings in dire need of retrofit, and pointing out how such retrofit works can improve comfort levels in a building, emphasising the importance of environmental and climate protection. • Other solutions offered were increased awareness through special campaigns by the government and professional bodies on issues relating to energy efficiency in buildings. • Also, training, in the form of certification for contractors and subcontractors, will equally add value,

	as suggested by the interviewees.

Source: (Researcher, 2018)

The pilot study revealed that building energy retrofit projects will need to change from traditional piecemeal fashion in which they are delivered to an adaptable (flexible) process, so as to better cope with the changing times. The following section discusses the investigation into four desktop projects from around the world. The projects follow the thread identified thus far and utilise the outputs of the literature review and the semi-structured interviews to obtain more in-depth findings.

5.3 PROJECT ANALYSIS

The projects were chosen to gather data on how energy retrofit of an existing building has been carried out in the international arena. This section introduces the details of the projects chosen, by providing the motivation for selection, the type of retrofit, details of the project, key retrofit features of the project, recorded challenges, and lessons learnt from the project. Four projects have been conducted on retrofit projects. The projects have been completed, and their document analysis is available in the public domain. The projects provide greater understanding of how energy retrofits have been done across the globe.

5.3.1 Selection of desktop projects

Information for the desktop studies was obtained from online newsletters, brochures, fact sheets, and articles. Table 5.5 provides an overview of the desktop cases. The data extracted from the desktop studies included key retrofit features, challenges, and lessons learnt. The projects were selected because of their uniqueness, the public attention they have received, the features of retrofitting that they demonstrate, and the availability of data from numerous sources about the same project.

Table 5. 5 : Overview of four desktop projects

Number	Country	Project name
1	Australia	Szencorp Building in Melbourne, Australia
2	Singapore	Zero Energy Building in Singapore
3	United States	Rocky Mountain Institute Innovation Centre in Basalt, Colorado, United States
4	China	MGM Macau Resort in Sé,

	Macau, China

Source: (Researcher, 2018)

5.3.2Desktop case study 1

Australia: Szencorp Building

1. MOTIVATION FOR SELECTION

The Szencorp Group purchased the 20-year-old Szencorp Building to retrofit as their headquarters. It was an underperforming building with high energy consumption. Sustainable development is Szencorp's key business activity, and it is important that their own premises reflect their capability in this regard. The motivation was to

1. Produce a high-end corporate look, with green credentials fully integrated into the design,

2. Substantially reduce energy and water consumption in the building,

3. MinimiseCO_2 emissions in the building, and

4. Create a pleasant and highly sustainable work environment.

2. TYPE OF RETROFIT PROJECT

The project involved a deep overhaul energy retrofit of the whole building.

3. PROJECT DETAILS

The Szencorp Building is located at 40 Albert Road, South Melbourne, and it combines a cutting-edge sustainable design with a sophisticated, contemporary appearance. The building, which was built in 1987 and refurbished in May 2004, has an area of1, 200m², and it is now the headquarters of the Szencorp group of companies. The Szencorp Building is a showcase of sustainable building performance and innovative technology. The building was transformed from an outdated inner Melbourne office to a state-of-the-art green building. The building became Australia's first retrofitted building to achieve a 6 Star Green Star Office Design v1 rating, which represents "world leadership" in green building. The design aims to be Australia's first zero-emissions building. It is demonstrating that an innovative, holistic and long-term approach to building energy retrofit design will reap business and environmental benefits, while maintaining commercial viability. The design teams are made up of SJB Architects and Interiors, Energy Conservation Systems Pty Ltd, and Connell Mott Macdonald Construction.

4. KEY RETROFIT FEATURES OF THE PROJECT

After a thorough iterative process with the design team, they concurred that the following will help in addressing the CO_2 emissions of the building: installation of an occupier integrated controls system of sensors, so that services such as air-conditioning and lighting are only provided if the area is occupied; on-site power generation from different sources, including multiple solar panel arrays and a ceramic fuel cell; lift controls and the lift car were completely modernised, for smoother, safer operation and reduced energy consumption; using rainwater capture and grey water recycling for flushing, waterless urinals, dual-flush toilets, low-flow taps, and cut-off sensors on basin faucets; natural ventilation through automated opening windows.

The lighting utilises new-generation triphosphor and T5 lamps, and dimmable DSI ballasts controlled via an intelligent occupancy-based system, achieving 1.4 watts per 100 lux. An integrated sensor and management system for occupancy lighting, HVAC and security control was installed. A ceramic fuel cell was installed, which generates low-emission, off-grid energy, with the potential to provide for >30% of the building's energy requirements on-site. Two solar photovoltaic (PV) grids (one amorphous) were also installed, which generate 5.5kW. With the ceramic fuel cell, these grids will potentially ensure zero grid energy consumption in future. The ceiling height was increased (reclaimed from the old building plenum), allowing for use of thermal mass for improved energy efficiency. Use of the Drykor dehumidification unit, which removes 94% of all micro-organisms and 77% of particles larger than 5 microns from the airspace, which helps to overcome "sick building syndrome", was also introduced, thereby increasing the productivity of the occupants. A refrigerant leak-detection and -monitoring system was installed to ease operation.

The following outcomes were recorded: energy savings of 61% in the first year and 71% in the second year; potable water usage is 94% less than in an average building; a 5 Star NABERS water and energy rating was achieved (NABERS is a national rating system that measures the environmental performance of Australian buildings); waste to landfill was reduced by 81%; the productivity of the workforce increased by13% within two years of occupation after project completion.

5. RECORDED CHALLENGES

Many challenges were identified on the Szencorp project. The challenges include selection of the right retrofit components for the whole building, developing a performance-based design, engineering capacity, and developing financial modelling for the project. The challenges of selecting the right retrofit components on the Szencorp project arose at initial stage, when the project team felt a little lost at first when considering new twists, such as conservation measures, implementation measures, financing, and measurement and verification.

6. LESSONS LEARNT FROM THE PROJECT

The Szencorp Group looked at life-cycle costing when undertaking this retrofit, as they benefit directly from the building's improved efficiency and performance. The lesson is that the strategy is paying off, with energy savings of over 70% and water savings of 94% less than the industry average in the second year of occupation after project completion. The company is also benefiting from a perceived overall productivity increase of 13% as a result of improved internal environment quality.

As a demonstration and partly experimental project, Szencorp believes “the money and effort expended would be difficult to justify for a single building”. However, they have proven that “the investment has more than paid for itself in terms of the learning’s, the profile the project has received and the ability of the owner to develop a new level of business services in the rapidly growing market of leading edge green buildings”.

5.3.3Desktop case study 2

Singapore: Zero Energy Building

1. MOTIVATION FOR SELECTION

The Building Construction Authority (BCA) in Singapore needed to retrofit its three-storey building on the BCA Academy campus. It decided to try to make it a net-zero-energy building, despite the challenge of doing so in a hot and humid tropical climate. BCA manages Singapore’s Green Mark building rating system and wanted the project to reflect the best sustainable building practices.

2. TYPE OF RETROFIT PROJECT

An integrated approach was adopted in engendering deep retrofit in the building.

3. PROJECT DETAILS

Before the retrofit, the building was used as a training centre for craft workers for the rapidly growing construction industry in Singapore. It was part of a larger campus that was restructured to become the BCA Academy. The retrofit project began in 2007 and was completed in 2009. As a public-private partnership project with the building owner (BCA), local designers/consultants and builders partnered with researchers from the National University of Singapore(NUS) and the Solar Energy Research Institute of Singapore (SERIS) to retrofit an existing building into a net-zero-energy building. The building footprint is about 250 ft (76 m) long and 65 ft (20 m) deep, with an external corridor on the longer east side, providing access to the deep building spaces on all three storeys. The east façade is oriented north-south and faces an internal rectangular courtyard.

Three identical buildings are opposite, another abuts the north side, and another abuts the entrance building on the south side. All six buildings are connected by internal walkways or intermediate staircase cores, forming the BCA Academy. The nearest building to the campus entrance was chosen for the net-zero-energy retrofit. The building was partially funded by the BCA, the Ministry of National Development (MND), and the Economic Development Board (EDB). The project used a design-build-operate process. Reducing operational costs and emissions were the driver for the design, rather than reducing upfront capital costs. In design charrettes, the stakeholders discussed passive design, energy efficiency, and renewable energy. International projects were analysed, and various concepts were developed and reviewed, often aided by computational simulation and visualisation. Various iterations helped to identify best practices and the need for supporting research projects. The main goals for the passive design included reducing heat transmittance, enhancing daylight, and increasing natural ventilation, followed by efficient electrical lighting and air conditioning and mechanical ventilation, using building management systems. Integrating photovoltaic cells into the building envelope was critical for achieving net-zero-energy goals.

4. KEY RETROFIT FEATURES OF THE PROJECT

Natural ventilation with solar chimneys

The building was cooled by natural ventilation. The average air temperature and relative humidity in tropical Singapore during the day is around 88°F (31°C) and 80%, respectively, with relatively little seasonal change. Building occupants in Singapore appreciate some air movement, as it reduces the effective temperature, and the new HVAC and natural ventilation systems provide increased indoor air movement. A solar chimney system was chosen for natural ventilation for the building. Four chimneys on the roof, which are the end of a series of partially hidden ducts along the building envelope, are the most visible part of the system. The system starts with exposed vertical ducts along the west façade, which then bend to follow the curved roof and eventually connect with the prominent central chimneys.

When exposed to sunlight, the vertical ducts heat up, creating internal hot air, which expands, becoming lighter, and rises (the buoyancy effect) and, in turn, 'sucks' warm indoor air through various inlets, drawing ambient air through the façade into the interior. In the building, air movement of up to 394 fpm (2 m/s) has been measured and has changed the thermal acceptability from unacceptable to acceptable. This improved thermal comfort was determined through predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) and was reconfirmed through an occupant survey. The cooling system is designed specifically for the tropics. Energy efficiency is achieved by cooling fresh and re-circulated air separately and by having separate fan controls with variable speed to match localised demand.

Tackling thermal gains

The original building envelope with exposed concrete walls and metal roofs that had little shading would get heated up during the day and would re-radiate the heat into the interior, due to the absence of insulation. The overall strategy was to add a cooling skin to the building envelope. Sun shades and vertical green walls were added on the western side, and the roof received a layer of photovoltaic (PV) modules. The PV roof was elevated about 1 ft (300 mm) off the metal roof and had horizontal gaps between the modules to ensure ventilation and cool the PV modules and the metal roof below. The cooling skins served additional purposes beyond shading. Some sun shades on the façade had PV modules on the upper parts, generating additional electricity. Others had reflective films, doubling as light shelves, redirecting daylight deeper into the building. The green walls and the roof system support the study of their shading and evaporative cooling effect on reducing heat transfer and resulting cooling energy use.

Day lighting

In addressing day lighting, an innovative design concept was to direct the windows towards the sun, or rather to collect the zenith light from the roof and the façade and redirect it to where it is needed. Several advanced day lighting systems were installed and tested for providing daylight for some selected zones, including vertical and horizontal hollow light guides and ducts, external light shelves and customised double glazing with integrated adjustable blinds, electro-chromic films, and semi-transparent PV modules. In conclusion, the concept of collecting bright zenith light on roofs and façades and directing it into deep building zones was found to be an effective and innovative alternative or supplement to electric lighting, and it provided excellent colour neutrality. However, this solution required more space and planning compared to electric lighting, and it slightly increased the mean radiant temperature, by 1°F (0.5°C).

Photovoltaic integration

The energy target for the building was to be net-zero, i.e., to produce as much electricity as the building consumes over the course of one year.

As there is no heating required, all energy was electric for air conditioning, ventilation, lighting and plug loads, which was estimated to be about 706,300 kBtu (207 MWh), or 14.6 kBtu/ft² (55.3 kWh/m²) per year. To produce an equivalent amount of electricity with PV modules, it became clear that the building roof would need to be completely reserved for PV modules. After a few iterations to define the benefits of electricity generation with PV modules versus energy savings through solar chimneys, roof greening, or reflective coatings, a PV system of 190 kWp capacity, covering some 16,577 ft² (1,540m²), was chosen. A large grid-connected system designed to produce a maximum electricity yield was installed on the roof. Therefore, a performance-based invitation to bid was launched. The supplier had to guarantee a certain amount of electricity production, which provided the motivation to install as well as operate and maintain the PV system efficiently. PV systems were also installed on the façades, designed here to demonstrate the variety of PV technologies and their multi-functionality, such as serving as sunshades, railings, opaque and semi-transparent walls, and windows. These smaller systems were off-grid, meaning that their DC electricity was consumed on the spot by a cell phone charger. Both grid-connected and off-grid systems are owned and operated by the BCA, following the requirements for electrical power systems set by Singapore's Energy Market Authority (EMA) and the design guidelines on conservation and development control formulated by the Urban Redevelopment Authority (URA).

5. RECORDED CHALLENGES

A further challenge is that space use may change over time. Here, some of the classroom spaces planned for natural ventilation was converted to air-conditioned spaces with a different use. Responding to increased energy use is another key take-away point. This requires constant monitoring to identify areas for further energy savings. For example, the initial lighting was using T5 lamps, but after replacing them with LED lamps, the energy consumption was reduced by about 40%, partially absorbing the increased energy consumption for the enlarged air-conditioned space. There were some difficulties, mainly due to the lack of experience and craftsmanship in installing green building technologies properly on-site. This was especially true if it was the first of its kind, such as the solar chimney system and the PV façades. Most of the extra work could fortunately be supported by the accompanying research projects, which also brought in foreign experts and their experience. What also turned out to be essential was the call for a performance-based arrangement for the building-integrated PV system, unlike the usual capacity-based arrangement. For the performance-based arrangement, the supplier had to ensure that the specified annual electricity generation is achieved.

6. LESSONS LEARNT FROM THE PROJECT

Many lessons were learnt regarding the generation of accurate energy models, enabling of monitoring and verification, designing for maintenance, and responding to increasing energy use. The integrated design process with all stakeholders at the early stage of the project was beneficial in setting the stage and identifying best practices. The design-build-operate approach was also beneficial, as it considered the operational costs, too, which are usually ignored in the standard design-build-sell approach.

Simulations on energy savings and yield were instrumental in sizing different energy systems. However, building accurate and integrated energy models with occupancy schedules and dynamically responsive systems was challenging. Occupancy schedules are very difficult to predict, but their resulting energy loads have a strong impact on the predicted energy consumption of a building. Actual and predicted occupancy schedules usually differ, especially if the prediction is outdated. The planning of the project included some reserves, e.g. for extension of air-conditioned spaces. In fact, the energy use intensity (EUI) of the building has increased by 15% over the first two years, and it keeps increasing, due to converting more of the naturally ventilated spaces into air-conditioned zones. But with additional energy efficiency measures, it has remained a net-zero-energy building over the first five years.

Building information modelling (BIM) was used to create and communicate design aspects. However, not all of the green building systems were a part of the standard building products library, and they had to be created and added first. Multifunctional objects, such as electricity-producing semi-transparent PV windows, are difficult to represent in BIM. Traditionally, windows only have thermal and optical properties, and not electrical, and PV modules have only electrical properties, and even if they are integrated in the building envelope, they remain mono-functional energy generators. Therefore, BIM was used for integration and communication purposes, but not as a front end for energy performance simulation. Energy simulations were performed independently from BIM, with the locally prevailing tools for PV system sizing, building energy performance, and HVAC and day-lighting systems.

5.3.4Desktop case study 3

United States: Rocky Mountain Institute Innovation Centre, Basalt, Colorado

1. MOTIVATION FOR SELECTION

Rocky Mountain Institute (RMI) is a non-profit organisation dedicated to transforming global energy use to create a clean, prosperous and secure low-carbon future. Therefore, when RMI needed a new office and convening centre for 50 employees in the mountain community of Basalt, Colorado, they seized the opportunity to practise what they preached, with a state-of-the-art building that achieved an unprecedented level of integration, automation, and performance. The resulting Innovation Centre (IC) is the highest-performing building in the coldest climate zone in the US, generating more energy on-site than it uses in a year. It serves as a replicable model, with its team dedicated to transparently sharing details on process, performance, and key lessons learnt, showcasing how net-zero-energy buildings are better for owners, occupants, and the environment.

2. TYPE OF RETROFIT PROJECT

An integrated approach was adopted in engendering deep retrofit in the building. In achieving this, the team devised a solution that focused on the process for system integration and commissioning itself. As each system to be integrated into the central controls was specified, they ensured the system could communicate with the central systems protocol, and the subsystem manufacturer provided support to integrate the system. This support was crucial and, in many systems, it was lengthened into a long-term relationship, through integration and operation to troubleshoot issues.

3. PROJECT DETAILS

The Rocky Mountain Institute (RMI) Innovation Centre, completed in December 2015, is a 15,610 ft² (1,450 m²) office building and state-of-the-art convening centre located in Basalt, Colorado. RMI developed the Innovation Centre to advance the organisation's mission, propel the industry, and demonstrate how deep retrofit buildings are designed, contracted, constructed and occupied.

4. KEY RETROFIT FEATURES OF THE PROJECT

What makes the IC so cutting-edge is not a single technology. Rather, it's the thoughtful combination of passive design features with best-on-the-market technologies, plus a careful balance of automated and manual controls. Four specific categories underlie performance optimisation: passive design, redefining thermal comfort, managing system control complexity, and renewable energy production and management.

Starting with passive design

When the RMI began working with the design team, they first considered what occupants would need from a building, namely a comfortable, pleasing and productive space, and then they maximised all passive approaches to meet these needs, before considering any mechanical means.

Passive solar design

At an elevation of 6,611 ft (2,015 m), Basalt has strong solar gain throughout the year, due to its high altitude and clear skies. By managing solar gain during the summer and maximising it during the winter, the design team was able to eliminate mechanical cooling and reduce heating systems to a small distributed system.

Daylight and heat gain are maximised with a narrow floor plate, a southern orientation, and a "butterfly" roof design, which together expose as much of the building's thermal mass to the strong winter sun as possible. The size and the type of windows for each façade were tuned to optimise southern gain, while minimising heat loss to the north (the window-to-wall ratios are 52% on the south, versus 18% on the north). The window properties on the south were optimised to let in more light and heat than the windows on the north. During the summer and shoulder seasons, external automated sunshades on the south façade control solar gain. The blinds automatically track the angle of the sun, to balance daylight, glare, and heat gain. By integrating the sunshades with the building's control system, the building is able to deploy them when spaces are getting too hot, or retract them when spaces need more heat.

The building is completely daylight-exposed for the majority of the year, thereby significantly reducing its use of energy-intensive interior lighting. The remaining lighting needs are met using efficient LEDs and personal desk lamps.

An airtight and super-insulating envelope

The IC is one of the most airtight office buildings measured in the US, with 0.36 air changes per hour, making it 97% more airtight than a conventional US commercial building. Advanced materials combined with precise construction details prevent leakage and make the building's incredible air tightness possible. The building is framed with structural insulating panels (SIPs), providing the dual benefit of continuous insulation and air tightness. Two coats of tape and air barrier material were applied outside the SIPs to ensure tight joints. The design process limited and consolidated essential penetrations, and a scale mock-up of key material connections ensured carefully thought-out connections. The construction team continually reviewed details and required high quality from all sub-consultants, and two building pressure tests performed before completion ensured execution of the tight construction details.

High-performing windows complete the super-insulating building envelope. Quad-pane windows (two panes of glass, two of film, filled with krypton gas, with rigid thermal breaks in the frames) serve the multiple functions of day-lighting, passive cooling and heating, insulation, and air-tightness, while creating an envelope with triple the code-required levels of insulation. The building's thermal mass is also important for passive heating and cooling, stabilising interior temperatures despite significant outdoor temperature swings. Exposed concrete floors provide the majority of the thermal mass. In the winter, the building heats the floors with sunlight, allowing them to radiate heat throughout the space. Phase-change material (PCM) is embedded in the walls and light shelves, providing even more thermal mass.

Maximise natural ventilation

Active natural ventilation strategies allow the IC to fully maximise its thermal mass throughout the day. To take advantage of cold evening temperatures, the building automatically opens the windows and cools the internal slab and PCM to keep the building cool throughout the next day. A controls strategy looks up the high temperature for the next day's weather and determines how low the building must pre-cool the slab that night. Due to this automatic temperature reset, the building is, ironically, coldest on the morning of the hottest day. During the day, the controls system monitors internal and external temperatures, and in the right conditions will automatically open the windows. Low windows on the south side and high windows on the north side, plus an open office plan, promote efficient air movement through the spaces.

After maximising passive design and innovative thermal comfort approaches, there remains a very small requirement for heating during the winter, the equivalent of one average home in this climate. The RMI used the most efficient heat-recovery ventilation systems (93% efficient) and a small electric radiant heating system under the carpet to achieve that.

Redefining thermal comfort

Most buildings rely on blowing hot or cold air using large HVAC systems to maintain a set temperature, which wastes energy and doesn't address the full thermal comfort of individuals. In contrast, the IC addresses all six thermal comfort indicators – air speed, temperature, humidity, radioactive temperature, metabolic rate, and clothing level – identified by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the University of California, Berkeley Centre for the Built Environment (CBE), while requiring dramatically less energy.

Breaking down thermal comfort into these indicators pushed the team to examine the best way to meet each requirement, and it resulted in using smaller systems targeted to meet each of those needs. For example, external sunshades were tailored to meet radiant needs, while ceiling fans provide airflow. Instead of traditional central systems, which are often oversized to meet every need in all conditions, the Innovation Centre uses smaller, more efficient and effective systems sized to address each thermal comfort indicator. Once these passive systems create a stable range of comfortable temperatures, smaller personal comfort approaches fine-tune people's comfort within that range. This approach can accommodate the significant range of perceived comfort due to metabolic, gender, health or clothing differences.

Controls integration

The multiple targeted systems that made this comfort strategy possible also added significant controls integration complexity, as many of these systems are designed to control independently, using their own proprietary systems. The team devised a solution that focused on the process for system integration and commissioning itself. As each system to be integrated into the central controls was specified, they ensured that the system could communicate with the central systems protocol, and the subsystem manufacturer provided support to integrate the system. This support was crucial and, in many systems, it lengthened into a long-term relationship through integration and operation to troubleshoot issues.

Moving beyond equipment-based commissioning

Thorough commissioning is a key to ensuring a high-performance building. Traditional commissioning, which looks at each individual piece of equipment and ensures it goes through its own sequence, can be sufficient for a traditional building with central systems. However, the IC's many targeted systems, and particularly the interactions and integration of those systems so critical to the building's performance, made a traditional approach impossible. These interactions are often controlled by many factors and, due to the passive nature of many of the systems, are difficult to simulate.

Instead, the commissioning approach evolved to look at how the building performed as a system. It included the usual functional testing of individual pieces of equipment and then shifted to a long-term building-tuning perspective, monitoring every point through a range of conditions over an extended period of time. This required a long-term relationship with the commissioning agent and the design team, along with the associated operating budget for this work. This relatively short-term investment quickly paid back, in lower energy consumption and fewer occupant complaints.

Occupant training and engagement

The IC's occupants play a critical role in achieving ambitious net-zero-energy goals and maintaining a high level of performance over time. Before occupying the building, staff received a short but in-depth training session on the building's design, performance goals, technologies and systems, to ensure that everything was operating as intended, to maximise performance.

To further drive engagement, the building utilises 122 energy meters, to monitor the power consumption of every piece of equipment and building circuit. In addition to these primary meters, the power usage for each individual power strip supplying each occupant's desk is monitored through a metering programme. Users can view the high-level results from a touch screen dashboard in the building lobby, or they can dig deeper into more granular data, using online platforms. This data has also been instrumental in continued commissioning of building systems and troubleshooting issues.

5. RECORDED CHALLENGES

The project team met with a number of design challenges in the development of the RMI Innovation Centre. Chief among these was the task of meeting the goal of net-zero energy for an office building in the coldest climate in the US.

Finding products with the proper performance and specifications presented an additional challenge. For instance, the windows needed to meet all of the following objectives: they needed to be operable, they needed to be automated to allow for night flush/natural ventilation, and they needed to be meeting stringent energy-performance specifications for the cold climate (U-value and air-tightness). The building energy controls also had to be designed correctly, to ensure that 'active' and 'passive' strategies functioned as intended for motorised exterior shading, automated operable windows, night flush, and backup electric resistance heating.

6. LESSONS LEARNT FROM THE PROJECT

The project team came away from the project with a number of lessons learnt:

1. With careful planning, net-zero-energy retrofitted building can be cost-effective and not difficult to achieve;

2. Commissioning and monitoring of the building systems is absolutely critical to achieving the desired levels of performance;

3. Tenant engagement and education is crucial to meet net-zero-energy goals;

4. Integrated project delivery is useful to help manage cost, contracts, and risk; and

5. A commissioning agent or controls expert must be engaged from the start of the design process, to check specifications, provide input, tackle system interoperability issues, and overcome scope gaps.

5.3.5Desktop case study 4

China: MGM Macau Resort

1. MOTIVATION FOR SELECTION

The sprawling resort of MGM Macau boasts nearly 600 guest rooms, suites and villas, plus casino facilities and amenities. With a property this enormous, energy management has always been the key focus. It is vital to see how energy retrofit is done in such an edifice.

2. TYPE OF RETROFIT PROJECT

It was a deep energy retrofit that focuses on continuous improved energy efficiency and reduction in energy consumption.

3. PROJECT DETAILS

The MGM Grand Hotel and Casino occupies prime waterfront land in Macau's central Nam Van gaming district in China. The 600-room, 35-floor unique structure of shimmering glass reflects the South China Sea. Its striking architectural design was inspired by the waves of the ocean surf that it overlooks. In March 2009 the management set out to retrofit the building.

4. KEY RETROFIT FEATURES OF THE PROJECT

MGM Macau initiated several modifications to improve the energy efficiency of the facility:

1. The chilled water network was designed as a de-coupler system, with two de-coupler bypasses. The chilled water design supply and return temperatures were 7°C and 12°C (45°F and 54°F), respectively. The team disabled the de-coupler bypasses and converted the system into a full variable primary system. The result was a reduction of 876,196 kWh (41%) of pumping power in the first year post-modification.

2. The secondary sides of the –7°C (19°F) heat exchangers' differential bypass were replaced with a variable-speed pumping system, using variable-speed drives. The on-off-type control valves on the primary sides of the heat exchangers were replaced with modulating valves. This has reduced the pumping power on the secondary sides of the plate heat exchanger and has improved the distribution transformer on both sides.

3. The oversized cooling water pump impellers were trimmed, with all the springs inside the constant-flow valve serving each chiller removed. The cooling water flow was carefully balanced using manual butterfly valves.

4. Variable-speed drives were installed on all cooling tower fans. During spring and autumn, there were 2 × n numbers of cooling fans in operation, with n number of operating chillers.

5. Chilled water supply temperature was reset linearly and inversely against outdoor air temperature, to minimise chiller power use, by reducing chiller lift between evaporators and condensers.

Boiler plant modification

The boiler plant initially consisted of two liquefied petroleum gas-fired (LPG-fired) steam-tube boilers, with an output of 7,800 kg/h at 10 bar (17,196 lb/h at 4,014 in. w.c.). The transferred energy was provided to facilities in the hotel and casino areas for pool heating, laundry, kitchens, space heating, and domestic hot water. After a feasibility study, the two larger boilers were replaced with two 1,500 kg/h (3,301 lb/h) smaller boilers as the primary source of steam for kitchens, laundry, and the pool, with three new 880 kW (250 ton) heat pumps at N+ 1 configuration. The heat pumps were installed to serve as the heat source for space heating, space dehumidification reheat, and domestic hot-water heating. One larger boiler was kept and not removed, to cater for extremely low-temperature weather, e.g. below 8°C (46°F) outdoor temperature.

Conversion to fan coil motors

There are 1,000 fan coil units (FCUs) in the nearly 600 guest rooms, suites and villas. All existing capacitance motors/fans were removed from the FCUs and replaced with electronic commutated motors. All FCUs are connected via a wireless mesh network through digital thermostats to the hotel management system, which can determine the room temperature and the on/off status of the FCUs, depending on occupancy.

Other retrofit measures

1. Variable-speed drives were installed for exhaust fans in busy kitchens, so the chefs can select cooking mode (normal speed) or standby mode (reduced speed) of fan operations.

2. Air handling unit (AHU) economiser mode was introduced to enable free cooling of indoor spaces when the outdoor temperature is low. Enthalpy wheels were also installed in AHUs to facilitate pre-cooling/pre-heating of outdoor air.

3. Programmable thermostats are used to control runtimes, fan speeds, and minimum adjustable temperatures of the FCUs in the back of house office areas.

4. Over 95% of the traditional halogen, filament, fluorescent, and cold cathode lighting at MGM Macau was replaced with LED lighting, resulting in an annual electricity reduction of 4,807,462 kWh. In addition, timer switches are used in plant rooms, and daylight sensors are used to control the operations of aesthetic façade lighting on the building perimeter.

5. Introduction of the primary variable system has helped to significantly reduce the maintenance cost of the chiller plant, through the removal of the 10 primary chilled-water pumps and the related pipe-work.

6. Energy-monitoring dashboards were installed to enhance staff buy-in and visibility. MGM Facilities Management introduced a plant-monitoring energy dashboard, which tracks the energy performance of both the chillers and the heat pumps. Regular reporting is done on the chillers and the heat pumps, and month-to-date electricity consumption of various components is measured. Monthly utility summaries are created automatically and are reviewed regularly, to ensure that the chiller plant and the heat pumps are running in optimal

condition. Energy consumption data is stored in 15-minute intervals, which allows International Performance Measurement and Verification Protocol (IPMVP)-compliant energy-saving projects, analysis of plant operating data through the monitoring-based commissioning (MBCx) platform, and record-keeping for the ISO50001 system, in which MGM Macau is certified. By deploying the energy-performance dashboards in addition to the Building Management Systems (BMS) functional dashboards, the contractors have strengthened data visibility and have made energy management part of the BMS control operation. This allows feedback on initiatives and operational issues, where lessons are learnt and mistakes are not repeated.

5. RECORDED CHALLENGES

The MGM Grand Hotel project is very complex, influenced by a wide range of HVAC systems. Several challenges were experienced such as ability to quantify and compare the relative cost and performance attributes of a proposed design in a realistic manner and even integration of experts in the project and optimal installation of technical requirements, as envisaged during the start-up of the project.

6. LESSONS LEARNT

Building energy retrofit is better served where building energy simulation is properly undertaken and tasks are properly assigned and integrated. This will help to engender sustainability in the delivery process.

5.4 DISCUSSION OF THE FINDINGS FROM THE CROSS-CASE ANALYSIS

The cross-case case analysis draws upon the findings of each case study and sets out to find literal replication across each case. This analysis provides significant evidence of literal replication. It is summarised in Table 5.6

.

Table 5. 6 : Literal replication from the cross-case analysis (desktop cases)

Theme	Szencorp Building, Australia	Zero Energy Building, Singapore	Rocky Mountain Institute Innovation Centre, USA	MGM Macau Resort, China
Retrofit features	Occupier integrated controls system of sensors, on-site power generation from different sources, including multiple solar arrays and ceramic fuel cell, and natural ventilation throughout. Automated opening windows were also installed. The lighting utilises new-generation triphosphor and T5 lamps, dimmable DSI ballasts controlled via an intelligent occupancy-based system, achieving 1.4 watts per 100 lux. An integrated sensor and management system for occupancy lighting. HVAC and security control were	An integrated approach was adopted in engendering deep retrofit in the building. For example, a solar chimney system was chosen for natural ventilation for the building. In tackling thermal gains, the strategy was to add a cooling skin to the building envelope. The cooling skin served additional purposes beyond shading. Some sun shades on the façade had PV modules on the upper parts, generating additional electricity. Others had reflective films, doubling as light shelves, redirecting daylight deeper into the building. The green walls and the roof system support the study of their shading and evaporative cooling effect on reducing heat transfer and resulting cooling	By managing solar gain during the summer and maximising it during the winter, the design team was able to eliminate mechanical cooling and reduce heating systems to a small distributed system. The building is framed with structural insulating panels (SIPs), providing the dual benefit of continuous insulation and air-tightness. Before occupying the building, staff received a short but in-depth training session on the building's design, performance goals, technologies and systems, to ensure that	The chilled water network was designed as a de-coupler system, with two de-coupler bypasses. The team disabled the de-coupler bypasses and converted the system into a full variable primary system. Chilled water supply temperature was reset linearly and inversely against outdoor air temperature, to minimise chiller power use, by reducing chiller lift between evaporators and condensers. There are 1,000 fan coil units (FCUs) in the nearly 600 guest rooms, suites and villas. All existing capacitance motors/fans were removed from the FCUs and replaced with electronic commutated motors. All FCUs are connected via a wireless mesh network through digital thermostats to the hotel management system, which can determine the room temperature and the on/off status of the FCUs, depending on occupancy. Energy-monitoring dashboards were installed to enhance staff buy-in and visibility. MGM Facilities Management introduced a plant-monitoring energy dashboard, which tracks the energy performance of both the chillers and the heat pumps. Regular reporting is done on the chillers and the heat pumps, and month-to-date electricity consumption of various components is measured. Monthly utility summaries are created automatically and are reviewed regularly, to ensure that the chiller plant and the heat pumps are running in optimal condition.

	also installed. The ceiling height was increased, allowing for use of thermal mass for improved energy efficiency.	energy use. In addressing day-lighting, an innovative design concept was to direct the windows towards the sun, or rather to collect the zenith light from the roof and the façade and redirect it to where it is needed.	everything was operating as intended, to maximise performance.	
Recorded challenges	Selection of the right retrofit components for the building, developing a performance-based design, engineering capacity, and developing financial modelling for the project	The use of building space use may change over time, considering its nature. There were some difficulties, mainly due to the lack of experience and craftsmanship in installing green building technologies properly on-site. Most of the extra work was supported by the accompanying research projects, which also brought in foreign experts and their experience.	The project team met with a number of design challenges in the development of the RMI Innovation Centre. Chief among these was the task of meeting the goal of net-zero energy for an office building in the coldest climate in the US. Finding products with the proper performance and specifications presented an additional challenge.	The project is very complex, influenced by a wide range of HVAC systems. Several challenges were experienced such as ability to quantify and compare the relative cost and performance attributes of a proposed design in a realistic manner and even integration of experts in the project and optimal installation of technical requirements, as envisaged during the start-up of the project.
Lessons learnt	The Szencorp Group looked at life-cycle costing when undertaking this	The integrated design process with all stakeholders at the early stage of the project was	Tenant engagement and education is crucial to meet net-zero-	Building energy retrofit is better served where building energy simulation is properly undertaken and tasks are properly assigned and integrated.

	retrofit.	beneficial in setting the stage and identifying best practices. The design-build-operate approach was also beneficial, as it considered the operational costs, too, which are usually ignored in the standard design-build-sell approach.	energy goals. Integrated project delivery is useful to help manage cost, contracts, and risk. A commissioning agent or controls expert must be engaged from the start of the design process, to check specifications, provide input, tackle system interoperability issues, and overcome scope gaps.	

Source: (Researcher, 2018)

5.5 SUMMARY OF THE FINDINGS

From the projects reviewed, it can be deduced that no two energy retrofit project deliveries are the same. The retrofitted case study buildings show that each building has its own unique retrofit features. This can be attributed to different factors, such as the building orientation, the building assessment, the detailed energy survey, the technical analysis, the retrofit technologies used, the cost-benefit analysis, the nature of the building, the implementation plan, and the geographical location, as identified in the study (see section 5.3). Research has suggested that no single solution or intervention is capable of delivering substantial reductions in energy usage, and, instead, a series of measures is uniquely required as per each project (Hewitt, 2012: 3).This is shown in the reviewed projects. While there are numerous technologies that have the potential to address carbon emissions in existing buildings, there remain problems associated with their deployment, which is clearly identified in the study. This entire consideration makes each building energy retrofit project optimisation a problem. However, in addressing this problem, an integrated approach should be adopted and tasks should be properly assigned and integrated (Hewitt, 2012: 3; Pielke, 2010: 770).The action should be targeted at making the best use of a situation or resource in implementing energy efficiency(EE) drives in any energy retrofit project delivery. The previous two sections have presented research findings from projects conducted across the globe. The following section continues this thread of investigation, with eight interviews of post-retrofit projects in South Africa.

5.6 INTERVIEWS

The interviews were conducted in South Africa, where the researcher undertook visits to the projects. The projects were undertaken with significant input from the project team members.

Interviews provide a unique opportunity to obtain insight into the actual running of a BER project, revealing the approach and skills of the project team. As an observer, the interviews provide greater understanding of how projects are being managed and how they contribute to informing the researcher on how best to achieve the research objectives.

5.6.1Selection of interviews

Information for the interviews was collected from project documents and by obtaining further details from the project leaders, team members, project partners and project recipients. This data collection is also to act as a confirming link between the literature review, the pilot interview, and the data collection in the form of the desktop projects.

- The interviewees were building energy retrofit experts who were selected based on their profession, their willingness to participate in the study, their experience, and their interest in improving the field of research. All participants were provided with an information guide about the study, and they consented to the interview by completing and signing a consent form. The interviews were descriptively analysed.
- The textual data presented here follows emergent themes from the interview. These include:
  - Theme 1: To see how the current best practices mentioned in section5.3 are being implemented in the delivery of energy retrofit projects,
  - Theme 2: To see how the key elements mentioned in section 5.4 are being integrated in energy retrofit of an existing building,
  - Theme 3: To see how the challenges mentioned in section 5.5 are prevalent in management of energy retrofit of an existing building, and
  - Theme 4: To seek potential improvement for the delivery of energy retrofit of an existing building.

5.6.2Data collection and analysis

Firstly, the main themes for this interview were gathered from the pilot interview (see section5.3). Information from the interviewees was gathered through the use of a digital recording device, which was clearly identified to them prior to the start of the interview, to confirm their consent to be recorded. The recording device allowed the researcher the opportunity to concentrate fully on the responses, although notes were also taken during and after the recording. These notes were taken into account during data analysis. Each interview was transcribed and underwent a series of coding exercises related to themes, relationships, and differences regarding the subject matter. Table 5.7 provides a profile of the interviewees.

Table 5. 7 : Analysis of participants in the interview

Category	**Classification**	**Frequency**	**Percentage (%)**

Gender	Female	1	16%
	Male	5	84%
Years of experience	5–10 years		
	10–15 years	1	16%
	15–20 years	4	68%
	20 years or more	1	16%
Profession	Architect	1	16%
	Electrical engineer	1	16%
	Facility manager	1	16%
	Mechanical engineer	2	36%
	Client	1	16%

Source: (Researcher, 2018)

This section justifies the suitability of the participants for this component of the study. The participation of professionals from building energy retrofit projects (BERPs) in this interview is paramount for obtaining in-depth analysis. The sample of respondents comes from diverse professionals who are saddled with such responsibility.

The balance of thought from the variety of professionals in different organisations and levels of experience was intentional. With an average of 16 years of experience in the field of BERPs, the experts are not only able to highlight the multiple issues for managing BER projects but also to demonstrate with their expertise the interconnectedness of the profession itself, and to inform on gaps which need to be filled. Consequently, six respondents were interviewed across 14 retrofitted projects in South Africa.

5.7 FINDINGS FROM THE INTERVIEWS

The line of inquiry for the interviews focused on how the themes identified earlier (see section 5.7.1) were applied across the projects, and the relevance of issues highlighted through the semi-structured interviews, reported on in section 5.3. The analysis of the findings is done thematically.

5.7.1Theme 1: To see how the current best practices mentioned in section 5.3 are being implemented in the delivery of energy retrofit projects

Most of the interviewees stated that in their projects a thorough building assessment was carried out, with the intention of determining current energy consumption, performance level of the building, and even collection of electricity bills for at least one year, to ascertain total energy used, which includes both purchased electricity and that generated on-site, but excludes renewable sources of electricity. In addition, they added that the energy performance index (EPI) needs to be calculated. The EPI is the ratio of total energy used to the total built-up area. They said that the EPI should then be compared with EPI standards with similar characteristics. The interviewees claimed that a detailed energy survey is conducted in order to identify needs, current operating and maintenance procedures, and existing operating conditions of HVAC, etc., so as to estimate occupant behaviour, energy use density, and hours of operation. According to the interviewees, these steps are carried out systematically in order to carry out a technical analysis, which assists in formulating an action plan for improving building energy performance, thereby benchmarking assessment to work out the best option for energy efficiency retrofit. Four of the six interviewees added that a cost-benefit analysis is undertaken to know the financing option to choose for the project. Two of the four interviewees said that they choose a self-financing retrofitting model. The other two said that they choose to partner with an energy service company (ESCO) and guaranteed savings contracts, respectively, in delivery of their building energy retrofit project.

In the area of energy efficiency measures implementation, the interviewees explained that thorough project planning is carried out to assign appropriate timelines to each retrofit activity. Of the six interviewees, three have a package that they use to educate the maintenance staff or the tenants about building efficiency measures used in the facility and their functionality, and subsequently to monitor operations for further improvements in terms of potential cost and savings.

5.7.2 Theme 2: To see how the key elements mentioned in section 5.4 are being integrated in energy retrofit of an existing building

Simply put, all the interviewees concur that they make sure at all times that they engage with the relevant stakeholders, such as government departments, property owners that own or operate the buildings that are to be retrofitted, and potential financiers, so that a high level of synergy is achieved moving forward. They added that the background of the tenant and their behaviour is paramount. They went on to say that understanding the existing building structure and systems, understanding the scope and costs of planned or needed renovations, and understanding what components of the building require replacement for energy reasons is crucial for the success of the energy retrofit.

5.7.3 Theme 3: To see how the challenges mentioned in section 5.5 are prevalent in management of energy retrofit of an existing building

Many challenges were mentioned by the interviewees. For instance, tenants genuinely complain about eye problems when the LED/T5 lights are installed, and the difficulty in decanting staff, especially when the building is a multipurpose building, which is often the case with government buildings. They stated that stakeholders are reluctant to cooperate with energy retrofit initiatives.

Four of the six interviewees stated emphatically that stakeholder management is difficult with respect to collaboration and cooperation. For instance, they mentioned that they always face a huge challenge when they are making a business case with the sponsors and the end user. According to the interviewees, most government projects do not have funding for retrofit. They said that the government always approaches ESCOs to finance government projects, and that this is a daunting task. In some cases the interviewees said that there are no existing drawings to work from, which makes energy retrofit projects a tedious task. The issue of changes in technology and challenges in the rate in retrofitting were also highlighted by the interviewees.

5.7.4 Theme 4: To seek potential improvement for the delivery of energy retrofit of an existing building

According to the interviewees, a detailed communication strategy should be developed and must be practically-driven; to inform the occupants on step-by-step procedures and the benefits of each activity that is going to be undertaken. This will ensure total buy-in among stakeholders. In addition, put it that raising awareness and promoting behaviour change through communication and education must be a push-up approach against a pull approach to the stakeholders. That this initiative should be created before energy retrofit activities and should be sustained after these activities. They added that there is a need to develop behaviour change initiatives in parallel with technological change, in order to maximise the benefits of both. Those occupants with genuine complaints as a result of post-retrofit activities should be acknowledged, and the issues highlighted must be addressed, according to the interviewees.

In the same argument, the interviewees reported that experience has shown that behaviour change can achieve energy savings of up to 5–15%, and that such initiatives must be intentional. For example, facilitating conditions for behaviour change is at least as important as trying to influence it directly. Behaviour change is most effective when a number of levers are pulled, in a coherent, coordinated and systematic way. The client and their wider partners need to be seen to be leading by example. Behaviour change needs to be coordinated across sectors and sections of society. Policies aimed at changing behaviour need to be simple and transparent. Awareness raising and information provision alone does not work effectively, but does work better when tailored to the target audience.

Feedback, for example the displays on smart meters, needs to be designed to prompt action. For instance, most occupants will be more receptive to financial savings than to energy or emissions savings, and substitute behaviour needs to be more attractive than the default. The interviewees went on to conclude that consultation, collaboration, and cooperation should be improved, as energy retrofit is a multifaceted activity, where different trades complement each other.

5.8 DISCUSSION OF THE FINDINGS FROM THE CROSS-CASE ANALYSIS

The cross-case analysis draws upon the findings of each case study and sets out to find literal replication across each of the cases. Of the 14 cases, eight were found worthy for this exercise. The cases were government administrative buildings. This analysis provided significant evidence of literal replication and is summarised in Table 5.8 below. The following sections draw upon the dominant aspects, which contribute to the development of the artefacts.

Table 5. 8 : Literal replication from the cross-case analysis (live cases)

Case	**Theme**
	Retrofit features
Case study A	Solar water heaters (SWHs) and pipe reticulation systems were installed to deliver hot water directly into the house. They were SABS-approved 100-litre low-pressure evacuated tube-type systems with no electrical backup connection. A 30mm-thick Iso-

	board (insulated ceiling board) with a thermal resistance value (called the "R-value") of 1 was installed to improve thermal performance in the home. A Wonder-bag, a locally produced heat-retention cooker, was adopted. The Wonder-bag is a highly efficient insulation cooker that saves energy and makes the kitchen much safer. Insulated roof paint was used to reduce internal heat and maintain a more balanced temperature.
Case study B	Building energy improvements at the building include the building envelope, interior lighting, heating, ventilation, and air conditioning (HVAC), and plug loads. This was achieved by replacing double-pane windows with triple-pane windows, upgrading to energy-efficient lighting fixtures throughout active areas (excluding equipment rooms), replacing fixtures with light-emitting diodes and additional occupancy sensors, installing occupancy sensors in conference rooms and equipment rooms, upgrading service elevator fixtures to 28-watt fixtures, and converting the constant-flow primary chilled water system to a variable-flow system.
Case study C	Optimal start/stop was implemented for all the major air handling units, and outside air dampers are closed during unoccupied hours, when outside-air enthalpy is greater than return-air enthalpy. Static pressure-reset air handling units were implemented, and dry, cooler heat is recovered for space conditioning. Variable-frequency drives were installed on fans, and only one condenser water pump is operated during low loads.
Case study D	Lighting design was optimised, with side light from windows and sensor placement. Each fixture includes day lighting and occupancy sensing in the open office as part of the controls system. The project utilised automated exterior shades and light shelves to balance and control daylight, glare, and heat gain. Task lighting is also used at individual workstations, to reduce the need for overhead lighting. An Energy Star-rated reflective roof membrane and high-performance glazing minimise heat gain and energy demand for the building. Due to the nature of the office occupancy and the low-energy design and technologies, the plug loads are by far the biggest energy end use of the project. The building has installed circuit-level metering in occupied spaces, which provides information about energy use at the space level to the operator and gives tenants real-time feedback about their plug energy use via central dashboard displays. In addition, all loads must be connected to advanced power strips that have occupancy sensors, to reduce energy use during unoccupied periods.
Case study E	The team investigated all opportunities for improvements during building assessments. Lighting upgrades are an obvious opportunity for energy savings. Beyond that, the team conducted walkthrough inspections of the building envelope and energy-using equipment, to further determine building energy usage and energy-conservation opportunities. The team installed high-quality LED-fixture replacements and occupancy sensors in classrooms and common areas. HVAC systems were upgraded to higher-performing DX Cooling (4 ton @ 16.4 SEER; 6 ton @ 13 EER/20.3 IEER) with improved heating efficiency (82%) with a differential dry-bulb economiser. At the building a software dashboard was installed to track and display real-time energy data from the building. Building tenants will be able to access the dashboard to view real-time energy consumption and savings due to behaviour change.
Case study F	Since day lighting is known to enhance occupant comfort and well-being, as well as push energy use intensity (EUI) and power needs down, the team prioritised access to natural light, through skylights, windows, and doors, during the renovation. The building's interior concrete walls and slab serve as an outstanding heat sink, however

	insulation had to be added on the exterior walls so the thermal mass was exposed on the interior and available to exchange with cool air in the evenings. Using a ceramic-based coating, five 5/8 inch-thick polystyrene strips were adhered to the outside of the building all the way down to the concrete slab. The concrete floor also acts as thermal storage, so the carpet was excluded from the design and is discouraged in tenant renovations. The addition of the insulation to the outside rather than the interior walls also added 326squarefeet of leasable space, adding 6 inches all the way round the building. After completion, the walls now have an R-20 insulatory value. Actuators open the skylights, and ground-level windows, and rising hot air is moved by eight-foot steel fans, as part of a night-flushing programme for pre-cooling of the thermal mass in the warmer months. Other perimeter windows are also operable for tenant adjustment. As part of the passive flow for the space, conference rooms and other larger spaces are located at the perimeter, so they can be passively heated and cooled. The HVAC system consists of two air-source heat pumps, which serve as the backup heating and cooling for the passive systems of the building. The HVAC system is 22% of a traditionally sized system
Case study G	Despite the fact that the existing building contained few windows, and only two façades offered daylight, day lighting is now the primary source of illumination. Property lines and building codes prohibited the design team from adding façade fenestration to bring in more daylight. Instead, they optimised the roof to enhance day lighting opportunities, by including 22 prismatic-lens skylights, four solar tubes, and two north-facing light monitors, to strategically illuminate workspaces and circulation paths. Interior glass walls (known as relights) distribute this light throughout the office and work to provide even light levels. Exterior glass curtain walls bring diffuse daylight into the lobby from the north and the east. High-efficiency LED lights supplement these day lighting strategies when the natural light levels decrease below an acceptable value. A highly efficient envelope helps reduce heating and cooling loads in the building, which allowed for downsizing of the HVAC system. Interior batt insulation and 3-inch rigid insulation yield an R-value of 38, a level twice as efficient as that required by energy code. Roof insulation, with 1-inch wool in addition to the batt and the rigid insulation of the walls, offers a 30% improvement above code, with an R-value of 40. All windows use glazing units that exceed code for solar heat gain coefficient (SHGC), with the curtain wall offering a U-value of 0.35 and an SHGC of 0.5. After addressing lighting, the reduction in cooling loads offered the most dramatic savings. The design team was unable to incorporate natural ventilation, because security concerns for the building prohibited additional openings in some rooms. The HVAC system needs to run year-round, so efficiency of the system was crucial. Three large high-volume low-speed fans circulate air more evenly, keeping occupants comfortable in both summer and winter. An intelligent HVAC system uses an efficient single-zone variable-air-volume (VAV) system. Controls sense room temperature and automatically adjust the frequency and the volume of air released, as needed. The system prevents overheating and overcooling, which typically account for a high

	percentage of energy use in buildings built to code.
Case study H	During planning and design, the team looked closely at how spaces were being used. They noticed that zoned HVAC systems were on a time clock, but sometimes they were heating and cooling empty rooms or rooms with doors open to the outside. The team chose to add interlock door controls to in the Bard units, to minimise energy use, while allowing for natural ventilation. These interlocks recognise when the door has been left open for a period of time and they turn off equipment, to avoid wasting heating, cooling and fan energy. Originally, the building had one boiler and five gas water heaters and one boiler sized to serve the kitchen, the locker rooms, and the bathrooms. The standard hot-water heaters were installed in 1998 and had 78% efficiency. When designed, the boiler was expected to serve the hot water demand for daily showering in the school locker rooms. However, this was no longer the case. As a result, the system continuously reheats a large volume of water that isn't being used. A key part of this retrofit was to replace two of the water heaters with tank-less-wall-mounted condensing water heaters, with a thermal efficiency of 92%. The gym shower boiler was replaced with a smaller, more efficient condensing unit, with a thermal efficiency of 95%.
Case	**Theme**
	Recorded challenges
Case study A	Active stakeholder engagement was problematic throughout the project, particularly with the tenants, and the project team had to work with a poorly constructed, under-maintained building.
Case study B	The building was built more than 50 years ago, and over its history it has seen several major renovations, additions and reconfigurations. Engineering drawings produced over the years show only incremental changes for each project, and it is thus a challenge to find and extract reliable information.
Case study C	Many of the technologies used in the building are rare and cannot be directly modelled. In addition, the building has changed ownership over time, and this limits the ability to obtain utility bills.
Case study D	A major challenge in working towards a widespread goal of energy improvement lies in monitoring the building's energy consumption and generation. The owners experienced an increase in the cost of monitoring services for the building's PV system, and they discontinued the service. This means they no longer have a record of how much energy the system produces each month. Although utility bills show the net metered amounts, i.e., the difference between energy consumed and energy produced by the building each month, the bills do not include total energy consumed. This makes understanding energy consumption and calculating gross energy use intensity (EUI) or renewable production intensity (RPI) difficult.
Case study	Stakeholder engagement was problematic, as was building of a business case for the project.

E	
Case study F	One challenge was that much of the technology used in the project was new to the market and may not have performed the way it was intended. In this case, the lighting sensor technology did not perform as expected, and it took tuning time for it to work as part of the Omni-control system. Multiple members of the original design team carried out commissioning. The general contractor, the master system integrator, and the rest of the design team continued to manage and adjust the Omni-control system and monitor the building operations post-occupancy.
Case study G	The amount of top lighting and the number of PV modules necessary for the project resulted in a substantial increase in the roof load, which required an upgrade to the structure. These improvements may have been more cost-effective if an entirely new roof had been constructed, rather than reusing the existing roof structure.
Case study H	Incorrect assumptions are a common risk of modelling, especially when the facility may only have one master meter.
Case	**Theme**
	Lessons learnt
Case study A	Impact measurement needs to be set up in advance and undertaken over a longer term, for at least a year after installation. Electrical rewiring is often required for a retrofit, especially in low-income housing, where many installations are not compliant with safety standards. Measurement of energy savings is very difficult in a low-income context.
Case study B	The overall lesson is that detailed models can be useful to examine interactive effects across building systems, but their cost and overall accuracy may be questionable in the building. Modelling requirements and limitations need to be recognised and made a part of project planning.
Case study C	The most important lesson is to take action and to use knowledgeable people to guide and implement improvements.
Case study D	Through its thoughtful retrofit design, project managers discovered that a highly efficient building could be created by simply selecting the most efficient mechanical and electrical components individually. The result is a flexible building system which is cost-effective and which operates as a net-zero-energy building. The creative design process used for this project resulted in a loose prototype for an ultra-efficient warehouse retrofit, which can be readily applied to other building retrofits across the country.

Case study E	Understanding occupancy and use patterns provides energy modellers with detailed information that can be used to most accurately calibrate energy model predictions. Engaging stakeholders is an investment in cultural change regarding energy efficiency. This has been seen to be essential for achieving improved energy efficiency.
Case study F	Lessons learnt include taking into account the effect occupant education has on energy consumption and the adjustment period for tenants. Building operators learnt the importance of involving commissioners throughout the entire construction process, so that issues can be resolved before the building is occupied.
Case study G	Building operators learnt the importance of involving commissioners throughout the entire construction process, so that issues can be resolved before the building is occupied. They also recognise the value of getting meters working as soon as possible, so that trends in energy use can be observed sooner and issues can be corrected early. There is an ideal balance point between energy efficiency and renewable energy generation, which should be targeted. Given the decreasing cost of solar energy systems, the building owner needed to consider the cost and the trade-offs of investing in energy efficiency versus additional renewable energy systems to achieve net-zero energy.
Case study H	During design it was important to understand how the spaces were being used in their retrofit design. They decided that choosing equipment with capacity to turn off lighting and HVAC equipment was very important for saving energy and streamlining system use during the design process. Sub-metering was installed pre-construction, and it will be used after construction to evaluate the actual energy savings of building retrofits.

Source: (Researcher, 2018)

5.9 SUMMARIZED CROSS-CASE INSIGHTS

Each individual case was analysed, and the findings were presented separately against the three themes which were established as a guide for the researcher in relation to the research objectives posed in section 1.6 of this research study. The findings clearly indicate the following with regard to delivery of building energy retrofit projects:

- In all eight cases (A to H), the delivery of the project is different in all the buildings;
- This is as a result of factors such as the orientation of the building, the technical analysis, the retrofit technologies used, and the technical know-how, as Hewitt(2012: 3) suggested;
- In all the cases, energy efficiency initiatives were implemented as the project managers deemed fit for their purpose;
- In the majority of the cases, active stakeholder management was highlighted as being problematic in delivery of the project;
- In the majority of the cases (A, B, D, E, F, and H), insufficient technical information was identified as challenge, as such making delivery a difficult task;

- In all the cases, a building assessment was carried out before any energy efficiency (EE) drives were implemented;
- In case study D, the owners experienced an increase in the cost of monitoring and verification services for their PV system, and, as such, they were discontinued;
- In case study F, one challenge that arose was that much of the technology used in the project was new to the market, and, as such, it may not have performed the way it was intended;
- In case study A, it was revealed that impact measurement needs to be set up in advance and undertaken over a longer term, for at least a year after installation;
- In case study B, it was revealed that detailed models can be useful to examine interactive effects across building systems;
- In case study D, the project managers discovered that a highly efficient building could be created by simply selecting the most efficient mechanical and electrical components individually;
- In projects E and F, the project managers claimed that engaging stakeholders is an investment in cultural change regarding energy efficiency. This is essential for achieving improved energy efficiency. They claimed that it is also important to take into account the effect occupant education has on energy consumption and the adjustment period for the tenant; and
- In case study G, it was highlighted that the importance of involving commissioners throughout the entire construction process is that issues can be resolved before the building is occupied**.**

This section and the previous three sections have presented the research findings from the interviews conducted across South Africa. The following section continues this thread of investigation with experts, in the form of focus group interviews.

5.10 FOCUS GROUP INTERVIEWS

The purpose of the focus group is to gain a range of opinions, so that consensus and differences will have credible explanations. The focus groups adopted allowed the researcher to focus on the targeted groups of people in the study location. It also enabled the researcher to answer the "what" (narrative content) and "how" (narrative procedures) questions in the set research questions (Jordan et al., 2007: 5). The focus group members were drawn from organisation that has delivered a BER project across South Africa. Table 5.9 provides a demographic profile of the experts that participated in the focus group interviews.

Table 5. 9 : The demographic information of the various firms in this study

Group	Experience (years)	No. of participants	Coded names
A	**>15**	**5**	**A_1 to A_5**
B	**>13**	**5**	**B_1 to B_5**
C	**>15**	**4**	**C_1 to C_4**
D	**>15**	**5**	**D_1 to D_5**

E	**>10**	**4**	**E_1 to E_5**

Source: (Researcher, 2018)

Table 5.9 shows the demographic information of the selected groups in this study. For ethical reasons, the names of the organisations are referred to by letters of the alphabet, as shown in the table. In this study, the criteria adopted by the researcher for the selection of the participants for the focus group interviews were based on purposive sampling techniques (Ritchie, Lewis and Elam, 2003: 77; Teddlie and Yu, 2007: 77), that is, participants that have extensive work experience in building energy retrofit projects were deliberately chosen in South Africa.

5.10.1 Justification for the choice of focus group participants

Regarding participant size, Stringer (2014: 111) states that the number of participants should be such that each member should have the opportunity to articulate their views based on the experience they have on the issues under discussion. Supporting the views of Merton, Fiske and Kendall (1990: 137) and Stringer (2014: 111) on focus group size, Gray (2014: 472), Stewart, Shamdasani and Rook (2007: 42), and Strickland (1999: 190) argue that in a focus group study a researcher is expected to determine the required number of participants to be recruited, and the criteria governing the recruitment exercise solely depend on the opinions of the researcher. Masadeh (2012: 65) argues that there is no appropriate or specific number of focus groups for scientific research, and that a researcher may continue running the study from one focus group to another until a clear pattern emerges, or until subsequent groups produce theoretical saturation. However, several authors, such as Evmorfopoulou (2007: 17), and Krueger and Casey (2015), suggest that for clear and understandable research questions that yield similar opinions from different groups, the number of groups may be limited to only three or four. Based on the views of Burrows and Kendall (2017: 244), Evmorfopoulou (2007: 17), and Krueger and Casey (2015), it can be deduced that the number of cases established for this study was adequate.

5.11 PERCEPTIONS OF INTERVIEWEES

Following the thread of information discovered thus far, the researcher deemed it necessary to conduct focus group interviews, so that consensus and differences would have credible explanations. The interview questions were analysed thematically.

5.11.1 Theme 1: Best practices for building energy retrofit

In groups A, B, C, D and E, participants stressed that it in any building energy retrofit project, there is always a best practice to be followed. Each best practice is unique to the contractors involved in the delivery process. However, participants in groups B, C and D listed and concurred on the following activities that constitute building energy retrofit best practices:

> *Step 1is to evaluate the characteristics of the energy systems of the existing building and the behaviour patterns of the tenancy. Step 2 is to identify potential energy-saving measures and the technicality required. Step 3 is to develop a base-case model, using energy analysis and simulation tools, that represents the existing energy use and operating conditions of the building. Step 4 is to list cost-effective energy-conservation measures, using both energy-saving and economic analysis.*

Step 5 is to implement an energy efficiency drive. Step 6 is to monitor and verify what has been installed, for continuous improvement.

Regarding a building analysis, all the participants in groups A to E stated that in any given project *"a thorough building analysis needs to be undertaken"*.

A_1, A_5, B_1, B_2, B_3, C_2, C_3, D_1, D_2, D_3, E_1, E_2, and E_3 concurred that *"a building analysis helps you to achieve your building's energy-saving potential and amortise the investment cost"*.

Supporting the above statement, A_2, A_3, B_5, C_5, and E_5 asserted that

> *Analysis conducted during the planning cycle is supported by different energy efficiency tools, to ensure an in-depth analysis and reliable estimates of energy savings. These tools also help secure a sound base for the improvement of building automation and control. Based on the identified potential, an action plan with appropriate measures is suggested to ensure that you sustainably reach your saving targets.*

The participants in group D articulated that *"the impact of a building analysis is to better leverage the energy-saving potential for control and operation of buildings"*.

The rest of the participants concluded that *"[t]hanks to this norm, the energy-saving potential resulting from a building analysis can make items work to be specified, thus enabling one to derive measures that improve energy efficiency in an existing building"*.

Based on the opinions of the participants in all the groups, it can be concluded that a building analysis is worth being adopted in any building energy retrofit project. This is observed in the previous findings of the study (see Table 5.9above) and is supported by the literature (see Al-Ragon, 2003: 2310; Chidiac, Catania, Morofsky and Foo, 2011: 614; Ma et al., 2012: 895; Mahlia, Abdul Razak and Nursahida, 2011: 1126), which confirm that it is imperative to conduct a building analysis in any building energy retrofit project.

Developing energy efficiency measures

Participants in all the groups pointed out that energy is consumed in the buildings, where it is used for space heating, cooling, ventilating, lighting, cooking, water heating, refrigerating, and operating electrical and mechanical devices.

They made it clear that there is *"an array of proven technologies, policies, and financing mechanisms to improve energy efficiency and capture cost-effective energy savings in buildings"*.

Participants A_1, A_2, A_3, C_1, C_3, C_4 and D_4 suggested the following three ways in which energy efficiency measures can be improved in buildings:

- *Through improved design and construction techniques that reduce heating, cooling, ventilating and lighting loads;*
- *Through building upgrades and the replacement of energy-using equipment; and*

- *By actively managing energy use. This can be achieved when a building analysis is overtly and covertly done.*

The stages at which energy efficiency measures can be implemented in an existing building, according to A_1 to A_5, B_1 to B_5, andE_1 to E_5, are *"when designing and retrofitting buildings"*. The participants asserted that the most effective way to ensure that energy efficiency is factored into the design and construction process is *"by introducing and enforcing building energy efficiency codes"*. They explained that a building energy efficiency code *"sets out the minimum energy efficiency requirements of a building, including the thermal performance of a building's 'envelope' and the energy efficiency standards of its internal equipment and devices"*.

The participants posited that *"retrofitting existing buildings and replacing energy-consuming equipment are critical for improving energy efficiency in existing buildings"*. They claimed that for this to happen, *"an enabling environment, effective project financing, and delivery mechanisms must be in place"*. Supporting this view, C_1, C_2, and C_3concurred that *"establishing and maintaining effective energy management systems for monitoring and controlling energy use in buildings is a low-cost means with which to improve energy efficiency and reduce energy demand"*.

A_4, D_3, E_4 andE_5 stated that *"there are a number of key barriers that must be overcome in scaling up energy efficiency measures in buildings"*. These include

> *the high cost of gathering reliable information on a building's energy performance, a lack of technical capacity with which to design, construct and maintain energy-efficient buildings, a lack of incentives to invest in energy efficiency, limited access to financing, and difficulties in coordinating the building sector's many stakeholders.*

All the participants concurred that *"overcoming these barriers requires strong commitment and leadership from key stakeholders"*.

Participants in groups A, C and E explicitly stated that

> *For systematic improvement in energy efficiency measures in existing buildings, clients should consider the following steps: carrying out a rapid energy efficiency assessment of the building sector (a building analysis) that identifies key opportunities and challenges, assesses stakeholders and resources, and determines priorities and next steps, and implementing energy efficiency initiatives.*

The findings from the interviews with the experts confirm assertions made by Chidiac et al.(2011: 615)and Ma et al.(2012: 897) regarding developing energy efficiency measures.

Human factors

Energy efficiency has a plethora of benefits for individuals, organisations, and societies. However, there is still a gap between knowledge and implementation. While market failure serves as an important barrier to energy efficiency uptake, so do the characteristics of human behaviour (Figueroa, 2015: 3; Owens and Wilhite, 1988). Supporting the view of these authors, the participants confirmed that *"it is needful to co-design interventions with actors who know the* *context"*. They claimed that *"while some behavioural principles are global, interventions often are not"*. The participants in groups A and E suggested that *"engaging stakeholders early in the process serves to understand and integrate cultural contexts in energy efficiency (EE) initiatives"*, and that *"this helps to identify and choose the right time for intervention"*.

The above views are clearly confirmed by the work of Owens and Wilhite (1988), Santin et al. (2009: 1224), and Yohanis (2012: 656), as they stress inclusion of human factors at the inception of any building energy retrofit project, claiming that this ensures total buy-in among the tenants of the building.

Participants in groups C, D and E suggested that *"an understanding of people's situations, preferences, and motivations, and using these as leverage points, is equally crucial in addressing this problem"*. Participants in groups A, B and C concurred that *"testing an intervention with a sample group before implementing it on a large scale is vital, and embedding behavioural interventions in a coherent package of measures that also addresses non-behavioural barriers, such as market failures, is also needful"*.

Participants in Group E stated emphatically that

> *Challenging the status quo, providing clear information to employees about energy efficiency, rewarding achievements, and drawing on social norms to create a focus on energy efficiency are some of the contributors to energy efficiency uptake. As this case demonstrates, behavioural insights can contribute near-term and low-cost opportunities for energy savings, which are especially important in the South African context, where they are greatly needed.*

These views are similar to the opinions of the experts in the live case study (see section 5.8.4) regarding raising awareness and promoting behaviour change through communication and education.

The opinions of the experts in groups B, C and Dare aggregated and summarised as follows:

> *Building energy retrofits are affected by different behavioural factors. Those affecting the locals are staff aversion to unknown and unclear programmes (ambiguity aversion), the framing and the communication of the line of funding, and a lack of commitment and positive incentives. Those affecting government decisions on energy efficiency investments are short-term thinking, a lack of business skills (e.g. inability to calculate payback periods), inefficient habits of government, a preference for the current state (status quo bias), and trust issues, particularly between the contracting parties from government.*

In conclusion, the participants argued that it is mandatory for stakeholders to include human factors in any building energy retrofit project. This notion is supported by various scholars (see Bayat, 2014: 1; Davies and Osmani, 2011: 294; Hermelink, 2005: 437; Koshman and Ulyanova, 2014: 38; Ma et al., 2012: 891; Swan and Brown, 2013: 181; Swan, Ruddock, Smith and Fitton, 2013: 181), as they opine that human beings are an integral part of the energy management system, but that many energy-saving measures focus only on technologies and appliances.

Implementation measures

Participants in all the groups acknowledged that there are three key elements to be considered in implementing energy efficiency initiatives: *"the scope and depth of the retrofit scheme, the delivery mechanism of the retrofit programme, and the financing and repayment arrangements for the project"*.

Participants in groups A, C and D added that *"the choice of which retrofit option to pursue is based on detailed energy audits, which are usually performed by the entities who undertake the retrofits, such as energy service companies, or ESCOs"*. This view is consistent with the study by Ma et al. (2012: 895) with respect to the need for thorough energy audits in any given energy retrofit project.

To get the value of the initiative, group members A_1, B_1, B_5, C_3 and C_4 stressed *"the need for sufficient evidence-based information on the costs and benefits of different retrofit measures and options"*.

Supporting this view, A_2, A_5, E_3, E_4, and E_5 suggested three levels of effort a client can consider, depending on the availability of resources:

- *Housekeeping activities amount to fine-tuning or improving the management of a building's energy systems.*
- *A partial retrofit typically involves cost-effective replacement of inefficient equipment or components, such as light fixtures, ventilators, air conditioners, pumps, and windows. While components may be replaced individually, it is generally more effective to replace them as part of a package.*
- *A comprehensive retrofit takes an integrated 'whole building' approach that addresses the energy efficiency (EE) of individual components and upgrading of the building's envelope, to reduce the structure's heating, cooling and lighting loads. Such retrofits usually yield energy savings of 40% or more, but are generally considerably more expensive and complicated to implement than partial retrofits.*

The participants further stated that *"implementation of energy measures in retrofit projects is generally outsourced to energy service providers"*. C3 gave the following explanation about contracting models, and the explanation was supported by the participants in groups A, B and E:

> *Depending on the complexity and the financing arrangements, clients may follow several commonly used contracting models, such as guaranteed savings contracts. These only require ESCOs to implement the retrofit projects, and can guarantee a stable stream of annual energy cost savings, to repay the financers.*.

In addition to the previous suggestion, participants E_2 andE_4added that *"outright funding can as well be adopted, which is synonymous with government projects"*.

Very importantly, participants in group B asserted that after appraising the required energy efficiency measures, the next challenge is *"sourcing the necessary capital to implement them"*.

They listed the following options for financing energy efficiency measures for buildings: *“internal funding, debt financing, lease or lease-purchase agreement, utility incentives, equipment rebate, design assistance, low-interest loans, and local and national assistance”*. These options are supported by the findings from the live case study (see section 5.8.1 above).

Monitoring and verification

In groups A, B and C, the participants contextualised monitoring and verification as follow:

> *Monitoring and verification is a crucial component of energy retrofit, with the focus primarily on the monetary costs associated with consumption, featuring critical facets to the bottom-line factors, such as detecting trends, illuminating inefficiencies, projecting and managing demand, and initiative verification.*

They concluded that this exercise can be used as *“verification against utility bills and initiatives, to better allocate resources, track consumption habits, and as an overall aid in decreasing energy costs”*. This stance of the experts is confirmed by the work of various scholars (see Mahlia et al., 2011: 1127; Sweatman and Managan, 2010: 11; Tobias and Vavaroutsos, 2009: 677) as regards the need for monitoring and verification in optimising building performance, tenant satisfaction and financial returns.

Participants in groups C, D and E explained the benefits of monitoring and verification as follows:

> *An effective monitoring and verification exercise allows users to capture energy consumption and trending data, accurately allocate and plan resources, locate energy cost savings, and monitor the efficiency and effectiveness of the systems. This, in turn, will improve the satisfaction level of the EE drives being undertaken.*

Supporting the above statement, participants in group D stated the following regarding energy efficiency measures:

> *Energy efficiency measures are to make a significant contribution to environmental sustainability. Measurement and verification of actual energy savings will be needed to demonstrate their short- and long-term impact. In most cases it is not captured in the contractual agreement.*

According to this group, *“this is a gap which needs to be filled, especially in those projects that are being delivered by the government”*.

The participants in group D added that

> *The central purpose of monitoring and verification is to verify the energy savings achieved by building energy retrofits, either to satisfy internal financial accounting and reporting requirements or to meet the terms of third-party contracts for project implementation and management.*

In another argument, participants in group B posited that

Measurement and verification is a process of quantifying energy consumption before and after energy-conservation measures are implemented, in order to verify and report on the level of savings actually achieved. This is supposed to be standard practice, but in real practice energy retrofit contracts are void of such practice.

The participants in this group promoted inclusion of this component in any building energy retrofit project. They had this to say about measurement and verification (M&V):

It is important for a building owner to determine early in the project planning process if M&V will be part of the project. If savings are to be accurately measured and verified, special planning is required and may involve metering and measurement activities prior to implementing any changes to the facility. Through metering and utility bill analysis, baseline energy uses and costs are established. Then, baseline energy use is adjusted to represent the costs that would have occurred under the same set of conditions that the post-retrofit costs are based upon. In that case, savings are finally estimated as the difference between the adjusted baseline energy use and the actual post-retrofit energy use.

One of the participants in group C pointed out that

One of the key issues to consider is how exact the reported savings need to be, which influences the scope and the level of rigour of the M&V activities. Proper planning can help integrate the verification activities into the project and can potentially leverage the work of the design team and the commissioning agent. A key goal is to keep the cost of the verification activities in line with the scope and the needs of the project.

The participants in group D confirmed that

Monitoring and verification is additional costs in the retrofit project. Often it is neglected in the contract. Even if the client is aware of the benefits of this exercise, it is usually not captured in the contractual agreement. In some cases, the metering system makes it a daunting task for such an exercise to be undertaken in the retrofitted building. As a result of this, even if metering is done, it cannot be traced directly where the actual savings is coming from. Determining the actual savings from an energy-efficiency retrofit project can help prove the effectiveness of a project. Since savings represents the absence of energy use, it cannot be directly measured. Although pre- and post-retrofit measurements are often used to determine project performance, simple comparisons of energy use before and after a retrofit are typically insufficient to accurately estimate energy savings, because they do not account for fluctuations in weather and building occupancy. Measurement and verification (M&V) is the practice of measuring, computing and reporting the results of energy-saving projects. Proven M&V strategies provide a means to accurately estimate the energy savings, by making adjustments to account for these fluctuations, allowing for comparison of baseline and post-installation energy use under the same conditions

Therefore, it can be established from the evidence from the findings, as well as from the work of various scholars, that the practice of monitoring and verification must be included in any building energy retrofit project, as its gains outweigh the cost.

5.11.2 Theme 2: Challenges in building energy retrofit

In all the groups, the participants asserted that there are a number of challenges inherent in building energy retrofit.

For example, participants in groups B and E stated that *"some challenges to building energy retrofit are specific to certain stakeholder groups"*. For instance, *"high transaction costs relative to returns and the perceived unreliability of repayment often deter commercial banks from financing building energy retrofit projects"*.

Other challenges, as suggested by group C, are *"sector-wide"*, such as *"energy subsidies and/or a widespread lack of data and information on building energy retrofit opportunities, costs and benefits"*.

According to the participants in this group, *"addressing these challenges requires policy interventions and support at national and regional level, although municipal governments can also be influential in policy design and implementation, as they are nearer to the people"*.

Participants in group D mentioned the following other challenges:

> *a lack of knowledge and know-how, a lack of reliable and credible information about energy performance and the costs and the benefits of energy efficiency (EE) improvements, a lack of implementation capacity, a shortage of the relevant technical skills in local markets, to ensure compliance with building EE codes, risk aversion to unfamiliar materials, methods and equipment, and uncertain outcomes.*

The views on technical know-how are confirmed in the pilot study (see section5.3.2).

Supporting the above views, participants in group (A) added that *"lack of national and/or local commitment to energy efficiency in general, and to energy efficiency in buildings in particular, is equally a challenge"*. They concurred that *"the internal procedures and lines of responsibility of government discourage energy efficiency in public buildings (e.g. budgetary and procurement policies are not conducive to contracting energy efficiency services)"*.

"The issues of local government budget constraints, lack of long-term financing at a moderate cost, high transaction costs due to small individual investments, unattractive financial returns, and unreliable repayments" were also highlighted by group A as key challenges in building energy retrofit projects.

In conclusion, the participants mentioned the following challenges:

> *split incentives, energy efficiency investment decisions being made by actors, who do not receive direct financial benefits, the making of sub-optimal decisions or choices, due to having insufficient information, the fragmentation of the building trades, and*

the phenomenon of multiple professions being involved in different stages or decision-making processes.

Split incentives are a barrier to the deployment of energy efficiency measures in buildings. Split incentives occur when those responsible for paying energy bills (the tenant) are not the same entity as those making the capital investment decisions (the landlord or building owner).In these circumstances, the landlord may not be inclined to make the necessary upgrades to building services when the benefits associated with the resulting energy savings accrue to the tenant. Such instances should be addressed, as suggested by HVAC-HESS (2013: 3).

5.11.3 Theme 3: Overcoming the challenges

The participants unanimously agreed that *"before committing any financial resources, it is imperative for key stakeholders to develop a clear view of the main opportunities, issues and options available in improving the energy efficiency of existing buildings"*.

For energy efficiency initiatives that are being delivered by government, the participants in group C stated that *"local governments should also lead by example, by initiating cost-effective measures that boost EE in municipal buildings and/or testing new EE policy initiatives"*.

Supporting this view, participants in groups A and E added that

> *It is critical for local government departments to work with national and provincial government departments, as well as other stakeholders, such as energy utilities, banks, building owners, and energy service trades, to address the major barriers to scaling up EE in buildings*.

In line with this argument, participants in groups B and D posited that *"the instruments and tools to improve delivery of building energy retrofit should be accompanied by specific support programmes, as a portfolio of actions is generally more effective than a single, standalone EE intervention"*. This view is in line with the opinions of the experts in the live case study (see section 5.8.4 above) as concerns the detailed communication strategy that should be developed, and which should be practically-driven, where such initiatives must be developed in parallel with technological change, in order to maximise the benefits of both.

The participants went onto list some interventions that will yield benefits in the energy efficiency drive in existing government buildings. Participants in groups A, B and E suggested that *"there should be energy regulatory policies formulated at the national or regional level that address general inefficiencies in energy markets"*. Examples include *"policies to replace general pricing subsidies with targeted social assistance schemes that require that users of network-based energies be charged based on metered consumption, and which introduce incentives encouraging energy utilities to carry out demand-side management activities"*.

The issue of financial facilitation schemes was highlighted by group D. These schemes include *"fiscal and monetary incentives to encourage investment in energy efficiency in the existing building"*. Examples include *"tax credits, cash rebates, and capital subsidies, as well as special funding vehicles and risk-sharing schemes, to increase funding and lending for investment in building energy retrofit projects, both in private and public buildings"*.

"Improvement in public-sector financial management and procurement policies" was highlighted by the participants in group A. They suggested that *"these can have a significant impact on municipal efforts to retrofit public buildings and upgrade inefficient, energy-consuming equipment"*.

Participants in group C had the following to say about awareness-creation and capacity-building initiatives:

> *Awareness-creation and capacity-building initiatives, in the form of outreach and public-information initiatives, can help increase the knowledge and know-how of stakeholders and can enable the design and implementation of effective EE programmes and investment projects. These may involve general awareness campaigns, as well as initiatives to train specialised trades in building energy retrofit projects. All this can yield substantial benefits to the EE drives in existing buildings.*

In addition, participants in group C suggested that *"government must ensure energy-performance benchmarking and disclosure for large public and commercial buildings that have been retrofitted"*, and that *"government must endeavour to increase its budgetary cycle, which will aid in successful delivery of building energy retrofit projects"*. The issue of *"monitoring and verification implementation of EE drives in any retrofit project"* was strongly emphasised.

This previous section has explicated the pertinent issues in this study. The data was collected through focus group interviews. It enabled the researcher to discover the concurrent and emerging themes as they impact on the delivery of building energy retrofit projects. The following section continues this thread of investigation, with experts in the form of a questionnaire survey.

5.12 EXPERT SURVEY

The purpose of the expert survey was to provide additional insights into the results of the qualitative strand of the data-collection exercise. The researcher targeted respondents who have been practically involved in delivery of building energy retrofit projects across the globe whose contact details are available on the Internet. These groups, as with the initial participants of the study, were purposively sampled. A total of 58 questionnaire surveys were electronically administered, and 38were received back, which represents a 66% response rate. The study adopted a 66% response rate, as indicated in Table 5.10 below. This response rate was considered sufficient for analysis, as Moser and Kalton (1971) argue that the results of a survey can be regarded as acceptable even if the return rate is as low as 30–40%.

Table 5. 10 : Demographics of the experts

Category	**Classification**	**Frequency**	**Percentage (%)**
Gender	Female	9	24%

	Male	29	76%
Years of experience	5–10 years	8	21%
	10–15 years	15	39%
	15–20 years	12	32%
	20 years or more	3	8%
Profession	Architect	4	11%
	Electrical engineer	13	34%
	Facility manager	7	18%
	Mechanical engineer	8	21%
	Project manager	4	11%
	Construction manager	2	5%

Source: (Researcher, 2018)

Table 5.10 above reveals that of the 38 respondents, 76% were male, and24% were female. The table indicates that 21% of the respondents had 5–10 years of experience, 39% had10–15 years of experience, and 32% had 15–20 years of experience, while 8% had 20 or more years of experience. Regarding profession, 11% of the respondents were architects, 34% were electrical engineers, 18% were facility managers, 21% were mechanical engineers, 11% were project managers, and 5% were construction managers.

5.12.1 Components of a building energy retrofit project

This section of the questionnaire measures the key components worthy of inclusion in an energy retrofit project. The experts were asked to assess the components of a building energy retrofit project according to a set of predetermined criteria. Possible scores for each of the criteria were 1(not important), 2 (somehow important), 3 (fairly important), 4 (definitely important), and 5 (very important). The five-point scale was converted to mean percentages and mean scores (MSes) for each of the aspects as rated by the respondents. The scores made it possible to recognise the level of significance of the different aspects as rated by the respondents. This technique was then used to decipher the data gathered from the questionnaires.

The numerical results of the relative mean scores (MSes) were deduced from the data. This depended on the rule that respondents' scores on all the chosen aspects, considered together, are the observationally decided findings of relative importance. The record of MS of a specific aspect is the sum of the respondents' genuine ratings given by every single respondent as a small amount of the aggregate of all the most extreme conceivable ratings on the five-point scale that every one of the respondents could provide for that particular criterion. A scale was allocated to every response, ranging from 1to 5.Itis expressed mathematically below. The mean score (MS) was calculated for each aspect as follows:

*mean score = (5*ns + 4*n4 +3*n3 + 2*n2 +1*n1)/ (5+4+3+2+1), where ns, n4… are corresponding responses relating to 5, 4…

Table 5.11 below shows the results for these measurements and their ranking.

Table 5. 11 : Components of a building energy retrofit project

Aspect	Scale (%)					MS	Rank
	5	4	3	2	1		
Building assessment	26.00	71.00	3.00	0	0	4.23	1
Detailed energy survey	24.00	71.00	5.00	0	0	4.18	2
Monitoring and verification of energy efficiency initiatives	18.00	82.00	0.00	0	0	4.18	3
Technical analysis	18.00	79.00	3.00	0	0	4.15	4

Cost-benefit analysis	15.00	82.00	3.00	0	0	4.13	5
Measurement of implementation	11.00	76.00	13.00	0	0	3.97	6
Project initiation	21.00	61.00	18.00	0	0	3.92	7

Source: (Researcher, 2018)

In this context, Table 5.11 indicates the extent of importance of seven components of building energy retrofit in terms of percentage responses on a scale of 1 (not important) to 5 (very important) and a mean score (MS) between 1.00 and 5.00. It is notable that 71% of the components have MSes of > 4.00≤ 4.30, which indicates that in general the components are very important factors, worthy of inclusion. It is also notable that the remaining components have MSes of> 3.80 ≤ 4.0, which indicates that they are definitely important in any building energy retrofit project.

From Table 5.11 above, it can be deduced that the aspect of a building assessment has a mean score of 4.23, which suggests that it is worthy of inclusion in any given building energy retrofit project. The mean scores for detailed energy survey, monitoring and verification of energy efficiency initiatives, technical analysis, and cost-benefit analysis are 4.18, 4.18, 4.15, and 4.13, respectively, which suggests that the respondents agreed that these aspects are relevant to delivery of any building energy retrofit project. Measurement of implementation has a mean score of 3.97, which shows the importance of this aspect in any building energy retrofit project, while project initiation has a mean score of 3.92, which indicates its importance.

The scores of each of the components are>3.80, which suggests that these components are important in delivery of any building energy retrofit project. Therefore, from the analysis it can be deduced that the various aspects are important in delivery of any building energy retrofit project. This finding is confirmed by the views of the experts in the pilot interview of the study (see section5.3 above) and by various scholars (see Bayat, 2014: 1; Davies and Osmani, 2011: 294; Hermelink, 2005: 437; Koshman and Ulyanova, 2014: 38; Ma et al., 2012: 891; Swan and Brown, 2013: 181; Swan, Ruddock, Smith and Fitton, 2013: 181) as it relates to the key components of a building energy retrofit project.

5.12.2 Factors that challenge implementation of a building energy retrofit project

This section measures the factors that negatively affect implementation progress of a building energy retrofit project. The experts were asked to rate the severity of various issues that challenge smooth implementation of a retrofit project, using a five-point scale, with the options of 1 (minor), 2 (near-minor), 3 (neutral), 4 (near-major), and 5 (major). The five-point scale was converted to mean percentages (MPs) and mean scores (MSes) for each of the aspects as rated by the respondents. Table 5.12 below shows the results for these measurements and their ranking.

Table 5. 12 : Factors that challenge implementation of a building energy retrofit project

Challenge	Scale (%)					MS	Rank
	5	4	3	2	1		
Lack of the required technical know-how	53.00	42.00	5.00	0.00	0	4.47	1
High investment cost	53.00	42.00	5.00	0.00	0	4.47	2
Limited access to finance	32.00	57.00	11.00	0.00	0	4.21	3
Lack of flexibility/adaptability in the delivery process	18.00	82.00	0.00	0.00	0	4.18	4
Piecemeal-fashion energy efficiency implementation	21.00	71.00	8.00	0.00	0	4.13	5
Lack of broad buy-in into the project	15.00	82.00	3.00	0.00	0	4.13	6
Uncertainty about the payback period	18.00	76.00	6.00	0.00	0	4.13	7
Lack of stakeholder agreement	21.00	71.00	3.00	5.00	0	4.08	8
Lack of psychosocial data in the project	16.00	76.00	5.00	3.00	0	4.05	9
Lack of as-built drawings for buildings	13.00	79.00	8.00	0.00	0	4.05	10
Poor understanding of building features	3.00	63.00	34.00	0.00	0	4.02	11
Lack of a collaborative work ethic	11.00	76.00	13.00	0.00	0	3.97	12
Lack of a standard rent or lease (income) rate for retrofitted buildings	18.00	60.00	13.00	7.00	0	3.89	13

Low stakeholder communication and consultation	16.00	60.00	18.00	6.00	0	3.87	14
Lack of existing user cooperation	11.00	55.00	29.00	5.00	0	3.71	15
Interruption of existing building operations	11.00	42.00	47.00	0.00	0	3.63	16
Delayed investment decisions	8.00	50.00	29.00	13.00	0	3.52	17
Poor selection of retrofit technologies	8.00	37.00	50.00	5.00	0	3.47	18
Education level of the occupants of the retrofitted building	8.00	32.00	57.00	3.00	0	3.45	19
Lack of user-friendly technologies	5.00	34.00	61.00	0.00	0	3.45	20

Source: (Researcher, 2018)

Table 5.12 indicates the extent to which the 20 challenges identified affect implementation of building energy retrofit projects in South African construction in terms of an MS between 1.00 and 5.00.

It is notable that 55% of the challenges have MSes of > 4.00 < 4.50, and can thus be deemed major challenges, which indicates in general that they hamper delivery of building energy retrofit projects to a great extent. The remaining 45% of the challenges have MSes of> 3.40 < 4.00,and can thus be deemed near-major challenges, as they affect delivery of building energy retrofit projects to a significant extent.

From Table 5.12 it is evident that the challenges that top the list are lack of the required technical know-how, high investment cost, limited access to finance, lack of flexibility/adaptability in the delivery process, piecemeal-fashion energy efficiency implementation, uncertainty about the payback period, and lack of broad buy-in into the project, with mean scores of 4.47, 4.47, 4.18, 4.21, 4.13, 4.13, and 4.13, respectively. These findings are consistent with those of the Chartered Institute of Building (CIOB)(2015), in its Carbon Action 2050 initiative. The findings are also consistent with various studies(see CORE net Global, 2012: iv; Miller and Buys, 2008: 345; Miller, Pogue, Gough and Davis,2009: 15; Phoenix Electric Corporation, 2015),which have found that energy retrofit of existing buildings is expensive and inconvenient, it has negative impact on heritage and archaeological assets, caused by usage of unproven methods, technologies or instruments, there is scant research, especially on insulation mechanisms on walls and the effect of retrofit on the building fabric, and there are no education and training activities for maintaining and preserving the buildings, and there is no awareness creation. These challenges have been experienced, with lack of competition seen to be increasing the cost and price of retrofit services. This also means delays for deliveries and long lead-in times, particularly when services and products are scarce. Having a limited choice between installers and funds can also lead to difficulties in procuring energy-efficient retrofit projects.

The findings further reveal that lack of stakeholder agreement, lack of psychosocial data in the project, lack of as-built drawings for buildings, poor understanding of building features, and lack of a standard rent or lease (income) rate for retrofitted buildings, with MSes of 4.08, 4.05, 4.05, 4.02, 3.89, and 3.87, respectively, are equally huge challenges that hinder delivery of building energy retrofit projects. These challenges can be attributed to the quality of information available. The existence of original drawings greatly facilitates understanding of the design intent. However, drawings are not always available, and information must also be obtained through on-site testing, which makes delivery problematic. These findings are consistent with what was found in this study (see sections5.3.2, 5.4 and 5.8.3) and by the CIOB (2015).

It is worth mentioning that all the challenges highlighted in the study have an above-average mean score, and, as such, they are equally significant. Therefore, the study suggests that the challenges highlighted above have the propensity to hinder delivery of building energy retrofit projects. Capability and capacity to mobilise the necessary stakeholders to steer complex long-term innovations across multiple challenges coherently and in a coordinated way is needful.

5.12.3 Steps that will help to improve delivery of a building energy retrofit project

This section measures the steps that will improve delivery of a building energy retrofit project. The experts were asked to rate the significance of various enablers of smooth implementation of a retrofit project, using a five-point scale, with the options of 1 (minor), 2 (near-minor), 3 (neutral), 4 (near-major), and 5 (major). The five-point scale was converted to mean percentages (MPs) and mean scores (MSes) for each of the aspects as rated by the respondents. Table 5.13 below shows the results for these measurements.

Table 5. 13 : Steps that will help to improve delivery of a building energy retrofit project

Enabler	Scale (%)					MS	Rank
	5	4	3	2	1		
Improved communication and consultation with all stakeholders	24.00	66.00	10.00	0	0	4.37	1
Provision of training for contractors, subcontractors, and installers	16.00	68.00	16.00	0	0	4.00	2
Improved collaboration and coordination between professionals	18.00	61.00	21.00	0	0	3.97	3
Provision of grants and low-interest loans for such retrofitting schemes	11.00	71.00	18.00	0	0	3.92	4

Awareness creation through targeted education to homeowners and occupants	18.00	55.00	27.00	0	0	3.92	5

Source: (Researcher, 2018)

Table 5.13 indicates the extent to which the respondents agreed that the listed enablers can aid in improving delivery of building energy retrofit projects in South African construction in terms of an MS between 1.00 and 5.00. It is notable that 40% of the enablers have MSes of > 4.00≤ 4.40, which indicates in general that these enablers are deemed major enablers, while the other three enablers (60%)have MSes of > 3.90 ≤ 4.00, and are thus deemed near-major enablers.

It was revealed that improved communication and consultation with all stakeholders has an MS of 4.37, and provision of training for contractors, subcontractors, and installers has an MS of 4.00.These enablers are thus deemed major enablers, as rated by the respondents. The table shows that improved collaboration and coordination between professionals has an MS of 3.97, while provision of grants and low-interest loans for such retrofitting schemes and awareness creation through targeted education to homeowners and occupants both have MSes of 3.92. The significance of this finding is that maximisation of the enablers is necessary, and a multi-stakeholder solution is needed.

From the findings it can be seen that the various steps to improve delivery of building energy retrofit projects have above-average MSes, which indicates that they are relevant for improving the retrofit trade as a whole. These views were also observed in previous sections of the thesis (see sections5.3.3, 5.4, 5.8.2 and 5.8.4)and in the literature (see Bayat, 2014: 1; Davies and Osmani, 2011: 294; ; Hermelink, 2005: 439; Koshman and Ulyanova, 2014: 40; Ma et al., 2012: 896; Mahlia et al., 2011: 1127; Miller et al., 2009: 25; Owens and Wilhite, 1988; Santin et al., 2009: 1227; Swan and Brown, 2013: 181;Swan, Ruddock, Smith and Fitton, 2013: 181; Yohanis,2012: 656) as pertains to improving the state of the retrofit trade in general. Therefore, it can be deduced from the study that the highlighted enablers can aid in improving delivery of building energy retrofit projects.

5.13 CONCLUSION

This chapter has presented the research findings and has interpreted the textual analysis of the results of the data collection. For instance, in the pilot study it was established that a building assessment, a detailed energy survey, a technical analysis, a cost-benefit analysis, an implementation plan, operation and maintenance procedures, and training of the occupants are prerequisites for delivery of an energy retrofit project. In exploring the key elements involved in energy retrofit of an existing building, the study highlighted the need to determine occupant behaviour and needs and services required by the occupants, to understand the existing building structure and systems, to understand the scope and the costs of planned or needed installation and what systems or components require replacement, to identify and select measures to reduce loads, and to select appropriate and efficient HVAC systems. In understanding the issues and challenges facing management of energy retrofit of an existing building, the study established that communication and consultation are key challenges facing the BERP delivery process, as well as lack of stakeholder agreement, the piecemeal fashion of delivering BERPs, the lack of social data incorporated in the project, among others. The pilot study also highlighted lack of flexibility/adaptability, lack of technical know-how, the capital cost of investments, uncertainty about the payback period, and limited access to finance as serious challenges in building energy retrofit projects.

From the projects reviewed, it can be concluded that no two energy retrofit project deliveries are the same. Most of the challenges highlighted in the pilot study were also evident in the desktop studies. The retrofitted case study buildings show that each building has its own unique retrofit features. This can be attributed to different factors, such as the building orientation, the building assessment, the detailed energy survey, the technical analysis, the retrofit technologies used, the cost-benefit analysis, the nature of the building, the implementation plan, and the geographical location.

In the live-projects examined, the findings show that delivery of the project is different in all the buildings. This was also evident in the project analysis. This can be attributed to factors such as the orientation of the building, the technical analysis, the retrofit technologies used, and the technical know-how, as the study suggested. The issue of stakeholder management was also highlighted. The focus interviews and the expert survey gave a range of opinions, where consensus and differences were drawn upon. This enabled the researcher to discover the concurrent and emerging themes as they impact on the delivery of building energy retrofit projects. Finally, these findings were used in the next chapter in evolving an artefact for improving delivery of building energy retrofit projects.

CHAPTER 6: ARTEFACT DEVELOPMENTAND VALIDATION

6.1 INTRODUCTION

This chapter introduces the development and testing of the artefact proposed for the delivery of building energy retrofit in South Africa. The chapter sets out to accomplish the main aim of the research study. The findings from the literature review, the semi-structured interviews, the projects, the focus group interviews, and the expert survey form the basis for the artefact development. The chapter also presents the principles guiding implementation of the proposed artefact.

6.2 THE PROBLEM

More than just an environmental challenge, the problem of CO_2 emissions must be treated as a basic human rights issue. Carbon emissions contribute to climate change, which has serious consequences for people on planet Earth, as the burning of fossil fuels releases CO_2 gases. Carbon emissions raise global temperatures by trapping solar energy in the atmosphere (Augustsson and Ramanathan, 1977: 448). This alters water supplies and weather patterns, changes the growing season for food crops, and threatens coastal communities with rising sea levels (Augustsson and Ramanathan, 1977: 448). Most of these emissions come from the combustion of fossil fuels to provide heating, cooling, and lighting, and to power appliances and electrical equipment. The impact of buildings on energy consumption and CO_2 emissions is undeniable. By transforming the built environment to be more energy-efficient and climate-friendly, the building sector can play a major role in reducing the threat of climate change.

Several authors (Augustsson and Ramanathan,1977: 448; Cato, 2008: 28; European Commission, 2013; Filippini, Hunt and Zorić, 2014: 76; Swan, Ruddock, Smith and Fitton, 2013: 189) have predicted that if left unchecked, emissions of CO_2 from existing buildings will raise global temperatures by 2.5ºF to 10ºF this century. The effects will be profound, and may include rising sea levels, more frequent floods and droughts, and increased spread of infectious diseases. To address the threat of climate change, CO_2 emissions must be slowed, stopped, and reversed. Meeting the challenge will require dramatic advances in technologies and a shift in how the world uses energy. Building energy retrofit is one of the best strategies for meeting the challenge of climate change, since large concentrations of building stocks are already built. The relevance of developing a holistic workable delivery system that will engender the most efficient heating, ventilation and air conditioning systems, along with operations and maintenance of such systems to assure optimum performance, is evident, hence the purpose of this study.

6.3 ARTEFACT DEVELOPMENT PROCESS

Herbert Simon’s (1996) *the sciences of the artificial*, first published in 1969(Gregor and Jones, 2007: 317; Iivari, 2013: 568), provides the knowledge on how to evolve artefacts. According to several authors, Simon believed that design theory was concerned with how things ought to be in order to attain goals. To Simon, an objective of design activity was the description of an artefact in terms of its organisation and functioning. The design process could be informed by knowledge of the laws of natural science, engineering, socio-technical factors, psychology, and sociology for an artefact’s internal operations and its interactions with the external environment (Gregor and Jones, 2007: 317; Iivari,2013: 568). However, the literature on artefact development in building retrofit studies is limited. As such, this research relied on prior work on artefact development and validation in other fields to arrive at the basic principles for artefact development, testing and validation presented in this chapter.

6.3.1 Artefact development

The artefact was developed through the case study-based research design discussed in chapter 5. The insights from the literature, the semi-structured interviews, the focus group interviews, and the expert survey contributed towards the development of the artefact. Are views of the design science literature led to the discovery of salient aspects of artefact development? In this study, the chapter emphasises design science as a knowledge-building activity. Such a process will engender a change from the piecemeal approach to a holistic approach towards effective delivery of a building energy retrofit project. According to Iivari (2007: 39) and Van Aken (2005: 20), the main goal of design science research is to develop knowledge that the professionals of the discipline in question can use to design solutions for problems in specific fields. Hevner (2007: 78) states that the main purpose of design science research is achieving knowledge and understanding of a problem domain by building and applying a designed artefact.

Hevner et al. (2004: 78) have presented a set of guidelines for design science research, which requires the creation of an innovative, purposeful artefact for a special problem domain. The artefact must be evaluated in order to ensure its utility for the specified problem. Iivari (2007: 39) asserts that in order to form a novel research contribution, the artefact must either solve a problem that has not yet been solved or provide a more effective solution. Hevner et al. (2004: 79) proposes seven guidelines for design science research:

1. **Design as an artefact:** Design science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation;

2. **Problem relevance:** The objective of design science research is to develop technology-based solutions to important and relevant business problems;

3. **Design evaluation:** The utility, quality and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods;

4. **Research contributions:** Effective design science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies;

5. **Research rigour:** Design science research relies upon the application of rigorous methods in both the construction and the evaluation of the design artefact;

6. **Design as a search process:** The search for an effective artefact requires utilising available means to reach desired ends, while satisfying laws in the problem environment; and

7. **Communication of research:** Design science research must be presented effectively to both technology-oriented and management-oriented audiences.

The researcher adopts the scholarly work of the above-mentioned scholars, which is based on the proposition that a design science framework detail show design and research problems can be rationally decomposed by means of nested problem solving. This new approach could lead to new competences and a new framework for continuous improvement and innovative opportunities. The artefact development stages revolve around identifying the component parts, the relationship between principal components, and the logical flow. This process of artefact development was underpinned by the theory of the complex adaptive system (CAS).

6.3.2 Identification of components

The operationalisation of the artefact consists of all the perceived components of BER practices and the expected outcomes. The expected artefact platform for BERP delivery is influenced by socio-technical aspects of energy retrofit. The proposed construct will comprise varying distinct but complementary parts, which include human factors (social viewpoints and attitudes towards energy), material culture (retrofit technologies and the building fabric), the retrofitting programme, end user energy management, and energy retrofit best practices.

The artefact is based on the concept of the CAS. The artefact is developed through a logical linking of multiple sequential areas of inquiry, which include (1) evaluating the current best practice of energy retrofit within the industry, (2) evaluating the key elements involved in energy retrofit of an existing building, (3) critical evaluation of the challenges and the solutions associated with BERPs, (4) the correlation between these variables and the impact on the project's whole life cycle, and (5) examining opportunities for this broader vision of the artefact to serve as a point of reference for continuous improvement of the industry, as the artefact is not an end in itself, but the means to an end.

6.4 ARTEFACT EVALUATION

Evaluation has been seen as a process that determines the quality of research output, often broadly classified into internal and external validity. According to Venable and John, (2012: 425), artefact evaluation is a scientific process of demonstrating the quality of work towards achieving the research objectives as demonstrated by the researcher and peers in the industry. Other researchers regard research as knowledge that can be replicated and assimilated into the knowledge base of a field of study (Yin, 2014: 45). Case study internal validity is the strength of a cause-effect link that is dependent on the absence of spurious relationships, while external validity is the extent to which the findings can be analytically generalised to other contexts that were not part of the original study, when based on the relevance of similar theoretical concepts or principles (Yin, 2014: 236–239). The testing and evaluation components complete the cycle in the BERP artefact. Hence, the proposed building energy retrofit project artefact is as presented in Figure 6.1.

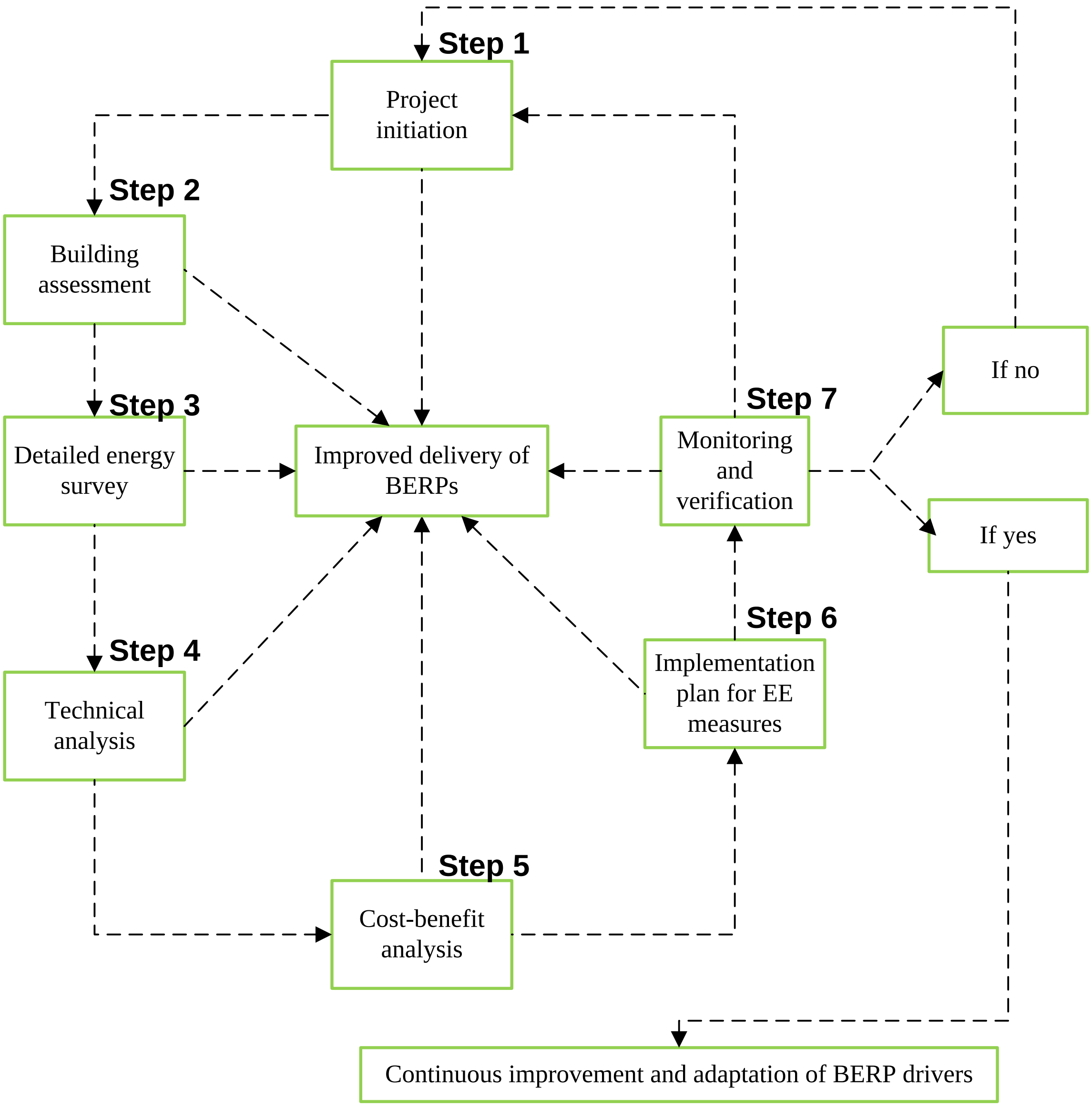


Figure 6. 1 : Pilot artefact for BERPs in South Africa (Source: Researcher, 2018)

Figure 6.1 presents the proposed artefact for BER project delivery in the South African built environment. The artefact is based on the concept of the CAS model (Gupta and Anish, 2012: 17; MacLennan, 2012: 3; Miller and Page, 2007: 6; Mitleton-Kelly, 2012: 13).It is anticipated that the proposed artefact will engender improved delivery for building energy retrofit in existing government buildings in South Africa. A detailed description of the artefact is presented in Table 6.1.

Table 6. 1 : A detailed description of the proposed artefact from a building energy retrofit study

Stage 1(BER project initiation): Key to successful delivery of a BER project is preparation, planning, and leadership. This can be achieved through the following steps: • Consultation with the stakeholders in the early stages of the project. • Collaboration and cooperation with the stakeholders in the early stages of the project. • A complete plan of action, stating what is to be done and how best to achieve it. • Clear, correct and concise modes of operation. • User engagement and education in the early stages of the project. • Thorough planning on how to meet user needs without stopping building operations. • Provide an overview of building energy used. • Provide a forward-looking view to guide investment for decision-makers. • Provide an evidence-based estimate of expected energy savings and associated benefits. The goal of this stage is to define various levels of effort needed for energy efficiency in existing buildings, to provide a point of departure for building owners, facility managers, contractors, government entities, and other stakeholders that are embarking on energy efficiency drives in existing buildings.
Stage 2(a building assessment):A building assessment can assist the stakeholders in establishing long-term strategies. Providing information on measures to stimulate cost-effective deep retrofit of buildings can unfold as follows: • Determine the energy consumption of the building. • Determine the performance level of the building. • Determine user behaviour. • Collect utility bills for at least one year, with the aim of lowering energy consumption. The goal of this stage is to review the collected data, so as to incorporate it in the final energy efficiency measures that are to be installed.
Stage 3 (detailed energy survey): In this phase, an energy survey is carried out with the help of an energy auditing team, so as to understand the energy system for the building. An energy audit needs to include all possible energy details in the energy system. The following should be observed in a detailed energy survey: • Identification of goals encourages recognising and providing energy savings in the installed electrical systems. The retrofit strategy must be tailored according to the needs of the facility. • The team should include professionals including architects, HVAC engineers, and electrical engineers. Team selection helps ensure that energy audit results can be implemented at the site, by involving experts from various disciplines. Importantly, while selecting team members, it is important for the owner to define shared goals. The team is responsible for a systematic approach in identifying, selecting and formulating recommended measures.

- Energy mapping is done to determine how much energy is consumed by the building. By collecting all information related to the energy system and equipment details, energy segregation can be estimated. A walk-through survey helps in providing adequate information, where familiarity with all the energy systems helps in generating recommendations for retrofit measures.
- In order to determine the baseline, an energy survey is performed to collect the operating condition details of the building. After the data-collection process is complete, a sheet could be formulated to analyse the building's energy consumption. Based on the operating characteristics, the minimum energy requirements of the building can be determined. This basic data collection helps to identify either a low-cost or a no-cost measure for improving energy efficiency.
- Historical building energy data needs to be collected for at least three years. This data is required to provide historical energy use profiles. The collected data needs to be put in graphical form to examine the patterns and identify the anomalies (pattern matching). By comparing the graphs and the values, unexpected patterns in energy use can be seen. More cost-saving measures can be identified. The baseline assessment after the energy survey will determine the minimum energy requirements of the building. It provides a critical reference point for assessing changes and impact, as it establishes a basis for comparing the situation before and after the intervention, and for making inferences as to how effective the installed system is.

Stage 4 (a technical analysis): A technical analysis studies the data from the energy survey, including energy consumption and peak demand analysis. It identifies and provides technical parameters, by selecting electrical product options through energy simulations. With more extensive data collection and engineering analysis, this plan provides most of the information, which can be acted upon. Based on the retrofit options available for energy efficiency, detailed analysis is carried out by formulating an action plan, conducting a benchmarking assessment, and doing analysis through software. Some features of a technical analysis are as follows:

- Formulating an action plan helps to improve building performance through maximum energy savings. To determine the energy plan, the following steps are to be followed:
  - Analyse the energy system of the building from on-site observation, measurement, and engineering calculations of the building envelope, lighting, HVAC, etc.
  - Review existing operations and maintenance, and then change plans, improvements, and estimations of costs.
  - Measure important parameters and compare them to the design levels.
  - Determine the rate structure for energy usage.
- A benchmarking assessment helps to work out the best option for energy efficiency retrofitting in existing buildings. Electrical measurement carried out through instruments helps in generating secondary data. Furthermore, it is required to work on the observations and then benchmark the received data, which can be compared to the design level as per codes and standards. Based on the comparison of information of existing levels, if there is a need to improve the energy levels, an organisation can opt for a more detailed energy audit. The most important factor for success is to identify where energy is exceeding and, based on the plan of action, to select the retrofit option that has maximum

saving potential. • After determining the gaps, it is advised to perform energy simulations, to determine the retrofit potential based on the best available technology and its respective payback period. After all the measurements and data collection, the team needs to identify the software (DIALux, Ecotect, Revit, etc.) on which the simulation is to be performed, to analyse the operating conditions and to determine the areas where most cost-benefiting retrofit plans can be executed. • After energy simulations of various electrical loads, a suggested plan of action should be carried out. Modelling (simulation) of annual energy performance needs to be done. It provides detailed project cost and savings calculations, with a high level of confidence. As for major capital investment decisions, a comprehensive life cycle cost analysis is the best decision-making tool. In addition, the following options can also be considered: ▪ Selection of BAT (best available technology): After performing the energy simulation, the team is required to provide the owner with a retrofit plan. The team should then look for best available technology present in the market and then decide on BAT they will adopt by working on the various parameters, such as efficiency, payback period, first initial cost, etc. ▪ A repeat energy audit: After selecting the BAT present in the market, the team needs to perform the energy simulation again, in order to determine the difference in efficiency, comfort level, etc., between the suggested retrofit option and the installed equipment.
Stage 5 (a cost-benefit analysis): In appraising the cost potential, with respect to the findings from the technical analysis, capital payback calculations should be performed. This helps to choose the best retrofit option in line with user requirements and budgetary constraints. For all the practical measures and recommendations, a cost-benefit analysis needs to be carried out. This is done to identify efficiency-modification opportunities. The energy auditor requires a building envelope expert, a mechanical engineer, and an electrical engineer (lighting and control system expert). The best outcome of retrofits depends on a combination of skills and procedures. Complex building and varied energy systems require a more experienced team. Importantly, the facility manager needs to develop synergy between site staff, contractors, and building occupants, to support and provide building information.
Stage 6 (an implementation plan of energy efficiency measures): Once the retrofit plan is finalised after conducting a thorough cost-benefit analysis, the team should then work on implementing the retrofit. Proper project planning should be done, in terms of assigning appropriate timelines and understanding the commitment and involvement mechanisms, as well as project finance, so that implementation is seamless.

Stage 7 (monitoring and verification): This serves to track implementation and outputs systematically, and to measure the effectiveness of energy efficiency (EE) drives. In addition, it helps to improve performance and achieve results. It helps to determine exactly when an EE drive is on track and when changes may be needed. Its goal is to improve current and future management of outputs, outcomes, and impact. Monitoring and verification provides information that will be useful in

- Analysing the situation in the BERP,
- Determining whether the inputs in the project are well utilised,
- Identifying problems facing the EE drivers, and finding solutions,
- Ensuring that all activities are carried out properly, by the right people, and in time, and
- Using lessons learnt for continuous improvement.

Source: (Researcher, 2018)

6.4.1 Testing procedure

The approach adopted was to look for differences between the views of the study participants and the experts in the development of the artefact. The responses from the participants in the development of the artefact serve to demonstrate internal validity. The artefact has also been validated through seminar presentations of the initial framework, and the various components have been used as part of the artefact development presented in academic conferences. The advantage of a larger group of participants (external experts) in the evaluation process of the artefact is to prove the external validity of the research, which might increase the possibility of generalisation beyond the research sample (Xiao, 2002: 103; Yin, 2014: 45).

The testing of the proposed artefact was achieved through a questionnaire survey of the experts on various workings of the artefact. Survey design was adopted to elicit experts' consensus, drawing from their industry experiences on retrofits, such as current trends, requirements, and the possible centrality of the artefact to industry practice. An expert survey is ideal for in-depth analysis, as it helps to ascertain a consensus view and explore in-depth opinions, judgements and evaluations of a particular subject (Creswell, 2009: 145; Fellows and Liu, 2008: 158; Tracy, 2013: 167).

6.4.2 Details of the participants in the artefact testing and validation

This section discusses the details of the experts that participated in the artefact validation process, as explained in chapter 4. Table 6.2 shows the background information of the 17experts that took part in the review of the artefact (see Appendix 4 for the validation instrument).

As shown in Table 6.2, the gender, years of experience in household energy-related issues, academic qualifications and professions of the interviewees are captured. The interview participants are made up of 11 males and six female experts. The academic qualifications of the participants reveal that the majority (N=6) of the interviewees hold a doctoral degree, which amounts to 35% of the interviewees, five of them hold master's degrees (29% of the interviewees), four of them (24%) hold a bachelor's degree, while the remaining 12% hold a diploma. The implication of this is that all the interviewees have the requisite academic qualifications qualifying them to presumably be knowledgeable about the issues being investigated by the study.

It is equally important to capture the years of experience of the interviewees, in order to ensure that those interviewed have been involved in and have deep knowledge of issues relating to building energy retrofit delivery. The interviewees have an average of 17.5 years of experience on issues relating to BERP delivery. This implies that the respondents that participated in the validation have the requisite years of experience. The purpose of the validation task and the expected outcomes were explained to each of the interviewees, mainly to ensure that the exercise was as clear as possible to them. The artefact was assessed in relation to its robustness for engendering industry change, its applicability, as well as the reasoning logic. Involvement of the views of the external experts is aimed at incorporating a sound theoretical base for the proposed artefact. The internal experts gave a practical dimension to the final artefact. The survey questions were conducted using both structured and semi-structured questions (see Appendix 4), which covered the logic structure, clarity, coherence, practical relevance, applicability and meaningfulness of the artefact, and suggested improvements based on experience.

6.4.3 Results of the artefact evaluation exercise

Table 6.3 presents the results of the artefact evaluation. Overall, the general feedback on the artefact is positive. The experts surveyed made positive comments on the artefact and its components. The systematic approach followed in its development was applauded, as well as its applicability. The artefact was classified as being a product of pioneering research with clear and comprehensive underlying relations, within its context. Moreover, the developed artefact was seen to be compatible with global contemporary thinking in attempts to find a new approach to BERP delivery.

Table 6. 2 : Background information on experts that participated in the artefact validation

Category	Classification	Affiliation	Frequency
Gender	Female		6
	Male		11
Years of experience	5–10 years		1
	10–15 years		4
	15–20 years		10
	20 years or more		2

Level of qualification	Diploma		2
	Bachelor's degree		4
	Master's degree		5
	Doctoral degree		6
Profession	Architect	Consultant	1
	Electrical engineer	Energy service company	3
	Facility manager	Client(municipal government)	4
	Mechanical engineer	Energy service company	3
	Building energy analyst	Consultant	6

Source: (Researcher, 2018)

Table 6.3 shows the artefact validation results. Of the 32 survey questionnaires administered, a total of 17 were returned and deemed useful for the intended purpose. This represents a response rate of approximately 53%.

For the scoring method, the interviewees were asked to assess the artefact according to a set of predetermined criteria based on the artefact reviewed by them. Chew and Sullivan (2010: 37) argue that the objective of any artefact validation is to ensure that it adequately reflects the artefact objectives. Further to this, Martis (2006: 39) and Sargent (2005: 14) suggest that the artefact developed should adequately meet the following criteria: logical structure, clarity, comprehensiveness, practical relevance, applicability, and meaningfulness. These criteria were the ones included in the questions asked. Possible scores for each of the criteria were 5 (excellent), 4(above average), 3(average), 2(below average), and 1(poor). Table 6.3 shows the results for this method of validation in terms of percentage responses on a scale of 5 (excellent) to1 (poor), and a mean score (MS) of between 5.00 and 1.00.

Table 6. 3 : Artefact validation based on the scoring method

Criterion	Excellent……………………………………..Poor					MS	Ranking
	5	4	3	2	1		
Practical relevance	41.00	53.00	6.00	0	0	4.35	1
Coherence	41.00	41.00	18.00	0	0	4.23	2
Applicability	35.00	53.00	12.00	0	0	4.23	3
Logical structure	29.00	59.00	12.00	0	0	4.17	4
Meaningfulness	23.00	71.00	6.00	0	0	4.17	5
Clarity	23.00	65.00	12.00	0	0	4.11	6

*Mean score = (5*ns + 4*n4 +3*n3 + 2*n2 +1*n1)/ (5+4+3+2+1), where ns, n4… are corresponding responses relating to 5, 4…

Source: (Researcher, 2018)

Practical relevance has a mean score of 4.35, which indicates that the idea is capable of being done or put into effect. The mean scores for coherence and applicability are both 4.23, suggesting that the respondents agree that the artefact is clear and relevant and that all the parts fit together. Logical structure has a mean score of 4.17, which indicates that this score is by far above average. Logical structure in this case assesses the consistency of the artefact, where the properties of the real system are mimicked. The results indicate that no logical disjoint exists. Artefact clarity has a mean score of 4.11, which shows that the artefact captures important variables that can aid in improving BERP delivery.

These scores are, once again, above average, which suggests that the artefact is useful. They also support the comments that the artefact is robust enough and covers important issues necessary for implementation of BER project delivery. Generally, the participants confirmed the uniqueness of the artefact in demonstrating the innovative features that can transform the current industry practices and avail the industry of some useful tools needed for raising awareness and understanding of implementation issues in BER projects. Its implementation should engender improved new leadership attitudes, knowledge and skills, and a new industry culture. In addition, the feedback on the artefact appropriateness to the industry was positive. Some of the respondents described the artefact as very comprehensive and expressed their willingness to adopt its principles for their future building works. However, some participants suggested some ideas and areas for improvement for the artefact operationalisation. Some such suggestions are: *"The project initiation should read 'BER project initiation', and the stages in the artefact should be clearly stated. Subsequently provide clarity in the flow of events"*. These suggested areas for improvement were analysed in the light of consistency with other comments, the available literature, and data, to justify their worthiness for incorporation in the BERP artefact.

6.4.4 Artefact improvement

The improved artefact is presented in Figure 6.2 below. It links the enabling drivers that would necessitate effective implementation of BERPs in the South African construction industry. The goal of this artefact is to define various levels of effort needed for energy efficiency in existing buildings, and thus provide reference steps for building owners, managers, government entities, and other stakeholders sharing different levels of energy assessment and different procedures.

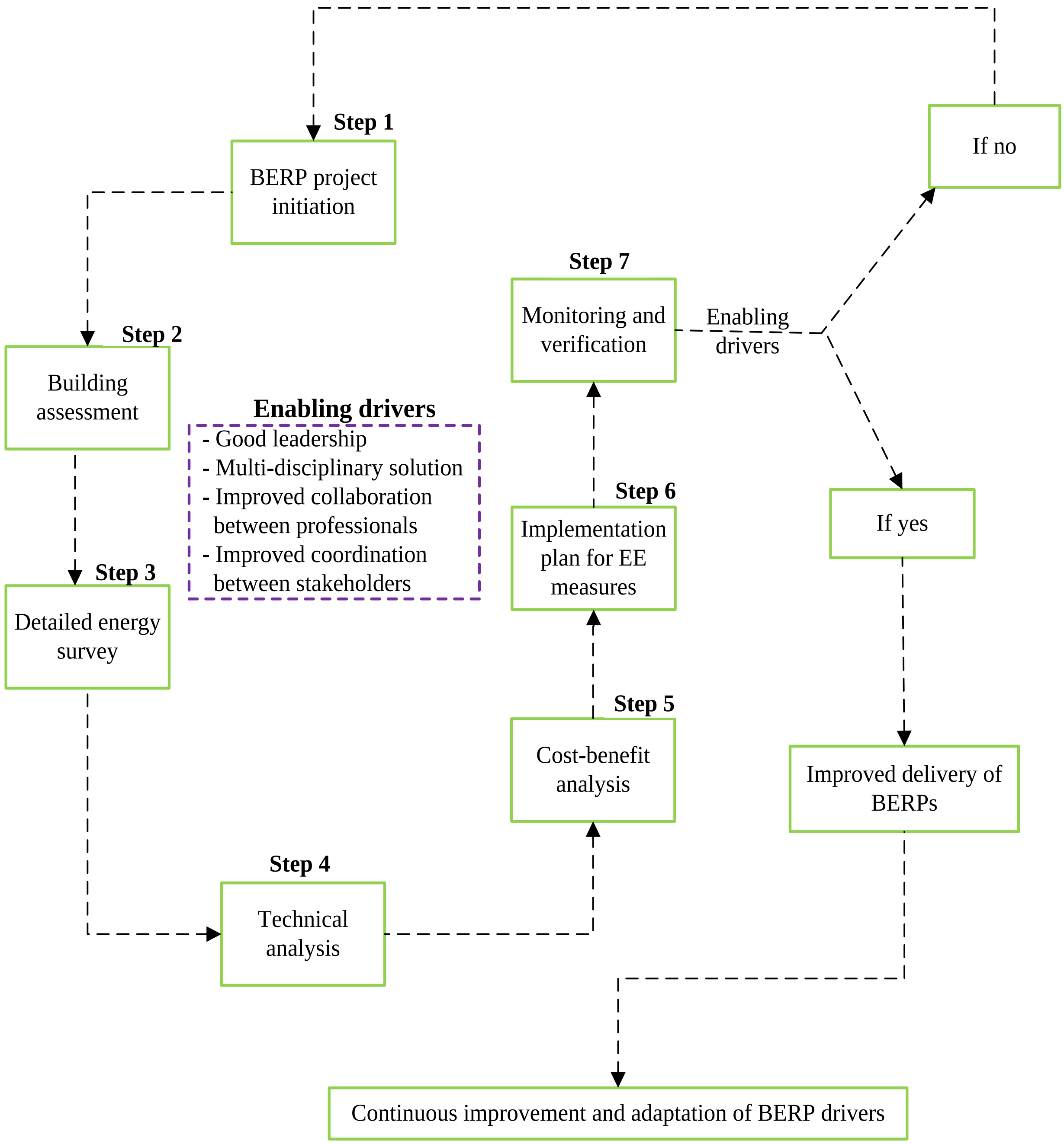


Figure 6. 2 : Artefact for BERP delivery in South Africa

Source: (Researcher, 2018)

Energy retrofitted building has proven to provide conservation of energy and to offer one of the quickest, most cost-effective and most environmentally friendly ways to reduce CO_2 emissions. In achieving this, a detailed process needs to be followed in the right order. Table 6.4 illustrates the step and processes that need to be followed in engendering BERP delivery, as the final artefact depicts.

Table 6. 4 : A detailed description of the modified artefact from the building energy retrofits study

Stage 1(BER project initiation): Key to successful delivery of a BER project is preparation, planning, and leadership. This can be achieved through the following steps: • Consultation with the stakeholders in the early stages of the project, • Collaboration and cooperation with the stakeholders in the early stages of the project, • A complete plan of action, stating what is to be done and how best to achieve it, • Clear, correct and concise modes of operation, • User engagement and education in the early stages of the project, • Thorough planning on how to meet user needs without stopping building operations, • Provide an overview of building energy used, • Provide a forward-looking view to guide investment for decision-makers, and • Provide an evidence-based estimate of expected energy savings and associated benefits. The goal of this stage is to define various levels of effort needed for energy efficiency in existing buildings, to provide a point of departure for building owners, facility managers, contractors, government entities, and other stakeholders that are embarking on energy efficiency drives in existing buildings.
Stage 2(a building assessment):A building assessment can assist the stakeholders in establishing long-term strategies. Providing information on measures to stimulate cost-effective deep retrofit of buildings can unfold as follows: • Determine energy consumption of the building, • Determine performance level of the building, • Determine user behaviour, and • Collect utility bills for at least one year, with the aim of lowering energy consumption. The goal of this stage is to review the collected data, so as to incorporate it in the final energy efficiency measures that are to be installed.
Stage 3 (detailed energy survey): In this phase, an energy survey is carried out with the help of an energy auditing team, so as to understand the energy system for the building. An energy audit needs to include all possible energy details in the energy system. The following should be observed in a detailed energy survey: • Identification of goals encourages recognising and providing energy savings in the installed electrical systems. The retrofit strategy must be tailored according to the needs of the facility. • The team should include professionals including architects, HVAC engineers, and electrical engineers. Team selection helps ensure that energy audit results can be implemented at the site, by involving experts from various disciplines. Importantly, while selecting team members, it is important for the owner to define shared goals. The team is responsible for a systematic approach in identifying, selecting and formulating

recommended measures.

- Energy mapping is done to determine how much energy is consumed by the building. By collecting all information related to the energy system and equipment details, energy segregation can be estimated. A walk-through survey helps in providing adequate information, where familiarity with all the energy systems helps in generating recommendations for retrofit measures.
- In order to determine the baseline, an energy survey is performed to collect the operating condition details of the building. After the data-collection process is complete, a sheet could be formulated to analyse the building's energy consumption. Based on the operating characteristics, the minimum energy requirements of the building can be determined. This basic data collection helps to identify either a low-cost or a no-cost measure for improving energy efficiency.
- Historical building energy data needs to be collected for at least three years. This data is required to provide historical energy use profiles. The collected data needs to be put in graphical form to examine the patterns and identify the anomalies (pattern matching). By comparing the graphs and the values, unexpected patterns in energy use can be seen. More cost-saving measures can be identified. The baseline assessment after the energy survey will determine the minimum energy requirements of the building. It provides a critical reference point for assessing changes and impact, as it establishes a basis for comparing the situation before and after the intervention, and for making inferences as to how effective the installed system is.

Stage 4 (a technical analysis): A technical analysis studies the data from the energy survey, including energy consumption and peak demand analysis. It identifies and provides technical parameters, by selecting electrical product options through energy simulations. With more extensive data collection and engineering analysis, this plan provides most of the information, which can be acted upon. Based on the retrofit options available for energy efficiency, detailed analysis is carried out by formulating an action plan, conducting a benchmarking assessment, and doing an analysis through software. Some features of a technical analysis are as follows:

- Formulating an action plan helps to improve building performance through maximum energy savings. To determine the energy plan, the following steps are to be followed:
    - Analyse the energy system of the building from on-site observation, measurement, and engineering calculations of the building envelope, lighting, HVAC, etc.
    - Review existing operations and maintenance, and then change plans, improvements, and estimations of costs.
    - Measure important parameters and compare them to the design levels.
    - Determine the rate structure for energy usage.
- A benchmarking assessment helps to work out the best option for energy efficiency retrofitting in existing buildings. Electrical measurement carried out through instruments helps in generating secondary data. Furthermore, it is required to work on the observations and then benchmark the received data, which can be compared to the design level as per codes and standards. Based on the comparison of information of existing levels, if there is a need to improve the energy levels, an organisation can opt for a more detailed energy audit. The most important factor for success is to identify where energy is

exceeding and, based on the plan of action, to select the retrofit option that has maximum saving potential.
• After determining the gaps, it is advised to perform energy simulations, to determine the retrofit potential based on the best available technology and its respective payback period. After all the measurements and data collection, the team needs to identify the software (DIALux, Ecotect, Revit, etc.) on which the simulation is to be performed, to analyse the operating conditions and to determine the areas where most cost-benefiting retrofit plans can be executed.
• After energy simulations of various electrical loads, a suggested plan of action should be carried out. Modelling (simulation) of annual energy performance needs to be done. It provides detailed project cost and savings calculations, with a high level of confidence. As for major capital investment decisions, a comprehensive life cycle cost analysis is the best decision-making tool. In addition, the following options can also be considered:
  ▪ Selection of BAT (best available technology): After performing the energy simulation, the team is required to provide the owner with retrofit plan. The team should then look for best available technology present in the market and then decide on BAT they will adopt, by working on the various parameters, such as efficiency, payback period, first initial cost, etc.
  ▪ A repeat energy audit: After selecting the BAT present in the market, the team needs to perform the energy simulation again, in order to determine the difference in efficiency, comfort level, etc., between the suggested retrofit option and the installed equipment.

Stage 5 (a cost-benefit analysis): In appraising the cost potential, with respect to the findings from the technical analysis, capital payback calculations should be performed. This helps to choose the best retrofit option in line with user requirements and budgetary constraints. For all the practical measures and recommendations, a cost-benefit analysis needs to be carried out. This is done to identify efficiency-modification opportunities. The energy auditor requires a building envelope expert, a mechanical engineer, and an electrical engineer (lighting and control system expert). The best outcome of retrofits depends on a combination of skills and procedures. Complex building and varied energy systems require a more experienced team. Importantly, the facility manager needs to develop synergy between site staff, contractors, and building occupants, to support and provide building information.
Stage 6 (an implementation plan of energy efficiency measures): Once the retrofit plan is finalised after conducting a thorough cost-benefit analysis, the team should then work on implementing the retrofit. Proper project planning should be done, in terms of assigning appropriate timelines and understanding the commitment and involvement mechanisms, as well as project finance, so that implementation is seamless.

Stage 7 (monitoring and verification): This serves to track implementation and outputs systematically, and to measure the effectiveness of energy efficiency (EE) drives. In addition, it helps to improve performance and achieve results. It helps to determine exactly when an EE drive is on track and when changes may be needed. Its goal is to improve current and future management of outputs, outcomes, and impact. Monitoring and verification provides information that will be useful in

- Analysing the situation in the BERP,
- Determining whether the inputs in the projects are well utilised,
- Identifying problems facing the EE drivers, and finding solutions,
- Ensuring that all activities are carried out properly, by the right people, and in time, and
- Using lessons learnt for continuous improvement.

Source: (Researcher, 2018)

6.5 CONCLUSION

This chapter discussed and summarised the findings of the research in relation to the main research question (see section 1.6). This chapter also discussed the elements of the artefact developed for deployment in the industry, and it therefore accomplished the main aim of the thesis. Industry stakeholders have expressed the need for a shift from a piecemeal fashion to a more holistic approach in delivery of BERPs (Swan, Ruddock, Smith and Fitton, 2013: 189). Such a shift will engender efficient and effective deployment of resources and techniques. This new paradigm will emerge when stakeholders are equipped to critically assess the impact of the interaction between the social and the technical components of building. For this interaction to be meaningful, stakeholders need to understand the socio-technical dimensions in building energy use. Industry stakeholders should be able to evaluate their current practices in terms of integrating this concept. Development of a workable artefact for meeting these requirements is beneficial to the industry, thus making such an endeavour worthwhile. The developed artefact will provide effective BERP delivery systems, in response to the demand from the industry.

The following chapter presents a summary of the research, conclusions, contributions to the body of knowledge, and recommendations.

CHAPTER 7: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 INTRODUCTION

This chapter presents a summary of the research, the findings with respect to the objectives, recommendations, and contributions to the body of knowledge. The chapter also highlights the limitations of the study and suggests areas for further research.

7.2 SUMMARY OF THE THESIS

The current piecemeal practice has been deemed ill-equipped to deliver on sustainable BER. As a remedy, previous studies have clamoured for integration of social and technical concepts and practice during project delivery. The general consensus is that there is a need for more comprehensive work on methodologies to be scientifically developed and empirically verified for this synergy to emerge in order to benefit the industry. Such consensus signals the need for scientifically-based artefacts for the integration of socio technical concepts in BERP delivery. In effect, the aim of this research work was to develop an artefact for operationalising the integration of social and technical aspects of building energy retrofit in the South African built environment sector. The specific objectives of the study were (1) to assess the current best practices in delivery of building energy retrofit projects,(2) to explore the key elements involved in energy retrofit of an existing building,(3) to understand the issues and challenges facing management of energy retrofit of an existing building,(4) to seek potential improvement for the delivery of energy retrofit of an existing building, and(5) to offer an artefact that can be adopted for promoting the deployment of retrofits in existing buildings.

The study was tailored to achieve development of the research problem and a clear understanding of the context (chapters 1 and 2), development of conceptual and theoretical perceptions underpinning organisational change, leading to development of an artefact for BERP delivery (chapter 3), explanation of the methodology deployed in achieving the set objectives (chapter 4),a discussion of the data collection and analysis (chapter 5),explanation of the development of the artefact and its evaluation (chapter 6), and discussion of the conclusions and recommendations (chapter 7).

In chapter 1 the background to the study, the problem statement, the research questions, the scope of the study, the aim and objectives of the study, and its justification were presented. Chapter 2 presented are view of relevant literature pertaining to the subject area. The focus of the chapter was on carbon emissions, low-carbon building, drivers of low-carbon building, and barriers to low-carbon building, globally and in South Africa, and the low-carbon economy in South Africa. Chapter 3 explored the theoretical and conceptual framework of the study. Chapter 4 presented the philosophical underpinning of the research, the various paradigms, the research methodology, the case-based method and case selection, the design of the interviews and/or the mixed-methods protocol, and how the data was collected and treated. Chapter 5 presented the findings and the data analysis of the research study, and answers were offered to the research questions in meeting the research objectives. Chapter 6 developed and presented the proposed artefact and the validation process. Chapter 7 summarises the whole study, conclusions are drawn, recommendations are made, and areas for further study are suggested.

7.3 CONCLUSION ONTHE CENTRAL RESEARCH QUESTION

The study attempted to provide answers to the central research question, namely “What artefact would engender effective delivery of building energy retrofit projects among existing building stock in South Africa?” Reflection on what kind of artefact could engender implementation of BERPs for the benefit of end users produced the research problem statement, namely “The lack of an empirical framework for the integration of socio-technical concepts of building energy retrofit as a catalyst for sustainability hinders the creation of project value and continuous improvement in South Africa”. Therefore, the central research question created a desire to uncover the actual artefact for operationalising the concepts of BER and the benefits of BER in the South African building sector.

7.4 CONCLUSIONS ON THE RESEARCH SUB-QUESTIONS

This principal question leads to the postulation of the research problem statement, which states that retrofitting of existing buildings remains a major challenge, which needs to be addressed to support emission reductions from the building sector (CIDB, 2009:69). From the above stated research question, the following sub-questions were formulated:

- What are the current best practices in delivery of building energy retrofit projects?
- What are the key elements involved in energy retrofit of an existing building?
- What are the issues and challenges facing delivery of energy retrofit of an existing building?
- What are the solutions facing delivery of energy retrofit of an existing building?
- How do we put forward a delivery system for energy retrofit of an existing building?

The research questions asked in sections 1.3 and 1.4 were answered by the findings that emanated from the analysed data.

7.4.1 What are the current best practices in delivery of building energy retrofit projects?

Based on the study conducted, it can be concluded that current best practice in delivery of building energy retrofit must revolve around these activities: a building analysis/internal assessment to establish the condition and functional ability of the building; conducting a detailed energy survey so as to determine occupant behaviour and the existing operating conditions of HVAC, etc.; conducting a technical analysis, in order to benchmark assessment, to work out the best option for energy retrofit; a cost-benefit analysis, to ascertain the best financial model suitable for the project; an implementation plan for the project, where project planning should be done in terms of assigning appropriate timelines with the stakeholders and understanding occupant behaviour involved in the energy efficiency measures; and monitoring and verification, where this involves educating the users of the building about the building’s energy efficiency measures, where operation and maintenance procedures need to be checked for further improvement. The aforementioned constitute the best practices in the subject area.

7.4.2 What are the key elements involved in energy retrofit of an existing building?

Based on the findings of the study, it can be deduced that the following elements are crucial for successful delivery of a BER project: human factors (social viewpoints and attitudes towards energy use); material culture (retrofit technologies and the building fabric);the retrofitting programme; end user energy management; and energy retrofit best practices.

The proposed elements illustrate how a holistic approach can be adopted to address the shortcomingsin theBERP delivery process. The study concluded that without considering all the factors takentogether and adapting the BER project, efforts to reducecarbon emissionsin existing buildings may not be effective.

7.4.3 What are the issues and challenges facing delivery of energy retrofit of an existing building?

Based on the study, the challenges that top the list were in the area of communication and consultation. The participants stated that the activities of stakeholders are insufficient and inadequate, there is a lack of stakeholder agreement, the piecemeal fashion of doing things is a challenge, and there is a lack of social data incorporated in projects, among other things. This is closely followed by a lack of collaboration and cooperation, which revolves around a lack of stakeholder activities to obtain buy-in into the project, and experts operating randomly, which makes work move haphazardly. The issue of flexibility/adaptability is another serious challenge in BER projects. The study also established that technical know-how is a key challenge. Other challenges, such as the capital cost of such investments, uncertainty about the payback period, and limited access to finance, are equally significant.

7.4.4 What are the solutions to delivery of energy retrofit of an existing building?

The results of the research indicate that improvement in the area of communication and consultation with all stakeholders, especially in affected buildings, will go a long way to addressing the challenge of lack of communication and consultation. The participants stated that information sessions are needed to receive and communicate details of activities, in order to deliver what is actually needed in the BERP. Collaboration and coordination between stakeholders is also a factor that can be improved upon. The study also found that training provision for contractors, subcontractors, and installers is of the utmost importance. Provision of grants and low-interest loans for such retrofitting schemes, to serve as incentives, is also crucial. Awareness creation through targeted education to homeowners and occupants, so that they can see the energy and cost-saving potential for such retrofit practices, is also needful. Proper planning of the retrofitting needs to be done, so that it does not affect or hamper the working of the building operations.

Simultaneous operation of old and new energy systems should be ensured. There is also the limitation of lack of information and availability of energy-efficient products. To overcome this problem, EE products should be bought through good vendors, after doing thorough market research. A well thought-out plan to manage different parties involved, in order to streamline implementation, is also crucial, in order to prevent, or at least minimise, fragmentation of the retrofit activities. The study suggested that experts dealing in BER projects should obtain substantial benefits from being flexible, by applying learning through continuous improvement and administrative innovation, because no two BER projects are the same.

7.4.5 How to put forward a delivery system for energy retrofit of an existing building?

The literature review confirmed the study's problem statement, namely the lack of empirically developed artefacts for effective delivery of BERPs in the South African construction industry. It led to discovery of a validated artefact. The reasoning behind the development of this artefact was underpinned by complex adaptive system theory, to create an adaptive form of implementation, which is needed for the socio-technical systems in BERP delivery. The artefact provides the principles and guidelines for stakeholder involvement and empowerment that focuses on the work process in an effective and efficient manner, to facilitate continuous improvement in the BERP delivery process.

7.5 CONTRIBUTIONS TO KNOWLEDGE

The study developed a comprehensive artefact for effective implementation of BER projects. The developed artefact provided an adaptive form of integration, which is needed for socio-technical systems, such as BERP delivery systems. This form of integration was achieved through focus on the socio-technical systems of BER projects in engendering a sustainable built environment. Based on the evaluated artefact, the main contributions of the artefact include the following:

- Compilation of best practice, which will help in ensuring performance improvement in the BERP delivery process,
- Identification of key elements needed in implementation of BER projects, and
- Offering solutions with respect to the challenges highlighted in the BERP delivery process.

As stated earlier, the piecemeal fashion of BERP delivery among South African construction stakeholders can be improved upon with adoption and implementation of the artefact. The artefact serves as a guide for innovation and a proactive tool to attain efficiency in the delivery of BER projects. The developed artefact is followed with detailed steps, which are understood by industry stakeholders, and which function as guidelines on how BER projects should be implemented. It also affords industry a tool for self-appraisal in the quest towards sustainability targets as they concern BERP delivery.

7.6 LIMITATIONS OF THE STUDY

The construction industry is notable for not responding to research requests for participation. Research data collection is often fraught with difficulty as a result. This was manifested during this research, as it adopted the mixed-methods research approach. Therefore, the first limitation for this study was that the researcher went through vigorous protocols with organisations relevant to the study, in order to gain access to information. Secondly, the registered phone numbers and email and physical addresses of some of the respondents were different from what was contained in the database. Additionally, some respondents bluntly declined, through emails and phone conversations, to participate in the research interviews, despite them having been assured of anonymity and confidentiality. Moreover, some of the confirmed and booked appointments for interviews were cancelled on arrival of the researcher at the contractor's premises. This scenario works against what the researcher intends to get. Nevertheless, the information obtained was adequate to carry out the task. However, it must be said that the artefact does not claim to have answers to all the issues of the BERP delivery process. The limitations of the artefact can be highlighted as follows:

1) The limited number of cases (in terms of the desktop projects, the interviews, and the number of respondents interviewed) limits generalisability of the findings of the study.

2) The artefact as a tool put forward an implementation guide. However, its success is dependent on the right leadership to engender the synergy needed among the stakeholders.

7.7 RECOMMENDATIONS

7.7.1 Recommendations for policy and practice

The following recommendations for policy and industry practice are made based on the findings and the conclusions:

- The artefact requires better leaders to engender its principles. Integrated forms of BERP delivery are required to deliver the type of value chain needed for BER projects, which can only be actualised through having better industry leaders.
- Industry stakeholders who are in the business of building energy retrofit should be developed with the skills required to engender such complex BERP delivery practices, in such a way that they will become standard practice.
- The study will assist stakeholders to have a comprehensive view of the evolved artefact and its impact on BER project performance.
- It offers a knowledge base for industry stakeholders and organisations that intend to implement BERPs.
- A legal framework informed by policy is required to promote sustainability practices, especially as they concern existing government buildings. This will create a platform for standardised operation for BERP implementation processes.
- There has to be training and certification given to retrofit professionals, where this can serve as a criterion for the awarding of contracts by government and its agencies.
- The South African government should avail funding for strategic collaboration for research and development support, aimed at improving carbon emission reduction in existing buildings.
- The South African government should avail funding for strategically promoting awareness of carbon emission reduction to the housing stock in general.
- The South African government should provide funding for their housing stock; this will ensure a holistic approach in BERP delivery.
- Client in BER project should seek multi-disciplinary solution in their project delivery than piece-meal fashion practice because the long-time benefit of the former outweighs the later.
- Contractors should strategically build their competitive capabilities and competencies, through acquisition of the relevant training, qualifications, experience and professionalism, which is a prerequisite for developing the skills needed for transformational change in the trade.
- The South African construction industry should intensify construction protocols, procedures and activities that will encourage synergy towards strategic alliances and subcontracting

partnerships, so as to facilitate skills and knowledge transfer between contractors, as the retrofit trade is relatively new to the country.

- The developed artefact is recommended for the South African construction industry. It will assist contracting organisations to be better equipped with a critical understanding of the strategies to be adopted, in order to enhance the overall sustainability of the trade.

7.7.2 Recommendations for further research

Further studies should be conducted to ascertain the effectiveness of the artefact put forward in this study. For example, future research could investigate why government finds it difficult to fund energy retrofit projects in its existing building stock. There is a need for further study to establish the factors that negate adoption of energy efficiency measures among building occupants. Another area of interest is a need for a study that will engender a framework for addressing retrofit challenges in general.

7.8 CONCLUSION

This chapter presented a summary of this research, conclusions, contributions to the body of knowledge, and recommendations. The following two sections present the references used in this study and the appendices.

REFERENCES

Allan, G. (2013). A critique of using grounded theory as a research method. *Electronic Journal of Business Research Methods*12 (1), 1–10.

Allen, S.R., Hammond, G.P. and McManus, M.C. (2008). Prospects for and barriers to domestic micro-generation: a United Kingdom perspective. *Applied Energy* 85(6), 528–544.

Al-Ragon, F. (2003). Retrofitting residential buildings in hot and arid climates. *Energy Conversion and Management* 44(14), 2309–2319.

Anfara, V.A.(2008).Theoretical framework. In:L.M. Given (ed.),*The SAGE encyclopedia of qualitative research methods*. Los Angeles: SAGE.pp 869–874.

Ang, S. L., and Wilkinson, S. J. (2008). Is the social agenda driving sustainable property development in Melbourne, Australia? Property Management, 331-343.

Augustsson, T. and Ramanathan, V. (1977). A radiative-convective model study of the CO_2-climate problem *Journal of Atmospheric Science* 34, 448–451.

Ayers, S. (1997). The application of chaos theory to psychology. *Theory & Psychology* 7(3), 373–398.

Baek, C.H. and Park, S.H. (2012). Changes in renovation policies in the era of sustainability. *Energy and Buildings* 47, 485–496.

Bahaj, A.S., Myers, L. and James, P. A. B. (2017). Urban energy generation: influence of micro-wind turbine output on electricity consumption in buildings. *Energy and Buildings* 39(2), 154–165.

Bayat, N. (2014). Exploring performance gap issues in retrofit processes of hard-to-treat properties in England: the recognised architects' perspective. *ARCOM Doctoral Workshop on Sustainable Urban Retrofit and Technologies*, London South Bank University, June 2014.

Beattie, M. (2011). *The road to 'green property': your handbook for energy efficiency and sustainability in property*. Davis Langdon, Version 3.

Bernstein, H.M. and Mandyck, J. (2013). *World green building trends: business benefits driving new and retrofit market opportunities in over 60 countries*. Bedford, MA: McGraw-Hill Construction.

Bernstein, H.M. and Russo, M.A. (2011). *Business case for energy efficient building retrofit and renovation*. Bedford, MA: McGraw-Hill Construction.

Blaikie, N. (2009). *Designing social research*. 2nd ed. Cambridge, UK: Polity Press.

Blumberg, B., Cooper, D.R. and Schindler, P.S. (2005). *Business research methods*. Maidenhead, UK: McGraw-Hill Education.

Bonting, S.L. (2005). *Creation and double chaos: science and theology in discussion*. Minneapolis, MN: Fortress Press.

Carbon Trust. (2011a). *A natural choice. Lessons learned from low carbon buildings with natural ventilation*. Available from: https://www.carbontrust.com/media/81365/ctg048-a-natural-choice-natural-ventilation.pdf[Accessed 23 March 2017].

Carbon Trust. (2011g). *Taking the heat. Lessons learned from using biomass heating in low carbon buildings*. Available from: https://www.carbontrust.com/media/81385/ctg061-taking-the-heat-biomass-heating-low-carbon-buildings.pdf [Accessed 24 August 2017].

Carson, D., Gilmore, A., Perry, C. and Grønhaug, K. (2001). *Qualitative marketing research*. London: SAGE.

Carter, E. (2006). *Making money from sustainable homes: a developer's guide*. Ascot, UK: CIOB Publications.

Cato, I. (2008). Carbon zero homes UK style. *Refocus* 9(2), 28–29.

Challenger, R. and Clegg, C.W. (2011). Crowd disasters: a socio-technical systems perspective. *Contemporary Social Science* 6(3), 343–360.

Chan, S. (2001). *Complex adaptive systems. ESD.83 Research Seminar in Engineering Systems*. Available from:http://web.mit.edu/esd.83/www/notebook/Complex%20Adaptive%20Systems.pdf [Accessed 31 May 2017].

Chartered Institute of Building (CIOB) UK. (2015). *Carbon Action 2050 (CA 2050): CIOB buildings under refurbishment and retrofit*. Available from: http://www.carbonaction2050.com/ [Accessed 23 August 2017].

Chartered Institution of Building Services Engineers. (2012). *GVF2012 Guide F: Energy efficiency in buildings*. London: CIBSE.

Checkland, P. (1981). Rethinking a systems approach. *Journal of Applied Systems Analysis* 8, 117–131.

Checkland, P. (1999). *Systems thinking, systems practice*. Chichester, UK: Wiley.

Cheng, C.-C., Pouffary, S., Svenningsen, N. and Callaway, J.M. (2008). *The Kyoto Protocol, the Clean Development Mechanism and the building and construction sector: A report for the UNEP Sustainable Buildings and Construction Initiative*. Paris: United Nations Environment Programme.

Chew J. and Sullivan, C. (2000). Verification, validation and accreditation in the life cycle of models and simulations. *Winter Simulation Conference Proceedings* 2000(1), 813–818.

Chidiac, S.E., Catania, E.J.C., Morofsky, E. and Foo, S. (2011). A screening methodology for implementing cost effective energy retrofit measures in Canadian office buildings. *Energy and Buildings* 43(2–3), 614–620.

Clegg, C.W. (2010). Socio technical principles for system design. *Applied Ergonomics* 31(5), 463–477.

Cleveland, J. (2005). *Complex adaptive systems theory: an introduction to the basic theory and concepts*. Innovation Network for Communities.

Clinch J.P. and Healy, J.D. (2010). Cost benefits analysis of domestic energy efficiency. *Energy Policy* 29(2), 113–124.

Collis, J. and Hussey, R., 2013. *Business research: A practical guide for undergraduate and postgraduate students.* 4th edition. New York: Palgrave Macmillan.

Cooper, D.R. and Emory, C.W. (1991). *Business research methods*.4th ed. Homewood, IL: Irwin.

COREnet Global. (2012). *Corporate occupier sustainability perspectives 2012*.San Diego: CBRE and the University of San Diego.

Creswell, J.W. (2009). *Research design: qualitative, quantitative, andmixed methods approaches*.3rd ed. Los Angeles: SAGE.

Creswell, J.W. (2013a). *Qualitative inquiry &research design: choosing among five approaches*. 3rd ed. Thousand Oaks, CA: SAGE.

Creswell, J.W. (2013b). *Research design: qualitative, quantitative, and mixed methods approach*. 4th ed. Los Angeles: SAGE.

Creswell, J.W. and Plano Clark, V.L. (2007). *Designing and conducting mixed methods research*. Wiley Online Library.

Davies, P. and Osmani, M. (2011). Low carbon housing refurbishment challenges and incentives: architects' perspectives. *Building and Environment* 46(8), 1691–1698.

Denzin, N.K., and Lincoln, Y.S., 2011. *The Sage Handbook of qualitative research.* 4th edition, London: Sage Publications.

Department of Energy and Climate Change, UK leads the world with commitment to cut emissions by 80%by 2050, Department of Energy and Climate Change, London, October 2008. Available from: Department of Energy and Climate Chan**ge** [14/01/09].

Diakaki, C., Grigoroudis, E. and Kolokotsa, D. (2008). Towards a multi-objective optimization approach for improving energy efficiency in buildings. *Energy and Buildings* 40(9), 1747–1754.

Dobson, A. (2007). Environmental citizenship: towards sustainable development, Sustainable Development 15(2007) 276-285.

Dobson, A. (2007). Environmental citizenship: towards sustainable development. *Sustainable Development* 15(5), 276–285.

Dobson, D. W., Sourani, A., Sertyesilisik, B., and Tunstall, A. (2013). Sustainable construction: analysis of its costs and benefits. American Journal of Civil Engineering and Architecture, 1(2), 32-38.

Dowson, M., Poole, A., Harrison, D. and Susman, G. (2012). Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal. *Energy Policy* 50, 294–305.

Easterby-Smith, M., Thorpe, R. and Jackson, P.R. (2012). *Management research*.4th ed. London: SAGE.

Eicholtz, P., Kok, N. and Quigley, J. (2010). *Sustainability and the dynamics of green building – new evidence on the financial performance of green office buildings in the USA*. London: Royal Institution of Chartered Surveyors (RICS).

Elbert, T., Ray, W.J., Kowalik, Z.J., Skinner, J.E., Graf, K.E. and Birbaumer, N. (2014). Chaos and physiology: deterministic chaos in excitable cell assemblies. *Physiological Reviews* 74(1), 1–47.

Essa, R.A. (2008). A framework for the pre-construction evaluation of sustainable housing projects in the UK. Unpublished PhD thesis. Edinburgh: Heriot-Watt University.

European Commission. (2013). *Europe 2020 targets: climate change and energy*. Available from: tp://ec.europa.eu/europe2020/pdf/themes/16_energy_and_ghg.pdf [Accessed 23 August 2017].

Eve, R.A., Horsfall, S. and Lee, M.E. (2011). *Chaos, complexity, and sociology: myths, models, and theories*. Thousand Oaks, CA: SAGE.

Evmorfopoulou, K. (2007). *Focus group methodology for the Madame Project*. Available from:http://www.shef.ac.uk/~scgisa/MADAMENew/Deliverables/FGEnd1.htm[Accessed 8 March 2018].

Fellows, R. and Liu, A. (2008). *Research methods for construction*. 3rd ed. Chichester, UK: Wiley-Blackwell.

Fellows, R. and Liu, A. (2015). *Research methods for construction*. 4th ed. Chichester, UK: Wiley-Blackwell.

Fenhann, J. and Hinostroza, M. (2011). *CDM information and guidebook*. 3rd ed. Roskilde: UNEP Risø Centre. Available from:http://cd4cdm.org/Publications/cdm_guideline_3rd_edition.pdf [Accessed22 March 2018].

Filippini M., Hunt, L.C. and Zorić, J. (2014). Impact of energy policy instruments on the estimated level of underlying energy efficiency in the EU residential sector. *Energy Policy* 69, 73–81.

Frodeman, R., Thompson Klein, J. and Mitcham, C. (eds). (2010). *The Oxford handbook of interdisciplinary*. New York: Oxford University Press.

Frost, J and Sullivan, K. (2014). Energy efficiency and large South African commercial businesses - Quick wins where high electricity tariffs can negatively affect profit margins. Available from http://www.frost.com/srch/catalog-search.do?queryText=energy+efficiency+south+africa [Accessed on 24 January 2019].

Fulford, M. (2011). *Carbon reduction without people is like a bird without wings*. RICS Modus.

Giorgi, A. (2012). The descriptive phenomenological psychological method. *Journal of Phenomenological Psychology* 43(1), 3–12.

Godwin, P.J. (2011). Building conservation and sustainability in the United Kingdom. *Procedia Engineering* 20, 12–21.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report*8 (4), 597–607.

Grant, C. and Osanloo, A. (2014). Understanding, selecting, and integrating a theoretical framework in dissertation research: creating the blueprint for your "house". *Administrative Issues Journal* 4(2).

Green Building Council of South Africa. (2014). *About green building*. Available from: https://www.gbcsa.org.za/about/about-green-building/ [Accessed 26 July 2018].

Gregor, S. and Jones, D. (2007). The anatomy of a design theory. *Journal of the Association for Information Systems (JAIS)* 8(5), 312–337.

Guastello, S.J., Koopmans, M. and Pincus, D. (eds). (2009). *Chaos and complexity in psychology: the theory of nonlinear dynamical systems*. Cambridge, UK: Cambridge University Press.

Guest, G., Namey, E.A., & Mitchell, M.L. (2013). *Collecting qualitative data: a field manual for applied research*.Thousand Oaks, CA: SAGE.

Gupta, A. and Anish, S. (2012).Complexity theory: understanding organisations better. *IIM Bangalore*.

Häkkinen, T. and Belloni, K. (2011). Barriers and drivers for sustainable building. *Building Research &Information* 39(3) 239–255.

Hermelink, A. (2005). *SOLANOVA – "Factor 10"-retrofit of large residential buildings*. Kassel, Germany: Centre for Environmental Systems Research (CESR), University of Kassel.

Hesse-Biber, S.N. and Leavy, P. (2011). *The practice of qualitative research*. 2nd ed. Los Angeles: SAGE.

Hevner A.R. (2007). A three cycle view of design science research. *Scandinavian Journal of Information Systems* 19(2), 87–92.

Hevner, A.R., March, S.T., Park, J. and Ram, S. (2004). Design science in information systems research. *MIS Quarterly* 28(1), 75–105.

Hewitt, N.J. (2012). Retrofit of existing buildings – a major technical, economic and social challenge. *International Journal of Ambient Energy* 33(1), 1. DOI: 10.1080/01430750.2012.666893.

Hill, M. (Singer-songwriter). (2014). Canada Green Building Trends: Benefits Driving the New and Retrofit Market. On: Canada Green Building Council.

Hills, J. (2009). Retrofitting existing buildings: the low cost, high volume solution to climate change. Richard Ellis, Sustainability Asia Pacific: Environment Matters for Real Estate (Issue 4):10–15.

Hoes, P., Hensen, J.L.M., Loomans, M.G.L.C., De Vries, B. and Bourgeois, D. (2009). User behaviour in whole building simulation. *Energy and Buildings* 41(3), 295–302.

IEA (2011b). *Co-Generation and Renewables*: Solutions for a Low-Carbon Energy Future. International Energy Agency, Paris, France, 35 pp. Available at: http:/

/www.iea.org/publications/freepublications/publication/name,3980,en. Html [Accessed 21 January, 2018].

Iivari, J. (2007). A paradigmatic analysis of information systems as a design science. *Scandinavian Journal of Information Systems* 19 (2),39–64.

Iivari, J. (2013). Towards information systems as a science of meta-artefacts. *Communications of the AIS* (12)37, 568–581.

Jaccard, J. and Jacoby, J. (2009). *Theory construction and model-building skills: a practical guide for social scientists*. New York: Guilford.

Jordan, J., Lynch, U., Moutray, M., O'Hagan, M.-T., Orr, J., Peake, S. and Power, J.(2007). Using focus groups to research sensitive issues: insights from group interviews on nursing in the Northern Ireland "Troubles". *International Journal of Qualitative Methods* 6, 1–19.

Karvonen, A. (2013). Towards systemic domestic retrofit: a social practices approach. *Building Research &Information* 41(5), 563–574.

Kats, G. (2009). *Greening our built world: costs, benefits, and strategies*. Washington, DC: Island Press.

Kaya, Y. (1990). Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris. (Mimeo).

Keeping, M. and Shiers, D.E. (2004). *Sustainable property development: a guide to real estate and the environment*. Oxford: Blackwell.

Kelly, S., (2011). Do homes that are more energy efficient consume less energy? a structural equation model for England's residential sector, EPRG Working Paper, Electricity Policy Research Group, University of Cambridge

Koshman, O. and Ulyanova, O. (2014). *Attitudes towards domestic energy efficiency among Russian consumers: factors influencing behaviour*. MSc thesis. Bodø, Norway: University of Nordland.

Krueger, R.A. and Casey, M.A. (2015). *Focus groups: a practical guide for applied research*.5th ed. Thousand Oaks, CA: SAGE.

Kumar, R. (2005). *Research methodology: a step-by-step guide for beginners*. 2nd ed. London: SAGE.

Kurul, E. (2007). A qualitative approach to exploring adaptive re-use processes. *Facilities* 25(13/14), 554–570.

Kvale, S. And Brinkmann, S. (2009), Interviews: Learning the craft of Qualitative Research Interviewing, Sage, Los Angeles, CA.

Langston, C., Wong, F.K.W., Hui, E.C.M. and Shen, L.-Y. (2008). Strategic assessment of building adaptive reuse opportunities in Hong Kong. *Building and Environment* 43(10), 1709–1718.

Langston, C.; Wong, F.K.W.; Hui, E.C.M.; Shen, L.Y.(2008) Strategic assessment of building adaptive reuse opportunities in Hong Kong. Build. Environ. 2008, 43, 1709–1718.

Laszlo, E. (1996). *The systems view of the world: a holistic vision for our time*. Cresskill, NJ: Hampton Press.

Leedy, P.D. and Ormrod, J.E. (2010). *Practical research: planning and design*.8th ed. Boston: Pearson.

Leedy, P.D. and Ormrod, J.E. (2013). *Practical research: planning and design*.10th ed. Boston: Pearson.

Lombard, L.J. (2013). *Empirical study into the benefits of the retrofitting of existing commercial buildings to improve energy efficiency*. MSc research report. Johannesburg: University of the Witwatersrand.

Love, P., Niedzweicki, M., Bullen, P. and Edwards, D. (2011). Achieving the Green Building Council of Australia's world leadership rating in an office building in Perth. Journal of Construction Engineering and Management, vol. 138, no. 5, pp. 652–660.

Lutzkendorf, T, and Lorenz, D. (2007). Integrating Sustainability into Property Risk Assessments for Market Transformation, Building Research and Information 35 (6) (2007) 644-661.

Ma, Z., Cooper, P., Daly, D. and Ledo, L. (2012). Existing building retrofits: methodology and state-of-the-art. *Energy and Buildings* 55,889–902.

MacLennan, B.J. (2012). *Evolutionary psychology*, *complex systems, and social theory*. Knoxville, TN: Department of Electrical Engineering & Computer Science, University of Tennessee.

Mahlia, T.M.I., Abdul Razak, H. and Nursahida, M.A. (2011). Life cycle cost analysis and payback period of lighting retrofit at the University of Malaya. *Renewable and Sustainable Energy Reviews* 15(2), 1125–1132.

Mark, C., Tatum, P.E. and Stallings, D. (2013). *Zero carbon buildings: implementation strategies utilized in Europe and the United States*. Auburn, AL: Auburn University.

Marshall, C. and Rossman, G.B. (2011). *Designing qualitative research*.5th ed.Thousand Oaks, CA: SAGE.

Martis M.S. (2006). *Validation of Simulation Based Models*: A Theoretical Outlook. *The* Electronic Journal of Business Research Methods**,** 4(1), 39-46

Masadeh, M.A. (2012). Focus group: reviews and practices. *International Journal of Applied Science and Technology* 2 (10), 63–68.

Maunsell, F. and Capener, P. (2007). *Supporting and delivering zero carbon development in the South West. Final technical report*. South West Regional Assembly and Taunton Dean Borough Council.

Mauro, G.M. (2015). *Multi-objective optimization for cost-optimal energy retrofitting: from the single building to a stock*. PhD thesis. Naples, Italy: University of Naples Federico II.

Meadows, D.H. (2008). *Thinking in systems: a primer*. White River Junction, VT: Chelsea Green.

Mele, C., Pels, J. and Polese, F. (2010). A brief review of systems theories and their managerial applications. *Service Science* 2(1/2), 126–135.

Merton, R.K., Fiske, M. and Kendall, P.L. (1990). *The focused interview: a manual of problems and procedures*. 2nd ed. London: Collier MacMillan.

Miles, M.B., Huberman, A.M.and Saldaña, J. (2014). *Qualitative data analysis: amethods sourcebook*.3rd ed.Thousand Oaks, CA: SAGE.

Milford, R. (2009). *Greenhouse gas emission baselines and reduction potentials from buildings in South Africa*. Paris: United Nations Environment Programme.

Miller, E. and Buys, L. (2008). Retrofitting commercial office buildings for sustainability: tenants' perspectives. *Journal of Property Investment & Finance* 26(6), 552–561.

Miller, J.H. and Page, S.E. (2007). *Complex adaptive systems: an introduction to computational models of social life*. Princeton, NJ: Princeton University Press.

Miller, N.G., Pogue, D., Gough, Q.D. and Davis, S.M. (2009). Green buildings and productivity. *Journal of Sustainable Real Estate* 1, 65–89.

Miller, P. (2008). Validity. In: L.M. Given (ed.). *The SAGE encyclopaedia of qualitative research methods*. Los Angeles: SAGE. pp. 909–910.

Milne, N. (2012). *The rands and sense of green building: building the business case for green commercial buildings in South Africa*. Cape Town: Green Building Council of South Africa.

Minichielle, V., Aroni, R. and Hays, T. (2008), In Depth Interviewing: Principles, Techniques, Analysis, Pearson, Sydney.

Mitleton-Kelly, E. (2012). Ten principles of complexity and enabling infrastructures. In: E. Mitleton-Kelly (ed.), *Complex systems and evolutionary perspectives of organisations: the application of complexity theory to organisations*. Amsterdam: Elsevier. pp. 23–50.

Moe, E. (2010). Energy, industry and politics: energy, vested interests, and long-term economic growth and development. *Energy* 35(4), 1730–1740.

Morris, S. (2013). Victoria State of Australia International Specialised Skills Institute Report on: Improving energy efficient, sustainable building design and construction in Australia– learning from Europe. Available from http://www.responsabilidadimas.org/web/f_fck/destacado_canal/MORRIS-ReportLowRes.pdf [Accesed on 24 January, 2019].

Morris, T. and Wood, S. (2011).Testing the survey method: continuity and change in British industrial relations.*Work, Employment and Society* 5(2), 259–282.

Moser, C.A. and Kalton, G. (1971). *Survey methods in social investigation*. 2nd ed. London: Heinemann Educational.

Moustakas, C. (1994). *Phenomenological research methods*. Thousand Oaks, CA: SAGE.

National Refurbishment Centre. (2012). *refurbishing the nation: gathering the evidence*. Available from: http://www.rethinkingrefurbishment.com/filelibrary/nrc_pdf/NRC_reportAUG2016web.pdf [Accessed 27 September 2017].

National Renewable Energy Laboratory. (2012). Biomass energy basics. Washington, DC: NREL, U.S. Department of Energy. Available from: http://www.nrel.gov/learning/re_biomass.html/ [Accessed 11 June 2016].

Natural Resources Canada. (2015). *Energy management best practices guide for commercial and institutional buildings*. Ottawa, ON: Natural Resources Canada. ISBN 978-1-100-24761-8.

Nelson, R., Peterhansi, A and Sampat, B. (2004). Why and how innovations get adopted: a tale of four models, Industrial and Corporate Change 13 (5) (2004) 679-699.

Neuman, W.L. (2006). *Social research methods: qualitative and quantitative approaches*. 6th ed. Boston: Allyn& Bacon.

Ng, I.C.L., Maull, R. and Yip, N. (2009). Outcome-based contracts as a driver for systems thinking and service-dominant logic in service science: evidence from the defence industry. *European Management Journal*27 (6), 377–387.

Okorafor, C., Emuze, F.A. and Das, D.K. (2017). Low carbon building: implementation strategies utilised in South Africa. *Proceedings of the International Sustainable Ecological Engineering Design for Society Conference*,13–14 September 2017, Leeds, United Kingdom. ISBN 978-0-9955690-2-7.

Osmani, M. and O'Reilly, A. (2009). Feasibility of zero carbon homes in England by 2016: a house builder's perspective. *Building and Environment* 44(9), 1917–1924.

Owens, J. and Wilhite, H. (1988). Household energy behaviour in Nordic countries—an unrealized energy saving potential. *Energy* 13(12), 853–859.

Paradis, R. (2012). *Retrofitting existing buildings to improve sustainability and energy performance*. Washington, DC: National Institute of Building Sciences. Available from:www.wbdg.org/resources/retrofitting-existing-buildings-improve-sustainability-and-energy-performance [Accessed 31 August 2017].

Peters, G.P., Andrew, R.M., Canadell, J.G., Fuss, S., Jackson, R.B., Korsbakken, J.I., Le Quéré, C., Nakicenovic, N. (2017). Key indicators to track current progress and future ambition of the Paris Agreement. Nature Climate Change 7, 118-122.

Phoenix Electric Corporation. (2015). Retrofit, refurbish, repair – what is the difference? Available from: http://www.pecusa.biz/page144.html [Accessed 15 June 2016].

Pielke, R.A. (2010). The carbon economy and climate mitigation: an editorial essay. *WIREs Climate Change* 1, 770–772.

Pitt, M., Tucker, M., Riley, M. and Longden, J. (2009). Towards sustainable construction: promotion and best practices. *Construction Innovation* 9 (2), 201–224.

Polkinghorne, D.E. (1989). Phenomenological research methods. In: R.S. Valle and S. Halling (eds), *Existential-phenomenological perspectives in psychology: exploring the breadth of human experience*. New York: Plenum. pp. 41-60.

Poyton, P. (2003). Perspectives on innovation: housing, Zed factory, Surrey, 2003.

Punch, K.F. (2015). *Introduction to social research: quantitative and qualitative approaches*. 3rd ed. Los Angeles: SAGE.

REN. (2011). Renewables 2011: Status Report. Paris: Renewable Energy Policy Network for the 21st Century. Available from: www.ren21.net/portals/97/documents/GSR/REN21-GSR2011.pdf.[Accesed on 24 January, 2019].

Rivers N. (2010). *Impacts of climate policy on the competitiveness of Canadian industry:* How big and how to mitigate? Energy Economics 32, 1092–1104. doi: 10.1016/j.eneco.2010.01.003, ISSN: 0140-9883

Robson, C. (2002).*Real world research: a resource for social scientists and practitioner-researchers*.2nd ed. Oxford: Blackwell.

Roth L, Eklund M and Simonsson A (2002). Assessing the building sector's most important materials from an energy and material resources perspective. In: Proc Sustainable Building 2002, September 23-25 Oslo, Norway.

Rubin, H.J and Rubin, I.S. (2005), Qualitative Interviewing: The Art of Hearing Data, 2nd ed., Sage, Thousand Oaks, C.A.

Santin, O.G., Itard, L. and Visscher, H. (2009). The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings* 41(11), 1223–1232.

Sargent R.G. (2005). *Verification and Validation of Simulation Models.* In: Yahaya, M.I. (2008). Developing a Model for Vision-Based Progress Measurement and Visualisation of As-Built Construction Operations, an unpublished PhD Thesis, School of the Built Environment, Heriot-Watt University.

Saunders, M., Lewis, P. and Thornhill, A. (2012). *Research methods for business students*. 6th ed. Harlow, UK: Pearson Education.

Schensul, J. (2008). Methodology. In:L.M.Given (ed.), *The SAGE encyclopedia of qualitative research methods*. Los Angeles: SAGE. pp. 264–268.

Shipley, R., Utz, S. and Parsons, M. (2006). Does adaptive reuse pay? A study of the business of building renovation in Ontario, Canada. *International Journal of Heritage Studies* 12 (6), 505–520.

Shipworth, M. (2000). Motivating home energy action: a handbook of what works. Available from:http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.475.7372&rep=rep1&type=pdf[Accessed 2 March 2018].

South African Property Owners Association. (2010). Operating Cost Report. Available from: https://www.google.com/search?q=SAPOA+Operating+Cost+Report&ie=utf-8&oe=utf-8&client=firefox-b&gfe_rd=cr&ei=a9u-V[Accessed 25 August 2017].

Sponge Sustainability Network. (2006). *Eco chic or eco geek? The desirability of sustainable homes*. UK: HBOSplc.

Stafford, A., Gorse, C. and Shao, L. (2011). The retrofit challenge: delivering low carbon buildings. York, UK: The Centre for Low Carbon Futures. Available from: https://leedsbeckett.ac.za/as/cebe/projects/retrofit_challenge.pdf [Accessed 31 August 2017].

Starks, H. and Brown Trinidad, S. (2017). Choose your method: a comparison of phenomenology, discourse analysis, and grounded theory. *Qualitative Health Research* 17(10), 1372–1380.

Stewart, D.W., Shamdasani, P.N. and Rook, D.W. (2007). *Focus groups: theory and practice. Applied social research methods series: vol. 20*. 2nd ed. Thousand Oaks, CA: SAGE.

Steyn, C.J. (2014). *Investigating selected retrofitted and reused buildings in Johannesburg to determine their economic and environmental impact*. MTech thesis. Pretoria: Tshwane University of Technology.

Strickland, C.J. (1999). Conducting focus groups cross-culturally: experiences with Pacific Northwest Indian people. *Public Health Nursing* 16(3), 190–197.

Stringer, E.T. (2014). *Action research*. 4th ed. Thousand Oaks, CA: SAGE.

Sullivan, L., Mark, B. and Parnell, T. (2006). Lessons for the application of renewable energy technologies in high density urban locations. *Proceedings of the 23rd Conference on Passive and Low Energy Architecture (PLEA2006)*, Geneva, Switzerland, 6–8 September 2006.

Sutrisna, M. (2009). Research methodology in doctoral research: understanding the meaning of conducting qualitative research.*Working paper presented in ARCOM Doctorial Workshop*.John Moores University, Liverpool, 12 May 2009.

Suzuki, H., Dastur, A., Moffatt, S., Yabuki, N. and Maruyama, H. (2010). *Eco^{2}cities: ecological cities as economic cities*. Washington, DC: International Bank for Reconstruction and Development/World Bank.

Svirejeva-Hopkins, A., Schellnhuber, H.J. and Pomaz, V.L. (2004). Urbanised territories as a specific component of the Global Carbon Cycle. *Ecological Modelling* 173(2–3), 295–312.

Swan, W. and Brown, P. (eds). (2013). *Retrofitting the built environment*. Oxford: Wiley-Blackwell.

Swan, W., Ruddock, L., Smith, L. and Fitton, R. (2013). Adoption of sustainable retrofit in UK social housing. *Structural Survey* 31(3), 181–193.

Swan, W., Ruddock, L. and Smith, L. (2013). Low carbon retrofit: attitudes and readiness within the social housing sector. *Engineering, Construction and Architectural Management* 20(5), 522–535.

Sweatman, P. and Managan, K. (2010). *Financing energy efficiency building retrofits: international policy and business model review and regulatory alternatives for Spain*. Madrid: Climate Strategy &Partners.

Tan, W. (2004). *Practical research methods*. 2nd ed. Singapore: Pearson Prentice Hall.

Teddlie, C. and Yu, F., (2007). Mixed methods sampling: a typology with examples. *Journal of Mixed Methods Research* 1(1), 77–100.

Thovhakale, B.T., McKay, T.M. and Meeuwis, J. (2013). Retrofitting to lower energy consumption. Published by University of Johannesburg with permission of AMEU, conference, 2011.

Tobias, L. and Vavaroutsos, G. (2009). *Retrofitting office buildings to be green and energy-efficient: optimizing building performance, tenant satisfaction, and financial return*. Washington, DC: Urban Land Institute.

Townsend, J.T. (1992). *Chaos theory: a brief tutorial and discussion*. Available from:http://www.indiana.edu/~psymodel/papers/Chaos%20Theory.pdf[Accessed 19June 2017].

Tracy, S.J. (2013). *Qualitative research methods: collecting evidence, crafting analysis, communicating impact*. Chichester, UK: Wiley-Blackwell. ISBN: 978-1-9203-3.

Tucker, A. and Topi, H. (eds). (2013). *CRC handbook of computing*. Boca Raton, FL: Chapman and Hall.

Unruh, G.C. (2002). Escaping carbon lock-in. *Energy Policy* 30(4), 317–325.

Unruh, G.C. (2010). Understanding carbon lock-in. *Energy Policy* 28(12), 817–830.

US DoE. (2011). *Heat Pump System*. Washington, DC: United States Department of Energy. Available from:www.energysavers.gov/your-home/space-heating-cooling/index.cfm/mytopic=12610[Accesed on 24 January, 2019].

Van Aken J.E. (2005). Management research as a design science: articulating the research products of Mode 2 knowledge production in management. *British Journal of Management* 16(1), 19–36.

Venable, J., Pries-Heje, J., Baskerville, and Richard, K. (2012). A Comprehensive Framework for Evaluation in Design Science Research. In K. Peffers, M. Rothenberger & B. Kuechler (Eds.), Design Science Research in Information Systems. Advances in Theory and Practice (Vol. 7286, pp. 423-438). Berlin / Heidelberg: Springer.

Verbruggen, A., Almarchohi, M. and Janssens, B. (2011). The anatomy of investing in energy efficient buildings. *Energy and Buildings* 43(4), 905–914.

Von Bertalanffy, L. (1968). *General system theory: foundations, development, applications*. New York: George Braziller.

Wafula, J.E. and Thalukhaba, A. A. (2013). Retrofits/renewals in buildings for energy efficiency and the building control regulations in local authorities in South Africa. *RICS Cobra Convention*, 2–3 September 2013, Dauphine University Paris.

Walker, I.S. (2003). *Best practices guide for residential HVAC retrofits*. LBNL53592. Berkeley, CA: Lawrence Berkeley National Laboratory. Available from: ducts.lbl.gov/HVACRetrofitguide.html[Accessed 23 July 2018].

Wang, L., Toppinen, A., and Juslin, H. (2014). Use of wood in green building: a study of expert perspectives from the UK. Journal of cleaner production, 65, 350-361.

Wang, Q. (2013). *Toward industrialized retrofitting: accelerating the transformation of the residential building stock in Sweden*. Licentiate thesis. Stockholm, Sweden: KTH Royal Institute of Technology. ISSN 0284-141X.

Wang, T., Foliente, G., Song, X., Xue, J., and Fang, D. (2014). Implications and future direction of greenhouse gas emission mitigation policies in the building sector of China. Renewable and Sustainable Energy Reviews, 31, 520-530.

Wang, U. (2011). The rise of concentrating solar thermal power. Renewable Energy world, 6 June. Available at www.renewableeergyworld.com/rea/news/article/2011/06/the -rise-of-concentrating-solar-thermal-power [Accessed on 24 January, 2019].

Watkins, K. (2007). *Fighting climate change: human solidarity in a divided world. Human Development Report 2007/2008*. New York: United Nations Development Programme.

Weber, C. and Shah, N. (2011). Optimisation based design of a district energy system for an eco-town in the United Kingdom. *Energy* 36(2), 1292–1308.

Wengraf, T, (2001), Qualitative Research Interviewing: Biographic Narrative and Semi-Structured Methods, Sage, Thousand Oaks, C.A.

Williams, J. (2010). The deployment of decentralised energy systems as part of the housing growth programme in the UK. *Energy Policy* 38(12), 7604–7613.

Williams, K and Adair, C. (2007). What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable development, Sustainable Development 15 (2007) 135-147.

Williams, K. and Adair, C. (2007). What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable development. *Sustainable Development* 15(3), 135–147.

Winkler, H. (2007). *Long term mitigation scenarios: technical appendix*. Prepared by the Energy Research Centre for the Department of Environmental Affairs and Tourism, Pretoria, October 2007. Available from: http://www.erc.uct.ac.za/Research/publications/07-Winkler-LTMS Technical%20Report.pdf [Accessed 15 August 2017].

Winkler, H. and Marquard, A. (2009). Changing development paths: from an energy-intensive to low-carbon economy in South Africa. *Climate and Development* 1, 47–65.

World Business Council for Sustainable Development. (2009). *Energy efficiency in buildings: transforming the market*. Geneva, Switzerland: WBCSD. Available from:http://www.wbcsd.org/Pages/EDocument/EDocumentDetails.aspx?ID=11006[Accessed22 August 2017].

World Commission on Environment and Development. (1987). *our common future: report of the World Commission on Environment and Development*. New York: United Nations. Available from: http://www.un-documents.net/ocf-02.htm [Accessed23 July 2018].

Yin, R.K. (2014). *Case study research: design and methods*. 5th ed. Thousand Oaks, CA: SAGE.

Yohanis, Y.G. (2012). Domestic energy uses and householders' energy behaviour. *Energy Policy* 41, 654–665.

Central University of Technology, Free State

APPENDIX

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

Central University of Technology, Free State

12th September 2017

To Whom It May Concern,

Sir/Madam,

Re: Retrofitting to reduce carbon emissions from existing government buildings in Bloemfontein, South Africa

This data collection is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this phase of the project is to conduct a pilot study that would provide insights into the central question and sub questions of the study.

Please be rest assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on+27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favorable consideration of the request.

……………………………………………………
Chikezirim Okorafor (Doctoral Student)

……………………………………………………
Prof FA EMUZE
Head of Department: Built Environment

INSTRUCTIONS:

Please answer the following questions by crossing (x) on the relevant block or writing down your answer in the space provided

EXAMPLE of how to complete this questionnaire:

Your gender?

If you are female:

Male	1
Female	2 (x)

Response Background Information

This section of the questionnaire refers to biographical information.

1. Gender

Male	1
Female	2

2. Years of experience in the industry (in absolute number)

5 years – 10 years	1
10 years – 15 years	2
15 years – 20 years	3
20 years & Above	4

3. What is your professional affiliation?

Architect	1
Electrical Engineer	2
Project Manager	3

Construction Manager	4
Civil Engineer	
Quantity Surveyor	
Mechanical Engineer	
Please specify Others:	

TECHNICAL INFORMATION

Please furnish us with the technical information related to the following questions:

1. What are the current best building energy retrofit practices in project delivery?

2. What are the key elements involved in the retrofitting of an existing building?

3. What are the challenges encountered when retrofitting an existing building?

4.What are the potential solutions the challenges outlined in question 3 above?
Skills

Based on your professional experience, kindly highlight common issues around the retrofitting of existing buildings.

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

Central University of Technology, Free State

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

Central University of Technology, Free State

25th November, 2017.

To Whom It May Concern,

Dear Respondent,

Re: Retrofitting to reduce carbon emissions from existing government buildings in Bloemfontein, South Africa

This interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State, South Africa.

The aim of this phase of interview is to ascertain perspectives and experiences from respondents on the topic.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request

…………………………………………………

Chikezirim Okorafor (Doctoral Student)

…………………………………………………

Prof FA EMUZE

Promoter

INTERVIEW PROTOCOL

Name of the firm: …………………………………………………………………………...

Name of the interviewees: ……………………………………………………………..

Position Held in the firm: ………………………………………………………………

Years of experience in the firm: ………………………………………………………..

TECHNICAL INFORMATION

Please furnish us with the technical information related to the following questions:

1. Following the response from the interviewee in the pilot study, they proffer the following; building analysis, developing energy efficiency measures, human factor, implementation of measures, monitoring and verification are paramount to efficient delivery of Building Energy Retrofit as the best building energy retrofit practices. In this building how do you implement such practices?...
....
....
....
....
....
....

2. Following the interview, the interviewee clearly demonstrates agreement on the strong need to integrate socio and technical element of building energy retrofit. Socio aspect regards the behaviour of occupant using the facility, how they accept and use the retrofit technology and the technical aspect such as; retrofit technology, building fabrics and how the technology will fit into the building going forward. Even the client resources and the payback period, all this element remains paramount in determining the overall success and ensuring that lessons are learned for future projects. In this building how do you engage with such elements in delivering of this retrofit project?...

....
....
....
....
....
....
....

3. Following the response from the interviewee, the challenges that top the lists were in the areas of communication and consultation-they reiterate that the activities of stakeholders are insufficient and inadequate; lack of stakeholder agreement; piecemeal-fashion of doing things; lack of socio data incorporated in the project amongst others. This is closely followed by collaborations and cooperation which revolves round (lack of stakeholders activities) to obtain buy-in into the project; expert operating randomly which makes work to move half-hazardly. The issue of flexibility/adaptability is another serious challenge because no single Building Energy Retrofitted projects are the same. In the same argument, the interviewee's posited that technical know-how is a key challenge. How is the challenge prevalent in your project?...
....
....
....
....
....
....
....

4. When asked to consider how best to overcome these challenges and what was needed to improve the delivery of Building Energy Retrofitted Project, the interviewee suggested improvement in the area of communication and consultation with all stakeholders, especially the affected building. This is an informative session to receive and communicate details of activities in order to deliver what is actually needed in the Building Energy Retrofitted Project. Collaboration and coordination is a factor to be improved upon. Despite the fact that it takes more time, money and effort to make decisions collaboratively, but its potential gains outweighs the cost involved. Collaboration and coordination happens on the assumption that the resulting decisions will be superior to decisions made individually as regards BERP. How do you adopt this solution in your project?...

………
………
………
………
………
………
………

Thank you for contributing to sustainable buildings research in South Africa

Central University of Technology, Free State

Central University of Technology, Free State

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

11th June2018

To Whom It May Concern,

Dear Sir/Madam,

Re: Retrofitting to reduce carbon emissions from existing government buildings in Bloemfontein, South Africa

This interview is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State, South Africa.

The aim of this focus group session is to discuss the perceptions of respondents to the study so that consensus and differences would have credible explanations.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request

…………………………………………………

Chikezirim Okorafor (Doctoral Student)

…………………………………………………

Prof FA EMUZE

Promoter

PROTOCOL

Name of the firm: ………………………………………………………………………...

Name of the interviewees: ……………………………………………………………..

Position Held in the firm: ………………………………………………………………

Years of experience in the industry: …………………………...

TECHNICAL INFORMATION

Please furnish us with the technical information related to the following questions:

1. Participants of the earlier phases of this study recorded notable practices in the field of retrofits. Could you therefore comments on the following best practices: building analysis, developing energy efficiency measures, human factor, and implementation of measures, monitoring and verification?

....
....
....
....
....
....

2. Participants of the earlier phases of this study recorded notable challenges in the field of retrofits. They flagged insufficient (or inadequate) communication and consultation, lack of stakeholder agreement, piecemeal-fashion of doing things, and lack of social data that is incorporated in the project. Could you please shed more light on these challenges? Please mention and discuss other challenges as well.

....
....
....
....
....
....
....

Central University of Technology, Free State

3. In your own opinion, how best can we overcome these challenges?

……
………
………
………
………
………
………
………
………
………
………

Thank you for contributing to the promotion of retrofitted buildings in South Africa

Central University of Technology, Free State

Central University of Technology, Free State

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

11th June 2018

To Whom It May Concern,

Dear Sir/Madam,

Re: Retrofitting to reduce carbon emissions from existing government buildings in Bloemfontein, South Africa

This data collection is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State.

The aim of this phase of the project is to conduct an expert survey that would provide additional insights into the results of the qualitative strand of the data collection exercise.

Please be rest assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on+27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favorable consideration of the request.

....
Chikezirim Okorafor (Doctoral Student)

....
Prof FA EMUZE

Promoter

QUESTIONNAIRE

INSTRUCTIONS:

Please answer the following questions by crossing (x) on the relevant block or writing down your answer in the space provided
EXAMPLE of how to complete this questionnaire:

Gender?

If you are female:

Male	1
Female	X 2

Background Information

This section of the questionnaire refers to biographical information.

2 Gender

Male	1
Female	2

3 Years of experience in the industry (in absolute number)

5 years – 10 years	1
10 years – 15 years	2
15 years – 20 years	3
20 years & Above	4

4 What is your Job Title in terms of professional affiliation?

Architect	
Electrical Engineer	
Facility Manager	
Construction Manager	
Civil Engineer	
Quantity Surveyor	
Mechanical Engineer	
Project Manager	
Please specify others:	

<u>Technical Information</u>

<u>Section A: Components of a building energy retrofit project</u>

This section of the questionnaire measures the key components worthy of inclusion in an energy retrofit project.

Please rate the importance of the under listed aspects of a typical retrofit project? Please indicate your answers using the following 5-point scale where:

1. = Not important
2. = Somehow important
3. = Fairly important
4. = Definitely important
5. = Very important

Aspect	Not important	Somehow important	Fairly important	Definitely important	Very important
	1	2	3	4	5
Project initiation					
Building assessment					

Detailed energy survey					
Technical analysis					
Cost-benefit analysis					
Measurement of implementation					
Monitoring and verification on energy efficiency initiatives					

Section B: Factors that challenges the implementation of a building energy retrofit project

This section of the questionnaire measures the factors that negatively affect the implementation progress of building energy retrofit project.

Please rate the severity of the under listed issues that challenge the smooth implementation of a retrofit project? Please indicate your answers using the following 5-point scale where:

1. = Minor
2. = Near minor
3. = Neutral
4. = Near major
5. = Major

Challenges	**Minor**	**Near minor**	**Neutral**	**Near major**	**Major**
	1	2	3	4	
Low Stakeholder communication and consultation					
Lack of stakeholder agreement					
Piecemeal-fashion energy efficiency implementation					

lack of psychosocial data in the project					
Lack of broad buy-in into the project					
Lack of collaborative working ethos					
Lack of flexibility/adaptability in delivery processes					
Lack of required technical know-how					
High investment cost					
Uncertainty about the payback period					
Limited access to finance					
Education level of the occupant of the retrofitted building					
Lack of user friendly technologies					
Poor selection of retrofit technologies					
Interruption of existing building operations					
Poor comprehension of building features					
Delayed investment decisions					
Lack of existing user cooperation.					
Lack of as-built drawings for buildings					
Lack of standard rent or lease (income) rate for retrofitted buildings					

<u>Section c: Steps that will help in improving the delivery of a building energy retrofit project</u>

This section of the questionnaire measures the steps that will improve the delivery of building energy retrofit project.

Please rate the significance of the under listed enablers of the smooth implementation of a retrofit project? Please indicate your answers using the following 5-point scale where:

1. = Minor
2. = Near minor

3. = Neutral
4. = Near major
5. = Major

Enabler	**Minor**	**Near minor**	**Neutral**	**Near major**	**Major**
	1	2	3		5
Improved communication and consultation with all stakeholders					
Improved collaboration and coordination among professionals					
Provision training for contractors, subcontractors and installers					
Provision of grants and low-interest loans for such retrofitting scheme					
Awareness creation through targeted education to homeowners and occupants					

THANKS FOR PARTICIPATING IN THE SURVEY

Central University of Technology, Free State

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

31st July, 2018.

To Whom It May Concern,

Dear Sir/Madam,

Re: An Artefact for Building Energy Retrofit Projects: The Case of Government Existing Building in South Africa

This expert survey is part of a research project aimed at meeting the requirement for a Civil Engineering doctoral qualification at the Central University of Technology, Free State, South Africa.

The aim of the questionnaire is to validate an artefact that has been developed for the improvement of the delivery for Building Energy Retrofit Project (BERP) in South Africa. The artefact was developed through case based research design. The results of the case-based study were used to evolve the artefact.

Please be assured that the confidentiality of your response is guaranteed.

Should you have queries, please do not hesitate to contact the promoter of the study, Prof FA Emuze on +27714509442 or per e-mail: femuze@cut.ac.za.

Many thanks for the anticipated favourable consideration of the request

…………………………………………………….
Chikezirim Okorafor (Doctoral Student)

…………………………………………………….
Prof FA EMUZE
Promoter

INSTRUCTIONS:

PLEASE ANSWER THE FOLLOWING QUESTIONS BY CROSSING (X) ON THE RELEVANT BLOCK OR WRITTING DOWN YOUR ANSWER IN THE SPACE PROVIDED.

EXAMPLE of how to complete this questionnaire:

Your gender?

If you are female:

Male	1
Female	2 (X)

SECTION Background information.

This section of the questionnaire refers to biographical information.

1. Gender

Male	1
Female	2

2. Years of experience in the industry (in absolute number)

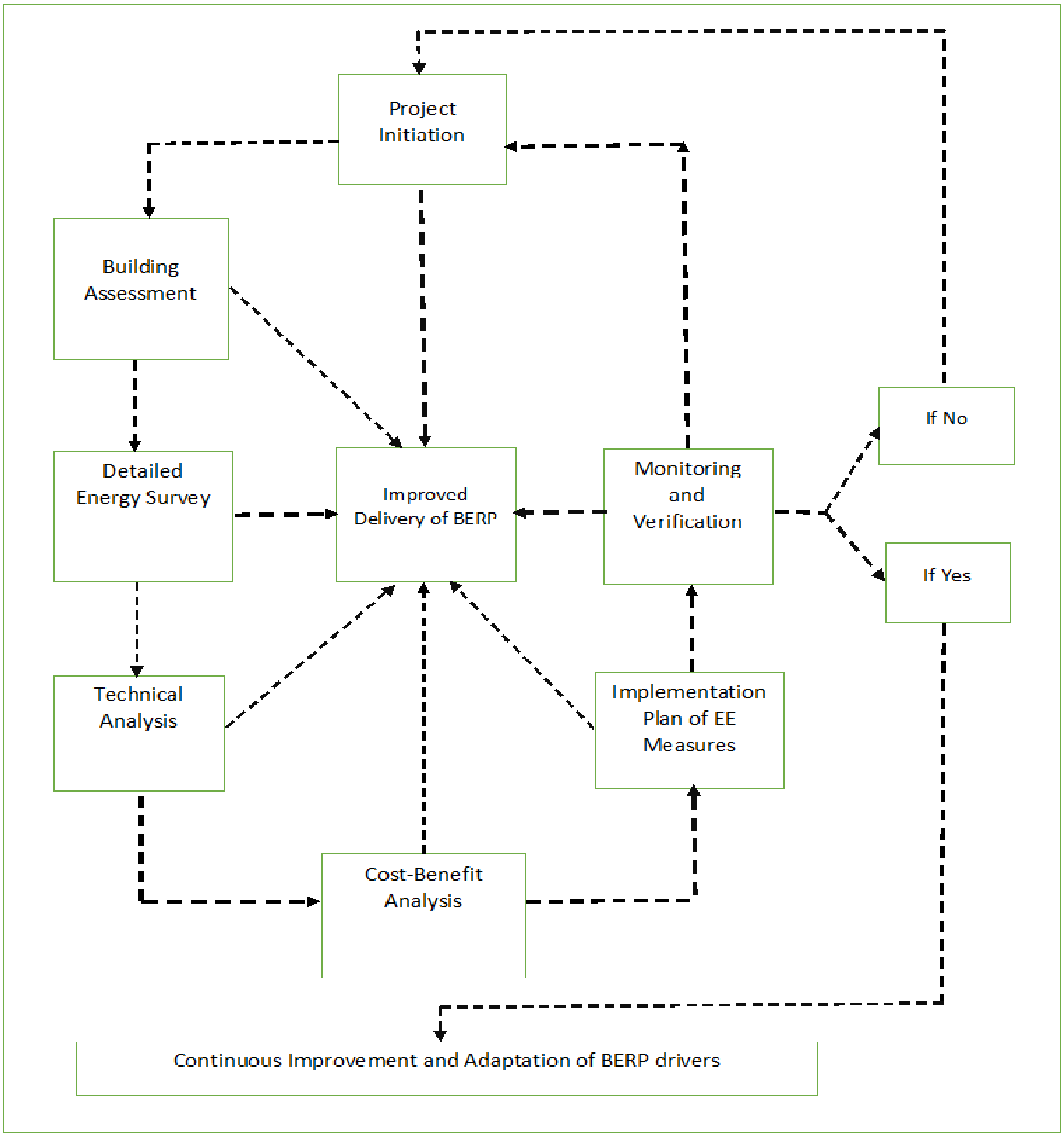
5 years – 10 years	1
10 years – 15 years	2
15 years – 20 years	3
20 years & Above	4

3. What is your highest level of education?

Matric	1
Diploma	2
Bachelor's degree	3
Master's degree	4
Doctorate degree	5
Post-Doctorate degree	6

4. What is your profession?

Architect	1
Electrical Engineer	2
Facility Manager	3
Construction Manager	4
Mechanical Engineer	5
Building Energy Analyst	6
Others: Specify	7



Source: Researcher, 2018

The artefact is based on the concept of Complex Adaptive System Model (MacLennan, 2012: 3; Gupta and Anish, 2012: 17; Miller, John and Scott, 2007: 6; Mitleton-Kelly, 2012: 13). The theory of complex adaptive system underpinned the development of the artefact. It is anticipated that the proposed artefact will engender improved delivery for Building Energy Retrofit in existing government building in South Africa. The detailed description for the artefact is as presented in Table 1 below.

Table 1: Brief description of the artefact

Stage 1(project initiation): Key to successful delivery of a BERP project is preparation, planning and leadership. This can be achieved through the following steps: • Consultation with the stakeholders at the early stage of the project. • Collaboration and cooperation with the stakeholders at the early stage of the project. • Complete plan of action stating what is to be done and how best to achieve it. • Clear, correct and concise modes of operation. • User engagement and education at the early stage of the project. • A thorough planning on how to meet user needs is done without stopping building operation. • Provide an overview of building energy used. • Providing a forward-looking perspective to guide investment decisions for decision makers. • Providing an evidence-based estimate of expected energy savings and associated benefits. The goal of this stage is to define various levels of efforts needed for energy efficiency in existing buildings to provide a point of departure for building owners, facility managers, contractors, government entities and other stakeholders that are embarking on energy efficiency drive in an existing building.
Stage 2(building assessment): The building assessment can assist the stakeholders in establishing long-term strategies. Providing information on measures to stimulate cost-effective deep retrofit of buildings can unfold as follows: • Determine energy consumption of the building. • Determine performance level of the building. • Determine user behaviour. • Collect utility bills for at least one year with the aim to lower it. The goal is to review the collected data with the aim to incorporate it in the final energy measures initiatives that is to be installed.
Stage 3 (detailed energy survey): In this phase, energy survey is carried out with the help of energy auditing team for understanding the energy system for the building. Energy audit needs to

include all possible potentials in the energy systems. The following should be observed in a detailed energy survey:

- Identification of goals encourages recognizing and providing energy savings in the installed electrical systems. Retrofit strategy must be tailored according to the needs of a facility.
- The team should include professionals including architects, HVAC engineers and electrical engineers. Team selection helps ensure that an energy audit results can be implemented at the site by involving experts from various disciplines. Importantly, while selecting team members, it is important for the owner to define shared goals. The team is responsible for a systematic approach in identifying, selecting and formulating recommended measures.
- Energy mapping is done to determine how much energy is consumed by the building. By collecting all information related to the energy system and equipment details, energy segregation can be estimated. A walk through survey helps in providing adequate information where familiarity with all the energy system helps in generating recommendations for retrofit measures.
- In order to determine the baseline, energy survey is performed to collect the operating condition details of the building. After the data collection process is complete, a sheet could be formulated to analyse the building consumption. Based on the operating characteristics the minimum energy requirements of the building can be determined. This basic data collection helps to identify either a low-cost or a no-cost measure for improving energy efficiency.
- Historical building energy data needs to be collected for at least three years. This data is required to suffice historical energy use profiles. The collected data needs to be put in graphical form to examine the patterns and identify the anomalies (pattern matching). By comparing the graphs and values, an unexpected pattern in the energy use can be seen. More cost saving measures can be identified. The baseline assessment after energy survey will determine the minimum energy requirement of the building. It provides a critical reference point for assessing changes and impact, as it establishes a basis for comparing the situation before and after the intervention, and for making inference as to how effective the installed system is.

Stage 4 (technical analysis): A technical analysis studies the data from the energy survey, including energy consumption and peak demand analysis. It identifies and provides technical parameters by selecting electrical products option through energy simulations. With more extensive data collection and engineering analysis, this plan provides most of the information, which can be acted upon. Based on the retrofits options available for energy efficiency, detailed analysis are carried out by formulating action plan, benchmarking assessment and analysis through software. Some features of technical analysis are as follows:

- Formulating an action plan helps to improve building performance through maximum energy savings. To determine the energy plan, the following steps are to be followed:
  - Analysis of energy system of buildings from on- site observation, measurement and engineering calculation for envelope, lighting, HVAC, etc.
  - Review existing operations and maintenance and then change plans, improvements, and estimation of costs.
  - Measure important parameters and compare them to the design levels.
  - Determine the rate structure for energy usage.
- The benchmarking assessment helps to work out the best option for energy efficiency retrofitting in existing buildings. Electrical measurement carried through instruments helps in generating secondary data. Further, it is required to work on the observations and then benchmarking the received data, which can be compared to the design level as per codes and standards. Based on the comparison of information of existing levels, if there is a need to improve the energy levels, an organization can opt for a more detailed energy audit. The most important success factor is to identify where energy is exceeding and based on the plan of action, select the retrofit option that has maximum saving potential.
- After determining the gaps, it is advised to perform the energy simulations to determine the retrofit potential based on the best available technology and its respective payback period. After all the measurements and data collection, the team needs to identify the software (DIALux, Ecotect, Revit, etc.) on which the simulation is to be performed to analyse the operating conditions and to determine the areas where most cost benefitting retrofit plans can be executed.
- After energy simulations of various electrical loads, suggested plan of action should be carried out. Modelling (simulation) of annual energy performance needs to be done. It provides detailed project cost and savings calculations with high level of confidence. As for major capital investment decisions, comprehensive life cycle cost analysis is the best decision making tool. In addition, the following options can also be considered:
  - Selection of Bat (Best Available Technology): After performing energy simulation, the team is required to provide the owner with retrofit plan. The team then should look for best available technology present in the market and then decide by working on the various parameters such as efficiency, payback period, first initial cost, etc.
  - Repeat Energy Audit: After selecting the BAT present in the market, the team needs to perform the energy simulation again in order to determine the difference in efficiency,

comfort level, etc., of the suggested retrofit option and the installed equipment.
• **Stage 5 (cost-benefit analysis):** In appraising the cost potential, with respect to the findings from technical analysis, capital payback calculations should be performed. This helps to choose the best retrofit option in line with the user requirement and budgetary constraints. For all the practical measures and recommendations, cost benefit analysis needs to be carried out. This is done to identify efficiency modification opportunities. The energy auditor requires a building envelope expert, a mechanical engineer and an electrical engineer (lighting and control system expert). The best outcome of retrofits depends upon a combination of skills and procedures. Complex building and varied energy systems require a more experienced team. Importantly, the facility manager needs to formulate a synergy between site staff, contractors and building occupants to support and provide the building information.
• **Stage 6 (Implementation Plan of Energy Efficiency Measures):** Once the retrofit plan is finalized after conducting a thorough cost benefit analysis, the team should then work on implementing the retrofit. Proper project planning should be done in terms of assigning appropriate timelines, and understanding the commitment and involvement mechanism as well as project finance so that the implementation is seamless.
Stage 7 (Monitoring and verification): This serve to track implementation and outputs systematically, and measure the effectiveness of energy efficiency (EE) drives. In addition, it helps to improve performance and achieve results. It helps determine exactly when an EE drives is on track and when changes may be needed. Its goal is to improve current and future management of outputs, outcomes and impact. Monitoring and verification provides information that will be useful in: • Analysing the situation in the BERP. • Determining whether the inputs in the projects are well utilised. • Identifying problems facing the EE drivers and finding solution. • Ensuring all activities is carried out properly by the right people and in time. • Using lessons learnt for continuous improvement.

Source: Researcher, 2018

Based on the artefact you have reviewed, please assess the framework according to the following criteria (with 5 – Excellent, 4 – Above average, 3 – Average, 2 – Below average, 1 – Poor)

Criteria	Response				
	5	4	3	2	1
Logical structure					
Clarity					
Coherence					
Practical relevance					
Applicability					
Meaningfulness					

Based on your expert knowledge, what general ideas should be incorporated into the artefact. ……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

MANY THANKS FOR YOUR VALUED CONTRIBUTIONS