MEASURING THE BENEFITS OF SOCIAL HOUSING RETROFITS: A COMPREHENSIVE FRAMEWORK FOR EVALUATING WIDER IMPACTS.

by

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BSc. (Hons), MSc.

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Declaration

I hereby, declare that this dissertation has not been submitted in part or whole as paperwork for a degree at any other university. I hereby declare that this dissertation is entirely my work and that all parts and thoughts, which have been taken from other persons, are marked, and identified by reference.

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Abstract

This thesis contributes significantly to the evaluation of retrofit benefits in the United Kingdom (especially within the social housing sector), by developing a multi-stakeholder framework that accounts for a wider range of benefits beyond the conventional focus on energy and carbon savings. Using a mixed-methods approach made up of a systematic literature review, detailed expert stakeholder interviews, and an AHP-Delphi prioritization process, this study not only identifies and maps wider retrofit benefits to individual stakeholders, but it also enables their measurement through a scoring tool. This tool (Retrofit Benefits Assessment Tool – REBAT) integrates 12 benefit indicators essential for preliminary assessments, enabling a more nuanced understanding of the impacts of retrofit investments.

Key findings from the qualitative expert interviews underscore the complexities involved in retrofit evaluations and validate the appropriateness and utility of the methodology and tools proposed by this research. The thesis' novel contribution lies in its multi-stakeholder perspective, which captures insights across the range of individuals and groups who are affected by or are involved in retrofit projects – from occupants and landlords to policymakers and society at large. This perspective ensures that the framework and tools developed are not only comprehensive but also aligned with the needs and priorities of stakeholders.

By bridging the theory-practice, this research provides a robust framework that not only enhances decision-making in retrofit projects but also supports policy development aimed at maximizing the benefits of retrofitting within the social housing sector. The implications of this research are broad, influencing both practice and policy by providing a methodological foundation for assessing the broader impacts of retrofits, promoting evidence-based strategies for achieving sustainability goals, and facilitating the development of retrofit policies that are grounded in comprehensive benefit analyses.

Also, this study addresses critical challenges in the retrofit industry, such as the need for standardisation in benefit evaluations and the integration of diverse benefits into retrofit planning and implementation. The operational tools, method and guidance developed as part of this study, particularly the prioritisation and scoring tools, offer practical, user-friendly resources for industry stakeholders, that will enhance the credibility and effectiveness of retrofit evaluations. Overall, this thesis fills a significant gap in the existing literature by systematising the assessment of retrofit benefits while setting a new standard

for how such evaluations should be conducted, ensuring they are thorough, inclusive, and directly applicable to real-world settings.

Dedication

To God and family – Beatrice, Immanuella, Teni Analia, Christina Asinyaka.

Acknowledgement

I want to express my sincere thankfulness to God, who is the fount of all wisdom and knowledge, for His never-ending mercy, direction, and provision along the way.

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Finally, I would like to dedicate this work to all those who value knowledge acquisition and constant learning. May we never lose our curiosity, humility, or desire to comprehend the world around us.

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List of Abbreviations

ALMO	Arm's Length Management Organisation
AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
BEIS	Department for Business Energy and Industrial Strategy
BMS	Building Management Systems
BPE	Building Performance Evaluation
CERT	Carbon Emissions Reductions Tariff
CESP	Community Energy Savings Programme
CIBSE	Chartered Institution of Building Services Engineers
CIMO	Context-Input-Mechanism-Output
CIOB	Chartered Institute of Building
CMBA	Combinatorial Mathematics-Based Approach
CO2	Carbon dioxide emissions
COPRAS	Complex Proportional ASsessment
DEA	Data Envelopment Analysis
ECO	Energy Company Obligation
ELECTRE	ELimination Et Choice Translating REality
EPC	Energy Performance Certificate
ESG	Environmental, Social and Governance
FiT	Feed-in Tariff
FPEERP	Fuel Poverty Energy Efficiency Rating
GHG	Greenhouse Gases
HEMS	Home Energy Management Systems
HUG	Homes Upgrade Grant
ICE	Institution of Civil Engineers
LADS	Local Authority Delivery Scheme
MIMA	Mineral Wool Insulation Manufacturers Association
NEP	Nottingham Energy Partnership
RdSAP	Reduced Standard Assessment Procedure
RHI	Renewables Heat Initiative
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
RO	Renewable Obligation

ROI	Return on Investment
RSL	Registered Social Landlord
SAP	Standard Assessment Procedure
SHDF	Social Housing Decarbonisation Fund
SMAA	Stochastic Multicriteria Acceptability Analysis
UKCMB	UK Centre for Moisture in Buildings
UKGBC	UK Green Building Council
UK	United Kingdom
VIKOR	Vlse Kriterijumska Optimizacija I Kompromisno Resenje

Glossary of Key Terms

Measurement: quantifying specific elements or benefits, often using numerical data. In the context of retrofits, this could involve quantifying energy savings, cost reductions, or improvements in air quality.

Evaluating: combines both measuring and assessing to form a judgment or determine the worth or effectiveness of something. In this thesis, evaluating might encompass the overall impact of retrofits, considering both quantitative measurements and qualitative assessments.

Assessing: a more qualitative approach, considering the value or significance of something. This might include examining the quality of living conditions post-retrofit or stakeholders' satisfaction with the living space of other elements of the retrofitted building.

Criteria: refers to the measures or benchmarks used to establish the success or otherwise of a retrofit project/investment. In this thesis, criteria are used to represent the set of important measures that are used to evaluate the outcomes of a retrofit project. For example, Improved indoor environment quality, reduced carbon emissions, fuel poverty reduction et cetera.

Indicator: provides the actual data points used to determine whether the criteria have been met for the project. In other words, they are the variables that are monitored to evaluate a project's success according to the criteria. For example, in this thesis, the indicators for improved indoor environment quality are levels of indoor air pollutants or households reporting improvement in indoor quality or reduction in air contaminants levels.

Metric: is the actual quantifiable (quantitative or qualitative) measure or numeral values obtained through measurements and used to assess the performance of a project. Metrics are closely related to the indicators of a project. In the context of a retrofit project, the metric for indoor environment quality indicator is the percentage of homes with improved indoor environment quality.

Retrofit or Home Energy Retrofit: "The directed alternation (upgrade) of the building fabric, systems and/or controls which comprise the built environment, to improve it energy efficiency or performance of the building/property."

Retrofit stakeholders: All the parties relevant and directly or indirectly involved in and benefit from investments in retrofits (see Table 2-1 for a definition of the major stakeholders considered for this thesis).

Retrofit benefits: The outputs, outcomes and impacts from any investment in retrofit (home energy retrofits) which accrues to one or more stakeholders in the project.

Fuel poverty: The condition where a household has a fuel poverty energy efficiency rating (FPEERP) of band D or below and if it were to spend its modelled energy costs, it would be left with a residual income below the official poverty line.

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List of Conferences and Presentations

Asinyaka, M. 2021, Seeing the big picture: How we measure the benefits of housing retrofit investments in the UK is not working. *2021 EMDOC PGR Conference: Change. 15th September 2021 – Online.*

Asinyaka, M. 2021, Towards a better approach for measuring the benefits of retrofit investments in the social housing sector. *CESW CCG Meeting, 11th May 2021 (Online, Industry Event).*

Chapter 1 : INTRODUCTION

1.1 Background of the Research

Mitigating climate change is critical to achieving sustainable development and forms a strategic policy priority for many governments. Global energy-related carbon emissions reached a historic high of 33.1Gt in 2018, 70% higher than the 2010 average, while energy consumption increased at nearly twice the 2010 average (IEA, 2019). The need for energy use and carbon emissions reductions undoubtedly is clear, with several governments setting ambitious CO_2 reduction targets. The UK has set such a long-term target to reduce net carbon emissions by 80% below its 1990 baseline by the year 2050 with a further commitment to net-zero emissions by 2050 (UK Parliament, 2019).

Globally, buildings consume a large share of the total energy used (40%) and emit 30% of annual greenhouse gases (Kariuki et al., 2014). In the UK, residential buildings directly emitted 66 MtCO2 in 2016 (CCC, 2017). The existing building stock in the UK and Europe is deemed inefficient (Dall'O', Galante and Pasetti, 2012) making decarbonization of the housing stock an important challenge in meeting carbon targets. Building retrofitting is, therefore, a key potential in actions to mitigate climate change, energy consumption and carbon emissions, with the EU issuing directives for its members to improve the efficiency of their building stocks (European Union, 2010).

Achieving the UK's carbon targets requires an annual CO_2 reduction of approximately 20% (or 13 MtCO2) from the buildings sector. By 2050, existing buildings will account for 85% of the stock that will be in use in the UK (UKGBC, 2017) and given very low stock replacement rates of efficient new builds, retrofitting the existing stock is imperative. Retrofitting has therefore received significant investments and policy attention from the government, the private sector and academic research.

Investments in retrofits are widely recognised for delivering diverse perceived social, economic, and environmental benefits to different stakeholders. In addition to carbon and energy savings benefits which dominate programme and policy designs and evaluations, other benefits yield from retrofit investments (Payne, Weatherall and Downy, 2015; Kerr, Gouldson and Barrett, 2017). Some of these identified benefits framed differently as 'multiple benefits', 'co-benefits', 'additional benefits' or 'productivity benefits' include *fuel poverty* (Thumim et al., 2014), *improved health and well-being, public health budget reductions* from improved health (Thomson *et al.*, 2013); *economic growth*, *increased industry/firm productivity*, *new* *job creation/employment, tax/fiscal benefits* (Washan, Stenning and Goodman, 2014), *safety and security of energy delivery* from reduced imports, *lower maintenance costs*, *premium rents/value of property*, *resilience* and *improved outdoor air quality* (UKGBC, 2017).

While the existence of these wider benefits is generally acknowledged, they lack the appropriate frameworks and tools to adequately assess and internalise them into decision-making on retrofit policy and work (IEA, 2014; CCC, 2019), thus failing to account for equally pressing and perhaps more important issues of housing quality including health, poverty and social. This narrow framing of retrofitting does not generate the justification needed for retrofit investments, especially in the social housing sector, with the potential to develop and deploy scalable retrofit solutions (IET & NTU, 2018). For one, it is the most cost-effective way to address fuel poverty (Fylan et al., 2016), a key challenge and priority of current UK energy policies and which affects 11% of UK households (UKGBC, 2017).

Social housing is a vital part of the UK's housing system, representing 17% of the total stock (ONS, 2017). However, social tenants are among some of the poorest households in the UK and an increasing proportion of them are unable to afford (ONS, 2017; Hickman, 2019) or heat their homes adequately (Hafner *et al.*, 2020). Lack of funding and unproven business case for costlier/deeper retrofit works needed are also key barriers identified in the sector (Palmer *et al.*, 2018). Retrofit decisions are therefore largely government-driven and funded. However, social housing has the potential to set and test workable business models and innovative solutions for retrofit work (Smith & Abbot, 2017). These risks and barriers highlight the importance of emphasising the additional benefits of retrofit investments beyond energy and CO_2 savings.

Illuminating the additional benefits entails their careful evaluation and measurement (qualitatively or quantitatively or both), without which their implications for retrofit policy and work are severely limited. Doing so implies first identifying and describing these benefits, and second measuring them to the extent possible. Both steps require empirical and theoretical approaches to accomplish. The theoretical level involves framework development to define, identify and categorise benefits together with their requisite indicators, metrics, and variables. The empirical level involves data collection and gathering to develop weightings for the indicators and metrics as well as guiding the actual measurement.

1.2 Research Problem

Current retrofit projects or investments lack robust evaluations and measurement of benefits. Some projects do not undertake evaluations post-projects (Energy, 2015) and when they do, the scope is woefully limited, largely due to the tools, methodologies and objectives employed. Also, evaluations are not built into most programmes from conception and follow-ups are few and shorter making evaluation post programmes, difficult to undertake and fraught with quality and reliability issues (Poortinga *et al.*, 2018). Consequently, strong heterogeneity in methodological approaches and the results obtained from their use is observed (Payne, Weatherall and Downy, 2015). Empirically, retrofit benefits evaluation has largely relied on existing methods such as building monitoring and surveys, modelling, and simulations. Prominent ones are post-occupancy evaluations (POEs) and direct scaling techniques. Scaling techniques typically require programme participants to express experienced benefits in terms of a numeraire, typically energy savings.

Other techniques include adaptations of cost-benefit and life-cycle cost methodologies including contingent and choice valuations (Damigos *et al.,* 2021) as well as capital budgeting tools like net present value (NPV), internal rate of return (IRR) and simple payback period (Popescu *et al.*, 2012), which can be inflexible to qualitative-based benefits. Arguably, such diversity of approaches results from the absence of a comprehensive conceptual framework that can guide and streamline the evaluation process, especially in capturing both ex-ante and ex-post non-energy benefits (Skumatz and Gardner, 2005; Thorne Amann, 2006). Such a conceptual void does not only stymie the evaluation of broader benefits but also introduces a significant amount of variability and inconsistency in the data that is produced.

Further to this is the presence of split incentives among retrofit stakeholders (Gillingham, Harding and Rapson, 2012; Melvin, 2018). In many cases, building owners are tasked with financing the retrofit, while the tenants directly benefit from reduced energy bills and improved living conditions. This division of costs and benefits poses a challenge in assessing the true value and impact of retrofit projects and can result in underinvestment in retrofits that would otherwise offer significant benefits. It also complicates attempts to generate comprehensive and relevant measures of the wider benefits of retrofit projects.

In addition to the well-documented issue of split incentives, retrofit projects often involve a multitude of stakeholders, each with their unique sets of interests and expected benefits.

These can range from government agencies aiming for carbon reduction and social welfare improvements to contractors seeking profitable ventures, and suppliers aiming for sustainable product integration. Such a multi-stakeholder environment complicates the measurement and valuation of benefits, as each stakeholder's perspective of what constitutes a 'benefit' can vary widely. This divergence of interests introduces another layer of complexity in developing a universally applicable benefits measurement framework for retrofit projects.

These issues constitute a significant barrier to informed decision-making and complicate the attempts to generate consistent and relevant measures of the wider benefits of retrofit projects and form the basis for this research. As discussed earlier, it is bad enough to exclude wider benefits of retrofits in retrofit evaluations, but equally worse is the inaccurate measurement of benefits when they are included or the accurate measurement of poorly defined benefits. This research therefore aims to bridge these gaps by developing a comprehensive toolkit for evaluating the wider social, environmental, and economic benefits of residential retrofit projects.

1.3 Research Aim

This research aims to identify and measure the wider benefits of retrofits by developing a comprehensive framework for accounting for and evaluating retrofit benefits from the perspective of social housing tenants and social landlords.

1.4 Research Objectives

To achieve the research aim, the following specific objectives were pursued.

1. To review the literature on the wider benefits of retrofitting and their categorisation.
2. To identify and evaluate the challenges of retrofit evaluation as well as the strengths and weaknesses of existing methods, tools, and frameworks for identifying and measuring the benefits of retrofits.
3. To develop a benefits measurement framework by synthesising existing literature to establish clear criteria, indicators, and metrics that effectively capture wider retrofit benefits.
4. To develop a weighting or prioritisation methodology for ranking the different retrofit benefit indicators and criteria at different levels and scales of measurement.

5. To develop a retrofit benefits scoring tool with criteria thresholds, data collection and implementation guidelines to assist the use of the tools.
6. Evaluate and test the developed framework and tools to assess their effectiveness as well as issues for further improvement.

1.5 Research Methodology

The overall research design follows both inductive and deductive approaches. The inductive approach allows general principles and inferences to be developed and drawn from specific observations while the deductive approach enables conclusions to be derived logically from a set of premises as well as establishing and explaining causal relationships between concepts and variables (Babbie, 2014; Saunders, Lewis and Thornhill, 2016; Bell, Bryman and Harley, 2018). A careful contemplative review of the research reveals that adopting a purely qualitative-inductive approach is not appropriate.

Given that the research also involves a quantitative aspect of understanding and quantifying the benefits of retrofit projects as well as the investigation of opinions and perspectives of home occupants and experts using the Delphi and Analytical Hierarchy Process group decision-making techniques, a mixed-methods deductive/inductive approach is deemed most appropriate for achieving the aims of the research.

Adopting a mixed methods research approach is also an effort to bridge the gap in ideology between adherents of qualitative and quantitative research approaches. Rather than following a particular approach, the practical significance of each approach can be fully explored to add more value to the research (Creswell and Plano Clark, 2017). The target sample population remains social housing tenants and registered providers (mainly local authority providers). However, some academics and supply chain partners can and have participated in the research.

Data collection has mainly been by interviews and documentary analysis. As indicated in chapter four below, the first part of the empirical work involved a detailed analysis of the issues, challenges, and opportunities in the evaluation of retrofit project performance and measurement of benefits. The second stage involved developing an empirical benefits measurement framework which includes a benefits prioritisation and a scoring tool for retrofit project performance. To generate the weightings for the benefit indicators needed to contextualise the computations and outputs of the measurement tool, a combination of Delphi and Analytic Hierarchy Process (Delphi-AHP) was used (Berghorn and Syal, 2016;

Kian Manesh Rad, Sun and Bosché, 2017a; Jafari, Valentin and Bogus, 2019). The Delphi technique "is a systematic and interactive research technique for obtaining the judgment of a panel of independent experts on a specific topic" (Hallowell & Gambatese, 2010, p99).

The draft tools were refined through interviews with stakeholders and a mini-validation workshop with stakeholders. The analysis of data collected from the interviews/surveys was done using thematic analysis with the help of the NVivo & MaxQDA software.

1.6 Thesis Structure

This thesis is organised into 9 chapters each covering specific aspects of the thesis. The first chapter outlines the background of the thesis and sets out the research problem, aim and objectives of the research. It also introduces the methods used to answer the research questions.

The second and third chapters both review the background and relevant literature that set the tone and stage for the rest of the thesis. Chapter two reviews the literature on the benefits of retrofits including how they are identified, categorised, and measured, calling for a multi-stakeholder approach to categorising benefits, while chapter three focuses on the approaches and methodologies employed in the literature to evaluate and measure retrofit benefits and ends with a conceptual development of the multi-stakeholder retrofit benefits framework. Both chapters aimed to identify the gaps in the literature.

The fourth chapter details the methodological underpinning of the research and justifies the methodological choices made. Chapter Five present the data analysis from industry engagements on the framework from Chapter Three and the state-of-the-art with retrofit benefits evaluation. Chapter six outlines the conceptual development of the methodology for the ranking and weighting of retrofit benefits and a scoring tool for retrofit benefits. Chapter seven presents the practical implementation of the two tools while Chapter eight presents an evaluation of the tools through a focus group interview. Chapter nine presents the research's conclusions, contributions to knowledge, limitations, and recommendations (including for future research). Figure 1-1 below gives an overview of the research/thesis structure.

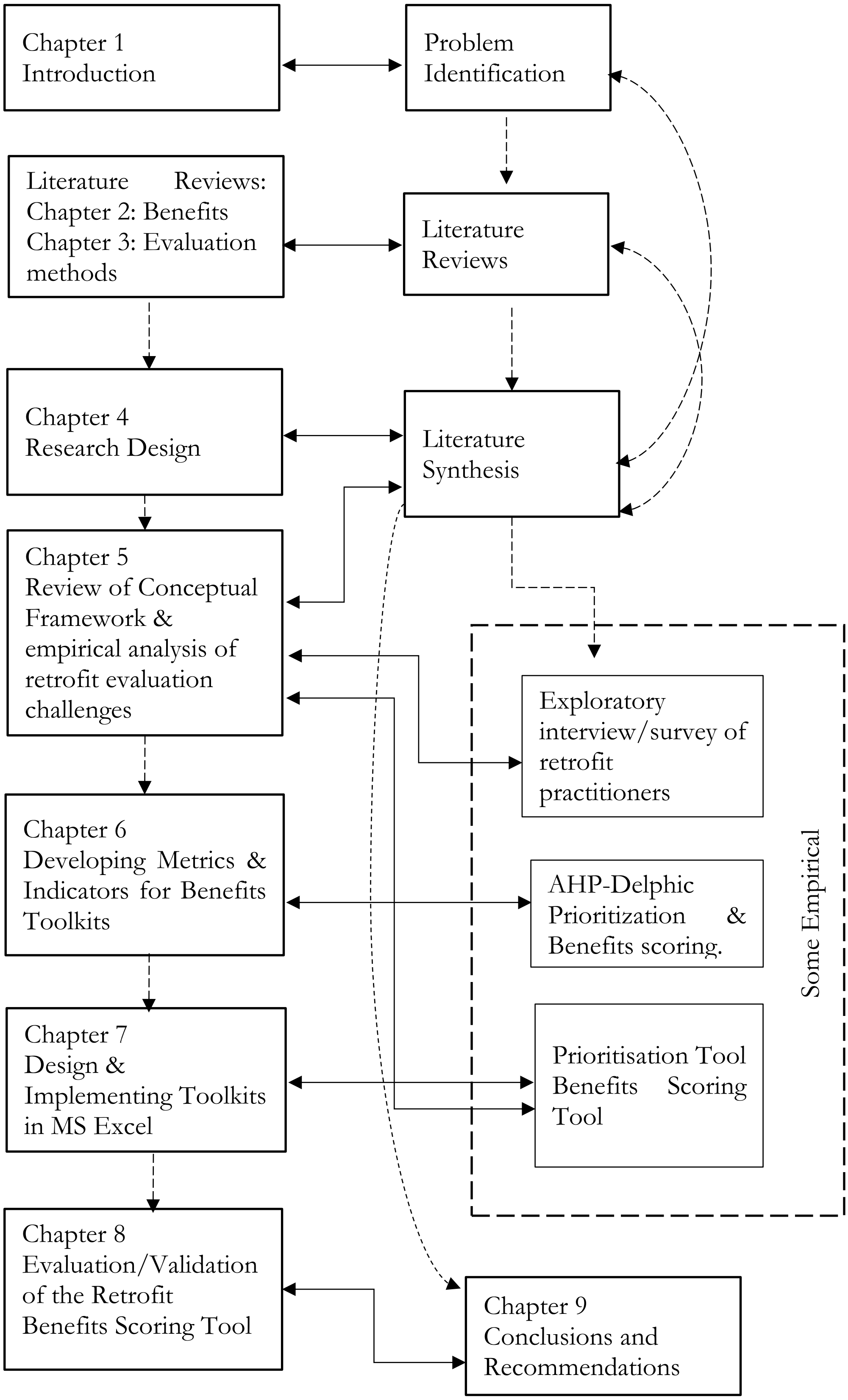

Figure 1-1 Thesis structure and research overview

Chapter 2 : BENEFITS FROM HOME ENERGY RETROFITS

2.1 Introduction

This chapter aims to review the existing body of academic and industry knowledge on retrofitting to identify and assess the main benefits claimed and the extent to which they are categorised and measured. It also addresses the first objective of the research. The overarching question under consideration here is two-pronged; what constitutes retrofit benefits and how can we categorise and talk about these benefits? The chapter also discusses and presents a multi-stakeholder framework for categorising retrofit benefits. Interwoven in the categorisation discussion will be an examination of the evidence base supporting these benefits, in other words, the extent to which these claimed benefits have been identified and measured. All discussions will aim to examine the UK evidence in the first instance but will always be aligned to the social housing sector which constitutes the geographical and disciplinary focus of the study.

2.2 **Home Energy Retrofits**

2.2.1 Defining Home Energy Retrofit

A good and proper understanding of housing retrofits is important to making sense of the plethora of research and practice-related issues arising from the sector. While the focus of this research and chapter is not dedicated to addressing the definitional arguments of the term (housing) retrofits, it is prudent that an attempt is made to establish a working definition both as a guidance for the rest of the research and to give a context within which to frame and view the arguments and results presented in this research. To do this, we start with the literal sense of the word 'retrofit'. It can be defined as:

> "to provide a machine with a part, or a place with equipment, that it did not originally have when it was built" *(Cambridge Dictionary*).

Dixon & Eames, (2013) notes the origin of the term in the late 1940s and 50s in the United States being a combination of two root words "retroactive" (looking to the past) and "fit" (to equip). Translating to the built environment context, the term retrofit has been used to denote applying significant changes to a physical building to adapt or reuse it (Wilkinson, 2012). In other words, any activities or works done to a building over and above what constitutes regular maintenance to change the capacity, function, or performance of the building (Douglas, 2006). While thinking about Douglas' definition, it can easily become confusing when one begins to consider other closely related terms such as 'refurbishment', 'rehabilitation', 'conversion', 'renovation', and 'refit', among others which are often used interchangeably with 'retrofit' (see Mansfield, 2002; Wilkinson, 2012 who provide some clarity on this issue).

From the foregoing, it is evident that retrofit can occur to a part of a building or the whole building, and it can be on a smaller number of locally clustered or isolated buildings or even at a much larger scale involving buildings within a city level. This speaks to the spatial scale of retrofit. Regardless of the scale or intent of retrofit, a common theme of home/housing retrofit is the need for "sustainability" or energy efficiency. This informed Eames et al., (2014) encompassing definition of retrofit (considering sustainable retrofit) as:

> "…directed alteration of the fabric, form or systems which comprise the built environment to improve energy, water and waste efficiencies" (Eames *et al.*, 2014), p2).

Analysing this definition, provides significant insights into what constitutes home retrofit, although some aspects do not necessarily apply to residential properties. Firstly, retrofit is intentional, initiated and directed by an agency – tenant, landlord, or government. Second, it involves altering a building's components, which include the physical fabric, as well as the technical and/or mechanical systems and/or structural elements. Third, it applies to all forms of building uses including residential, commercial, and industrial with their respective submarkets, although for this research, the use is residential. Finally retrofit cuts across the domains of energy, water, and wastes – energy being the default topic when discussing retrofit with the last two not receiving much attention in the general literature.

Saffari and Beagon, (2022) define a home retrofit as "The upgrading of the building fabric, systems and/or controls to improve the energy performance of the property" (p. 2).

Combining this definition with that of Earnes et al., (2014), this study adopts the following definition for "retrofit" or "home energy retrofit".

> "The directed alternation (upgrade) of the building fabric, systems and/or controls which comprise the built environment, to improve it energy efficiency or performance of the building/property."

This definition captures the central themes, arguments and objectives of this research and presents a contextually nuanced understanding of the term as it has evolved over the period and in use. A home retrofit is thus considered by this study to encompass energy efficiency improvement or upgrade to a building. The upgrades are to either the fabric, systems/ controls, or both. The controls are to reflect all the modern and smart building controls implemented as part of retrofits, while ‘systems’ consist of all the “energy-conversion systems for space and water heating, typified by heat pumps, combined heat and power, and the electricity and gas systems supplying them” (Lowe, 2007). In essence, this definition is focused on building fabric, systems and control upgrades aimed at reducing energy consumption which in turn generates other ripple impacts on carbon emissions, indoor environment quality and health and well-being among others.

Returning to the original dictionary definition, we glean also that “retrofitting occurs sometime after the initial construction and adds or substitutes more modern parts and new elements as needed. Retrofitting technologies include 'fit and forget' technologies as well as those that require attention to control systems, management, and maintenance. Retrofit measures may include PV panels (with or without the incentive of feed-in tariffs) that contribute to larger networked decentralised energy systems) (Gleeson et al., 2011, p. 6).

Furthermore, retrofits can be considered at the spatial scale of the upgrade, the timing as well and the depths of upgrades implemented. There is consensus regarding the timing of retrofit across academia and industry that implementing retrofits alongside typical improvements such as kitchen upgrades and loft conversions represents a great opportunity and potential to scale retrofit uptake (Killip et al., 2014; Fawcett, Killip & Janda, 2014; Wilson et al., 2015). Similarly, a holistic approach to retrofit has strong support among key stakeholders in the sector including the Registered Social Landlords (RSLs), the UK Centre for Moisture in Buildings, The Retrofit Academy, the HEMAC Network, Department for Business Energy, and Industrial Strategy (BEIS), the Good Homes Alliance, the United Kingdom Green Building Council (UKGBC) and Mineral Wool Insulation Manufacturers Association (MIMA). Regarding scale, the need to escalate retrofits from single projects to more coordinated urban or city-wide level retrofits to benefit from economies of scale has been argued and pushed for by government funding schemes (BEIS, 2022), and the social housing sector identified as a potential market leader in achieving this scaling up.

Closely related to scale is the depth of retrofit work. The more general approach - ‘shallow’, and ‘basic’ typically involves upgrading specific components of the building fabric or systems. Deep or whole house retrofit on the other hand combines measures including fabric, energy systems and lighting. Safari and Beagon (2022) examined the targets, optimal spatial scales, and methods used to evaluate current home energy retrofits. They found that carefully selected targets, combined with a deep and staged retrofit approach implemented at the neighbourhood scale, have the potential to yield the most significant impact on emissions reduction and climate change mitigation. In other words, the kind of retrofit needed to achieve stated carbon targets and commitments must be holistic, utilizing a whole house approach, achieve significant spatial scale, enjoy strong stakeholder support, especially from tenants/occupants, and contain a good mix of measures for attaining depth of retrofit.

2.2.2 Major Stakeholders in home retrofits (in the UK)

The very nature and structure of the built environment (as identified previously) create multiple layers of stakeholders in the sector, and thus, in home retrofits. In the past, the UK housing market was driven and guided by the national government agenda and policy (Forrest & Hirayama, 2015). While that remains true in the present, particularly regarding standards, regulations, and rules of engagement, the sector is now largely autonomous and private sector-led, especially in terms of pricing and its associated dynamics (Mulliner & Maliene, 2011).

This section presents an overview of the key stakeholders of the home/housing retrofit industry. Several stakeholders are identified in the literature including tenants, homeowners, housing associations, manufacturers and designers, project managers, consultants, energy suppliers and lastly funders and government or public institutions. Miu et al.'s (2018) main retrofit stakeholder groups are adapted and modified for this study. However, this study aggregates tenants and homeowners under the collective term "occupants", while manufacturers, designers, architects, engineers, and project managers, among others, come under the collective term "retrofit industry supply chain". Energy and building consultants encompass professionals providing expertise in energy assessments, building performance modelling, and evaluation. Occupants for this thesis are limited to only residents occupying properties that they rent, or partially own from a registered social provider or similar (this excludes private renters and owners). Social housing providers/associations, energy suppliers and utilities, financial/capital providers, energy and building consultants and public or governmental authorities make up the remaining key stakeholders. This brings the total to seven (7) main actor groups compared to 5 groups from Miu et al., (2018). Table 2-1 below outlines these 7 major stakeholders.

Table 2-1 Main Stakeholders in the UK (social housing) retrofit sector (adopted from Miu et al., 2018).

Stakeholder Group	Definition
Occupants	All residents occupying properties that they do not own, partially or wholly own and all private landlords (although these are not the focus in this research).
Social housing association/providers	All social housing associations that own residential property. include local authorities, housing associations, Arms-Length Management Organisations (ALMOs) and other organizations that own, manage, and maintain social housing stock. They are responsible for meeting energy efficiency standards, addressing fuel poverty, and ensuring a decent quality of life for their tenants.
Retrofit industry & supply chain	Companies and individual experts involved in the planning and design of retrofit projects including suppliers and installers of measures and maintenance processes. Also includes individuals managing a retrofit project.
Energy and building consultants *(merges with the retrofit supply chain in the Framework)*	Companies or individuals hired to provide expert advice on a retrofit project including energy assessments, building performance modelling, and energy efficiency measures tailored to the unique context of social housing retrofits.
Energy Suppliers and Utilities	Companies that deliver energy products to occupants and social housing associations/providers.
Financial/Capital providers	All financial institutions including banks, lenders or investors providing access to capital to finance retrofit projects. Social housing providers in the UK tend to rely on government funding, grants, or other support mechanisms to fund retrofitting.
Public or Government authorities	Governance agencies that are responsible for oversight and strategising of housing development projects including building regulations and standards. They also set specific targets, regulations, and funding schemes for the social housing sector, with a focus on addressing fuel poverty and reducing carbon emissions.

2.2.3 The UK's legal and policy landscape for home energy retrofit.

The legal and policy landscape for home retrofits and climate change mitigation in the UK more generally has been a complex one characterized by a variety of programs and policies with mixed levels of success and some degree of fragmentation. Over the years, policies have been introduced, amended, or discontinued, which could lead to confusion among stakeholders and create challenges for effective implementation (Rosenow & Eyre, 2013). As mentioned in the previous section, these constitute the government's efforts to drive the scaling up of retrofit spearheaded by the social housing sector.

Some of the factors that contribute to the complexity of the landscape include changing political priorities, an evolving understanding of the most effective approaches to energy efficiency and decarbonization, and the need to balance various policy objectives (e.g., affordability, energy security, and environmental protection) (Kerr, Gouldson and Barrett, 2017). For instance, the Green Deal aimed to provide financing for energy efficiency improvements but faced challenges due to high interest rates and low uptake, leading to its discontinuation (Rosenow & Eyre, 2013). On the other hand, the Energy Company Obligation (ECO) has been more successful in achieving energy efficiency improvements, particularly for low-income households (Ofgem, 2013).

This section provides a broad overview of the landscape (which is summarised in Table 2-2 below) to give a background for contextualising the discussions in the rest of the thesis. Overall, these legislations and policies have contributed to various degrees of success in promoting home energy retrofits in the UK. A common theme throughout these initiatives is the need for simplified processes, improved targeting of vulnerable households, and more robust enforcement mechanisms (Preston et al., 2013). Additionally, the potential synergies between energy efficiency improvements and renewable energy adoption should be further explored in future policies to maximize their impact on home retrofits (Sorrell et al., 2009).

Given the variety of programmes and policies and their varying degrees of success, a more cogent and consistent long-term strategy is required to overcome the difficulties that this landscape's complexity and fragmentation have presented for the effective implementation of home retrofits. Better coordination between various programmes, a focus on vulnerable households, and attention to synergies between energy efficiency improvements and the adoption of renewable energy sources should all be taken into consideration to improve the policy environment (Kerr et al., 2017). Within this context, social housing in the UK emerges as a critical focus area. Serving some of the most vulnerable populations and boasting unique characteristics such as a critical mass of properties, social housing presents an invaluable opportunity to pilot and scale up effective retrofit strategies (IET and NTU, 2018). By embracing such a multi-faceted strategy, the UK stands to create a more conducive environment for home energy upgrades, thereby advancing its broader objectives of combating climate change and enhancing energy efficiency.

Table 2-2 An Overview of the UK legal and policy landscape of housing retrofitting/ decarbonization.

Legislation	**Description**	References
The Climate Change Act (2008)	Requires emissions reductions of 80% by 2050, introduces legally binding carbon budgets and sets a legal framework for climate change adaptation. This Act established ambitious targets for emissions reductions, providing a legislative framework for transitioning to a low-carbon economy (Lockwood, 2013). While it has driven various policies and initiatives, the lack of specific energy efficiency targets for homes has left room for improvement in the residential sector (Rosenow & Eyre, 2013).	Lockwood, (2013) Rosenow & Eyre, (2013)
Energy Act 2011	The Act introduced initiatives like the Green Deal and ECO, aiming to improve energy efficiency and reduce carbon emissions. While the ECO has had a positive impact on low-income households (Rosenow & Eyre, 2016), the Green Deal faced criticism for its complex implementation, low uptake, and lack of focus on the most vulnerable households (Wilson, 2016).	Rosenow & Eyre, (2016) Wilson, (2016)
The Energy Efficiency (Private Rented Property) (England and Wales) Regulations 2015:	These regulations set a minimum energy efficiency standard for privately rented properties. While they have contributed to improving the energy performance of rental properties (BEIS, 2019), there are concerns about enforcement and exemptions that may limit the overall impact (Bright & Weatherall, 2017).	Bright & Weatherall, (2017) BEIS, (2019)
Building Regulations, Part L and associated technical guidance.	Includes legislative requirements for energy efficiency and GHG emissions. These regulations set minimum energy efficiency standards for new buildings and renovations. They have been effective in improving the energy performance of new homes (Mallaburn & Eyre, 2014), but there are concerns that compliance and enforcement are not always stringent enough (Killip, 2013). ions from new buildings as well as requirements for retrofitting existing buildings.	Mallaburn & Eyre, (2014) Killip, (2013)

Policies, Incentives and Standards	Description	Comments
Renewables Obligation	The Renewables Obligation (RO) aimed to increase the share of electricity generated from renewable sources. While it did not directly target home energy retrofits, it contributed to the wider transition to low-carbon energy production. Between 2002 and 2017, the RO supported a significant increase in renewable electricity generation in the UK, from 1.8% in 2002 to 24.5% in 2016 (House of Commons Library, 2018). However, some critics argue that the RO led to higher electricity costs for consumers, which could hurt vulnerable households (Grubb, 2016).	House of Commons Library, (2018) Grubb, (2016)
Warm Front	Warm Front was a government-funded program that provided grants for energy efficiency improvements in low-income households in England. Between 2000 and 2013, the scheme helped over 2 million households with insulation and heating upgrades (National Audit Office, 2009). As a result, the program contributed to a reduction in fuel poverty and improved energy efficiency in homes. However, it has been criticized for its relatively high administration costs and its limited reach to the most vulnerable households (Preston et al., 2013).	Gilbertson et al. (2006) Preston et al., (2013) National Audit Office, (2009)
Carbon Emissions Reduction Tariff (CERT)	CERT was an energy efficiency program that obligated larger energy suppliers to reduce carbon emissions by promoting energy efficiency measures for households. During its operation from 2008 to 2012, CERT achieved a 293 MtCO2 lifetime carbon saving, exceeding its 293 MtCO2 target (Ofgem, 2013). The program increased the uptake of energy efficiency measures, such as loft and cavity wall insulation (Sorrell et al., 2009). However, it has been criticized for focusing on low-cost measures rather than comprehensive retrofits (Rosenow & Eyre, 2013).	Druckman and Jackson, (2008) Rosenow & Eyre, (2013) Sorrell et al., (2009) Ofgem, (2013)
Community Energy Savings Programme (CESP)	CESP targeted energy efficiency improvements in low-income areas. Between 2009 and 2012, the program achieved 16.31 MtCO2 lifetime carbon savings, reaching 94% of its 17.3 MtCO2 target (Ofgem, 2013). CESP supported measures such as solid wall insulation and boiler replacements in low-income households. However, the program faced challenges in reaching the most vulnerable households and delivering cost-effective energy savings (Rosenow & Eyre, 2013). Additionally, CESP has been criticized for its limited scale and geographic targeting, which may have left some vulnerable households underserved (Gouldson & Kerr, 2012).	Reeves et al., (2010) Gouldson & Kerr, (2012) Ofgem, (2013) Rosenow & Eyre, (2013)

The Green Deal	The main national incentive for retrofitting existing dwellings include a loan scheme covering loft and external wall insulation (including solid and cavity walls), boiler upgrade or replacement with heat pump, renewable energy generation (solar panels or wind turbines), double glazing and draught-proofing. Expected financial savings must be equal to, or greater than, the costs (the golden rule). Loans are attached to property utility bills. The Green Deal aimed to improve energy efficiency in homes without upfront costs. However, it suffered from low uptake, high interest rates on loans, and a complex application process, which limited its overall impact (Rosenow et al., 2013; Wilson, 2016) and ultimately withdrawn – largely seen as a failed policy attempt (Dowson et al., 2012; Gupta & Barnfield, 2014).	(Mark Dowson *et al.*, 2012; Gupta and Barnfield, 2014a; Rosenow and Eyre, 2016).
Energy Company Obligation (ECO) - ECO1 - ECO2 - ECO3 - ECO4 - ECO+ (Great British Insulation Scheme)	This is a requirement for Energy Companies to fund energy efficiency improvements under three obligations (i) provision of insulation to low-income households in specific target areas; (ii) provision of heating and insulation for beneficiaries in private tenure and (iii) installation of less cost-effective measures not meeting the financial savings requirements of the Green Deal (e.g., solid wall insulation). Energy companies are expected to respond to these obligations by increasing energy prices. ECO has been successful in delivering energy efficiency improvements to low-income households (Rosenow & Eyre, 2016). It is considered the UK's current major energy efficiency programme (Miu et al., 2018). However, it has been criticized for its reliance on energy suppliers as the main delivery agents and for not always targeting the most cost-effective measures (Rosenow et al., 2013).	Seen as complementary to the Green Deal Miu, et. al., (2018) DECC, (2012a) (DECC, 2012b; Sweett, 2014)
The Renewables Heat Incentive (RHI) (Non-domestic)	RHI has increased the adoption of renewable heating systems (DECC, 2016). However, the domestic RHI has faced challenges, such as a complex application process and high upfront costs (Curtis et al., 2018).	DECC, (2016) Curtis et al., (2018)
Feed-in-Tariff (FiT)	The FiT scheme successfully encouraged the adoption of small-scale renewable energy technologies, including solar PV installations (Curtis et al., 2018). However, the scheme's closure in 2019 may have reduced the incentive for homeowners to invest in renewable energy systems alongside energy efficiency retrofits (Woodman & Baker, 2011).	Curtis et al., (2018) Woodman & Baker, (2011)

Domestic Renewables Heat Initiative (RHI)	This is an extension of the non-domestic RHI to houses, providing seven-year financial support for the installation of eligible renewal heating technologies (such as biomass boilers, ground/water and air source heat pumps, and solar heating). The scheme run from April 2014 and was officially closed to new applications in March 2022.	Ofgem, (2022)
The Green Homes Grant (2020 – 2021)	The scheme aimed to provide financial support for homeowners and landlords to implement energy efficiency improvements. However, it faced challenges such as a short timeframe, complex administration, and low uptake, which limited its overall impact (BEIS, 2021).	BEIS, (2021)
Social Housing Decarbonisation Fund (SHDF) - SHDF Demonstrator - SHDF Wave 1 - SHDF Wave 2.1	This fund aims to improve the energy efficiency of social housing. It started with a demonstrator which retrofitted about 2,300 homes to EPC band C (BEIS, 2021). Following this, the SHDF wave 1 was launched in August 2021 and projects are now nearing completion after an extension from the original January 2023 closure date. Wave 2.1 has just announced £1.8bn of funding and is expected to run until September 2025. The full impact of home energy retrofits is to be comprehensively assessed but will depend on the scale of the investments and the ability to address the specific challenges faced by the social housing sector (Gillard et al., 2017).	Gillard et al., (2017) BEIS, (2022)
Homes Upgrade Grant (HUG) - Phase 1 - Phase 2	This scheme aims to support off-gas grid households in upgrading their homes' energy efficiency. Up to £630 million in funding has been earmarked for phase two. As it was announced in 2021, the long-term impact of the HUG on home energy retrofits remains to be seen.	BEIS (2022b)
Local Authority Delivery Scheme (LAD)	This initiative supports energy efficiency improvements for low-income households through collaboration between local authorities and energy suppliers. While it has the potential to address fuel poverty and improve energy efficiency, its overall impact will depend on the effectiveness of the collaborations and the ability to reach vulnerable households.	BEIS, (2020)

PAS 2035:2019	PAS 2035 is a comprehensive specification for the energy retrofit of domestic buildings, providing a framework for a whole-house approach to retrofit projects. It covers the assessment, design, installation, and monitoring of energy efficiency measures, aiming to improve the quality and effectiveness of retrofit projects (BSI, 2019). By providing clear guidance on best practices, PAS 2035 helps to ensure that retrofit projects deliver the expected energy savings and carbon emissions reductions, while also minimizing potential risks such as poor workmanship or unintended consequences (e.g., moisture issues). In this way, PAS 2035 can have a positive impact on home retrofits by raising the overall quality of the work and promoting a more comprehensive approach to energy efficiency improvements.	BSI (2019a)
PAS 2030:2019	PAS 2030 sets out the requirements for the installation of energy efficiency measures in existing buildings. It is designed to ensure that installers meet consistent quality standards, and it is a mandatory requirement for companies seeking to access government-funded retrofit schemes, such as the Energy Company Obligation (ECO) (BSI, 2019). By establishing standardized criteria for the installation process, PAS 2030 helps to ensure that energy efficiency measures are installed correctly and perform as expected. This, in turn, can contribute to the overall success of home retrofit programs by increasing consumer trust in the measures and ensuring that they deliver the intended energy savings and carbon emissions reductions.	BSI (2019b)

See (L. Miu *et al.*, 2018) for an assessment of housing retrofit policies in the UK up to 2018. Source: Adapted and modified from (Shrubsole *et al.*, 2014)

2.2.4 A focus on social housing retrofits

One of the central arguments of this research is that social housing holds significantly high potential to both lead and drive the development of scalable retrofit solutions for the housing sector towards achieving the government's decarbonisation agenda. This argument is premised on the following peculiar characteristics of the social housing sector.

2.2.4.1 Poor Thermal Performance in Social Housing

Social housing units often have poor thermal performance, resulting in inefficient energy consumption and higher carbon emissions (Gupta & Dantsiou, 2019). the age of the building stock, inadequate insulation, and outdated heating systems. The reasons for this poor performance can be attributed to The UK has some of the oldest housing stock in Europe, with a significant portion of social housing built before the introduction of modern energy efficiency standards (Power, 2008). Consequently, retrofitting these units can help to improve energy efficiency, reduce energy costs for tenants, and contribute to the UK's climate change mitigation efforts.

2.2.4.2 Vulnerable Tenants and Fuel Poverty

Social housing tenants often come from low-income backgrounds and are more likely to experience fuel poverty (Bouzarovski & Petrova, 2015). Fuel poverty is defined as a situation where a household is unable to afford the necessary energy services to maintain a healthy and comfortable living environment (Filho *et al.*, 2021). The combination of poor thermal performance in social housing and the financial constraints faced by low-income tenants can exacerbate the effects of fuel poverty. Retrofitting social housing can help alleviate fuel poverty by lowering energy costs and improving living conditions for vulnerable households.

2.2.4.3 Improved Living Conditions and Reduced Emissions

Improving the energy efficiency of social housing can lead to better living conditions for tenants, such as increased thermal comfort, reduced dampness, and better indoor air quality (Hamilton et al., 2015). At the same time, retrofitting social housing contributes to the reduction of carbon emissions and supports the UK's transition to a low-carbon economy. This dual benefit of improved living conditions and reduced emissions underpins the importance of focusing on social housing retrofit as a strategy for addressing the wider challenges of energy efficiency and climate change.

2.2.4.4 Health and Well-being of Social Tenants

Poor-quality housing leads to poor health outcomes among social tenants, with implications for the health budget of the country or local authorities (Thomson et al., 2013). Cold, damp, and energy-inefficient homes can cause or exacerbate respiratory illnesses, cardiovascular diseases, and mental health issues (Wilkinson *et al.*, 2001). Research has shown that:

a. Additional health costs on the NHS due to bad housing amount to £1.4 billion, out of which £145 million is due to cold homes (Nicol et al., 2015).
b. Deaths due to excess winter are approximately 35,000 annually, though this number might change over time due to changing weather patterns (ONS, 2021).
c. Reducing social care budgets for the ageing population can lead to cost savings of £1,700-4,500 per person per annum, and GP visits cuts of almost 50% (Marmot Review Team, 2011).

By retrofitting social housing to improve energy efficiency, policymakers can not only address fuel poverty but also help improve health outcomes and reduce the burden on healthcare services.

2.2.4.5 The Role of Housing Policy

Housing policy is not always about the return on investment (ROI) or the risk-return ratio (RRI). Developing and maintaining a housing policy that is based only or largely on the economic and financial dimensions leads to an asymmetrical housing policy that fails to account for equally pressing and perhaps more important issues of housing quality, including health, energy efficiency, poverty, and social inclusion (Mullins, 2010). Retrofitting the social housing stock represents taking a holistic approach to housing policy which ensures that a broader range of social and environmental factors are considered alongside economic factors, leading to more effective and sustainable outcomes.

2.2.4.6 Housing and General Economic Development

The housing sector, including social housing, affects general economic development in various ways. For instance, the construction and retrofitting of social housing can create employment opportunities and stimulate economic growth (Gibb, 2011). Moreover, improving energy efficiency in social housing can lead to reduced energy consumption and lower energy bills for tenants, freeing up disposable income that can be spent in other areas of the economy (Ambrose et al., 2019). In this way, social housing retrofits can have wider economic benefits beyond their immediate impact on housing quality and energy efficiency.

Thus, the importance of focusing on social housing retrofits in the UK's efforts to reduce carbon emissions and improve living conditions for vulnerable populations is clear. The poor thermal performance, prevalence of fuel poverty, and health implications of inadequate social housing make this sector a prime target for retrofit interventions. Moreover, the broader economic benefits of social housing retrofit, including job creation, and increased disposable income for tenants, underscore the potential for this approach to contribute to the UK's overall decarbonisation agenda.

By taking a multi-faceted approach to social housing retrofit, policymakers can develop more effective and sustainable strategies for addressing the challenges of energy efficiency, climate change, and social inequality. The following section however argues that while social housing presents a good opportunity for scaling up retrofits, policy discrepancies detract significantly from realising this potential.

2.2.4.7 Social housing retrofits and policy instability

While the following discussion applies to home retrofits in general, it has a slight bias towards social housing retrofits for the reasons outlined in the previous section. Despite the many benefits of retrofitting, several barriers might hinder their adoption. Numerous studies have explored this dichotomy within the retrofit issue.

As mentioned previously social housing has been postulated as the most appropriate starting point for large-scale retrofitting programs, particularly deep or whole-house retrofits (IET & NTU, 2018). This is due to the nature of social landlords, who often have explicit social objectives and can recognize the impact of retrofitting on tenant welfare (Smith and Abbot, 2017). The soaring cost of living and fuel prices, reaching a 40-year high (ITV, 2022), further underscores the relevance of this assertion.

Despite this, it is crucial to question whether these social landlords are equipped and staffed with the required knowledge and skills to enable and implement retrofitting. There's a consensus in the literature that the capacity and skills of social landlords in retrofitting can greatly vary, largely dependent on factors such as size, resources, existing housing stock, and the specific needs and circumstances of their tenants (Gilbertson *et al.*, 2006). While Gilbertson et al., (2006) suggest that social landlords may lack the necessary understanding of the potential benefits of retrofitting and the most effective methods to achieve energy efficiency, Brown, Sorrell and Kivimaa, (2019a) on the other hand posits that many social landlords have a strong commitment to improving the energy efficiency of their housing stock, demonstrating considerable expertise and capabilities in this area.

Given that social housing providers directly interface with occupants, they bear the brunt of their clients' dissatisfaction when incentives and programs are half-executed or not initiated due to shifts in government priorities or strategy. Therefore, a critical examination of factors driving investments in social housing, beyond the apparent ones, is crucial. This deeper understanding could offer fresh insights into why social housing indeed presents a suitable starting point for large-scale retrofit initiatives.

Table 2-3 below illustrates the numerous changes in government policy and strategy on energy efficiency and climate change, using the ECO and Green Deal as examples. On one hand, these changes might reflect the industry's ongoing evolution due to advances in retrofitting knowledge and technology. On the other hand, frequent changes could indicate a policy dilemma on the part of policymakers. The cumulative effect of this lack of policy focus are series of new laws, policies, strategies, and incentives which become difficult to keep track of and keep up with regarding implementation. Social housing providers may find themselves in a start-stop cycle and not having enough time to strategize and put in place structures to execute incentives, schemes, and policies before they’re changed.

It can also be argued that such an approach leads to wastage and inefficient use of already scarce and limited human and capital resources affecting most providers. Also, the uncertainties in policy can affect the commitment of providers in initiating retrofit projects and completing existing ones. Furthermore, given that social housing providers are the ones directly facing occupants, they incur the displeasure of their clients/occupants when incentives and programmes are half executed or not initiated after being announced due to changes in government priorities or strategy.

Table 2-3 Major changes and announcements in ECO and Green Deal (2010-2023).

Year	Month & major changes and announcement	Government in Power
2010	**April**: Energy Act 2010 came into force, mandatory social price support to reduce energy bills for the most vulnerable	Conservative-Liberal Democratic Coalition
2011	October: The Energy Act 2011 introduced the Green Deal Policy	Conservative-Liberal Democratic Coalition
2012	**April**: DECC announced a list of pioneer Green Deal providers. **July**: Electricity and Gas (Energy Company Obligation) Order 2012 introduced ECO. **June**: Green Deal Oversight and Registration Body (GDORB) put into launch. October: Soft Launch of Green Deal	Conservative-Liberal Democratic Coalition
2013	**January**: Official launch of Green Deal and ECO CERT and CESP schemes were closed and replaced by ECO. ECO phase 1 delivery plan **February**: Green Deal and ECO launched in Scotland. **May**: Green Deal Finance Company (GDFC) operational **December**: DECC announced the Second stage of the Green Deal which was called the 'streamlined and improved' Green Deal. £450 million was allocated to household energy efficiency for three years. Energy Act 2013 came into force.	Conservative-Liberal Democratic Coalition
2014	February: DECC announced changes to the Green Deal scheme's cashback rates, timings and insurance-backed guarantees. **May**: New Green Deal Home Improvement Fund (GDIF) announced **October** £100 million for households' energy efficiency announced (in addition to the previous 450million) **November**: Green Deal Finance Company bailed out; The Department of Energy and Climate Change stepped in and gave a £340 million loan. **December**: The Electricity and Gas (Energy Company Obligation_ order 2014 came into force, changes in ECO1 and set legislations for a new obligation period (1 April 2015 to 31 March 2017)	Conservative-Liberal Democratic Coalition
2015	**March**: The original ECO scheme closed on 31 March **April**: The new obligation period (ECO2) started on 1 April 2015 Covered three obligations. Carbon Emissions Reduction Obligation (CERO) Carbon Saving Community Obligation (CSCO) Home Heating Cost Reduction Obligation (HHCRO)	Conservative-Liberal Democratic Coalition
2017	**March:** The original ECO2 scheme closed on 31 March**.** **April:** The Electricity and Gas (Energy Obligation) (Amendment) Order 2017, came into effect, called ECOt with CERO and HHCRO	Conservative
2018	**September:** The ECO2 extension scheme ended on 30 September. **October**: Official launch of ECO3 scheme (third iteration so far). Had only one obligation (HHCRO).	Conservative

2021	**July:** Mandated incorporation of a consumer-focused, whole-house approach, quality standards (PAS 2030:2019 and PAS 2035:2019) by TrustMark to ensure assurance of quality.	Conservative
2022	**March:** Original ECO3 officially closed on 31 March. **July:** DECC announces the launch of ECO4 to last till March 2026. ECO4 adopts a whole-house approach to retrofits and HHCRO obligations.	Conservative
2023	**April:** Great British Insulation Scheme (formerly called ECO+) launched. Expected to run till March 2026. Complements ECO4 but focuses on single insulation measures for least-efficient homes. **September:** The Great British Insulation Scheme opens officially and starts receiving applications (with a new Online Checker Tool).	Conservative

Sources: Adopted, adapted and expanded from (Paneru, 2019).
Additional sources: *(Gov.UK 2010; Gov.UK 2011b; Gov.UK 2015a; Gov.UK 2015b; Gov.UK 2012; Gov.UK 2014; Energy Act 2013;* (Ofgem, 2019, 2023) *Ofgen 2015;* (Gov.UK, 2022)*;* (UK Parliament, 2010, 2011, 2013; Gov.UK, 2013; IET & NTU, 2018; GOV.UK, 2023)

2.3 **Retrofit Benefits**

2.3.1 Identifying the literature sources

To identify relevant and important literature from which to extract the benefits of retrofits, a comprehensive literature review approach following Kamal et al., (2019) and Rasmussen, (2017) was performed. The approach is in three stages – an initial non-structured snowballing, a systematic review (protocol-driven database search), followed by a manual search (see Figure 2-2 below). This approach overcomes the challenges of protocol-driven systematic literature reviews. Greenhalgh and Peacock (2005) concluded in their work on the effectiveness of search methods in systematic reviews that such protocol-driven methods are in themselves alone not always the most effective method for reviews, no matter how many databases are consulted. They further added, some sources are best found only through direct manual searches of 'obscure' or grey literature. This study is such that several important and relevant publications including policies and industry reports may never be discovered except through manual search methods.

In the non-structured snowballing approach, an initial exploratory review of the literature was performed to unearth the key concepts and words and get a general overview of the landscape (i.e., the depth and breadth) of studies associated with energy efficiency in buildings. Rasmussen, (2017 and 2014) was the initial paper consulted and from there an unstructured type of snowballing approach was followed to find new sources (Wohlin, 2014).

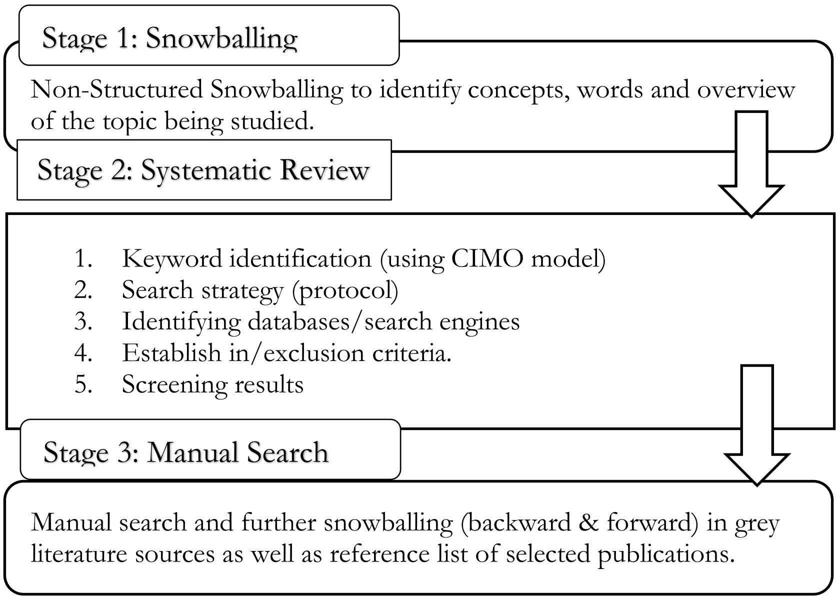

Figure 2-1 Systematic literature search process/stages. Source: Adapted from Wohlin, 2014

Following this exploratory snowballing phase, a systematic review was performed using the 'Context-Input-Mechanism-Output' (CIMO) framework (see Chapter 4, section 4.4.1.1 for a discussion of how this was implemented and an overview of CIMO). Compared with other forms of reviews such as a traditional narrative or a weighted and ranked literature review, the systematic review offers a straightforward, simple-to-update standard of text production (Kamal, Al-Ghamdi and Koc, 2019) and the exploratory review conducted initially generated several keywords which were then employed as search phrases. The use of search terms and search strings reduces biases and ensures the quality of the review because the process is both transparent and replicable (Tranfield, Denyer and Smart, 2003; Collins and Fauser, 2005). The systematic search strategy produced 134 results from the Web of Science database while Scopus produced only 29 (in Table 2-4 below). Chapter 4, section 4.4.2 provides details on the inclusion/exclusion criteria used to select the final papers for analysis.

Table 2-4 Results from database searches using the CIMO-model keywords.

Database	Initial search results	Screening
Web of Science	134	13
Scopus	29	3
Grey sources		7
Reference list search		8
Total	163	32

The last stage incorporates backwards and forward snowballing with a manual literature search of 'grey' or non-academic literature to uncover pertinent and significant publications and reports relating to industry or practice. Several organisations and research centres have undertaken a vast amount of work and research and produced reports and policy briefs among others about residential retrofitting, to which researchers have consulted and referenced including official government policies and publications. It was thus necessary to include these publications to augment those from the search protocol and ensure the comprehensiveness of information sources. The reference lists of the literature from the first two stages on retrofits and their benefits were examined to identify additional retrofit benefits. The manual search included a desk search to identify relevant industry-relevant publications such as reports and policy reviews/analyses. This brought the total number of literature sources to 32 (following the screening process).

2.3.2 Identifying retrofit benefits (claimed benefits) from literature.

Housing retrofit has become a complex issue with strong correlations to many social and economic issues. Understanding the benefits of retrofits therefore requires a broader perspective. A careful review of the retrofitting or housing decarbonisation literature produces a plethora/ an array of outcomes including favourable (benefits) and unfavourable (disbenefits), both of which may be intended or unintended (see the next section on categorising benefits for more on this). Some benefits put extra income or money at the disposal of homeowners or landlords, whether through cutting back on energy usage, adding a premium to the rental or sale value of a property or less repair and operating expenses. Other benefits concern the day-to-day welfare of building users, whether that is physical or mental health or the quality of the air they're breathing.

Using a 2-step process involving i) an explorative search and ii) synthesis and interpretive analysis, a list of these benefits was extracted from the literature in 2.3.1 above.

- **Step 1:** Explorative search to identify a list of benefits. An explorative search is carried out on the literature sources to identify relevant retrofit benefits or claims.
- **Step 2:** Synthesis and explorative analysis of the benefits list using a spreadsheet table to synthesise and organise the benefits to consolidate the list.

The explorative search was carried out on the sources (generated in section 2.3.1 above), generating more than 60 retrofit project benefits including those with similar or overlapping meanings. This list was then reorganised through a synthesis analysis to consolidate them into an aggregated list of 26 main benefits (Table 2-5 below). The next section discusses these benefits in much detail.

Table 2-5 Aggregated list of 26 retrofit benefits from literature search.

Social Benefits
Health and Well-being
Tenant Comfort & Satisfaction
Tenant Awareness (and Agency)
Goodwill/Reputation/ Political Credibility
Jobs/Employment Generation
Neighbourhood Quality or Regeneration
Fuel Poverty Reduction/ Improved Social Welfare

Economic Benefits
Energy Costs savings
Improved Tenancy Management (Positive Tenant experiences)
Fiscal Benefits (Tax/Revenue/ GDP/Growth)
Maintenance & repairs savings
Property Value Improvement
Improved Productivity
Innovations in Business, Products, Processes and Services
Supply Chain Development

Environmental Benefits
Building Physics
Building Quality/ Home Upgrade
Energy Savings
Regulatory compliance
Air pollution reduction
Waste Reduction
Local energy supply chain development
Carbon savings
Resilience or adaption of homes to climate change
Energy Security
Improved environmental & resource management

2.3.3 The (wider) benefits of retrofit investment.

This section outlines and discusses all the benefits identified and revised in section 2.3.2 above. However, given the number of benefits, it was considered more practical to further abstract the benefits into 9 key areas or benefit groupings taking into consideration the nature of the benefit, the beneficiary, and the spatial scale of their significance (see Table 2-6 below).

Table 2-6 The wider benefits of retrofits.

Benefit group	Description	Literature source
Tenant Health and Well-being (HW)	All benefits related to the physical health and well-being of building occupants, including mental well-being.	Hamilton *et al.,* (2015); Santamouris (2016); Gilbertson and Green (2008); Matte and Jacobs (200); Pevalin *et al,* (2017); Evans (2003)
Fuel poverty (FP)	A key policy area for all retrofit incentives and policies of government and social providers. Addresses the alleviation of homes from fuel poverty	Boardman (1991); Liddell and Morris (2010); Thumim *et al.,* (2014); Bolton, Kennedy and Hinson (2022); BEIS (2021a, 2021c);
Financial benefits to Landlords and Tenants (FB)	Captures the monetary savings that accrue to occupants and landlords such as reduced energy bills but also potential value appreciations in the housing stock as well as repair and maintenance savings.	Energy Saving Trust (2018); Rosenow *et al.,* (2016); Fuerst *et al.,* (2015);
Tenant Comfort and Satisfaction (TCS)	Encapsulates the improvements to indoor comfort parameters resulting from retrofits to include air quality, temperature, and humidity levels as well as aesthetics and general satisfaction with the spatial aspects of the home.	(Brown, Swan and Chahal, 2014)Jansson-Boyd *et al.,* (2017); Walker et al., (2014). Elsharkawy and Rutherford (2018).
Environmental and climate change benefits (EC)	Carbon reduction remains an ultimate benefit of interest, although futureproofing the housing stock against climate change events is equally important.	Saffari & Beagon, (2022); Assefa & Ambler (2017); Shrubsole *et al.,* (2014); Williams *et al.,* (2012)
Economic incentives to the broader society (EI)	Investment in retrofits creates ripple effects and incentives for the wider society such as new jobs, securing energy supply, and healthcare cost savings among others. Similar to neighbourhood quality improvements, scale is crucial to realising many of these benefits.	Turner *et al.,* (2016, p1); Maidment *et al.,* (2014); Washan *et al.,* (2014); Brocklehurst et al., (2021); Owen (2023); Killip, Owen and Topouzi (2020); Genovese, Lenny Koh and Acquaye (2013)
Built heritage and Neighbourhood preservation (BHN)	Addresses the benefits of an improvement in the general attractiveness of a neighbourhood or community including social relations, sense of safety as well as renewal potentials from retrofits. Potentially applicable to large-scale community-wide projects.	Power (2008); Foster, Giles-Corti and Knuiman, (2010); Kearns and Parkinson (2001)

Regulatory Compliance (RC)	Retrofitting homes demonstrates compliance with regulations and landlords' ability to capture and communicate this effectively affirms commitment to improving the living conditions of tenants while avoiding risks of penalties, reputational damages, and devaluation of their stock.	Lowe and Oreszczyn, (2008); Sayce and Hossain, (2020); Fuerst *et al.,* (2015); Fuerst *et al.,* (2016)
Reputation or Goodwill benefit (RG)	Achieving net-zero/carbon targets through retrofits greatly enhances the reputation and goodwill of providers/landlords which can translate into financing opportunities through ESG reporting and funding mechanisms.	Lyons (2019); Willcox (2020); MacNaughton *et al.,* (2017); Ameli *et al.,* (2020)

This is not the final categorisation approach used for this research, although it influenced the selection of an approach (section 2.4 presents a discussion of categorisation approaches and the adopted one for this study).

2.3.3.1 Tenant (Occupant) Health and Well-being

The relationship between the indoor environment of a home and health outcomes has long been established (Archer et al., 2016; Krieger & Higgins, 2002; Hamilton et al., 2015; Raw, 1996; Urlaub & Grün, 2016). Poor heating, building fabric and ventilation affect indoor air quality, temperature and humidity which facilitates mould and damp growth, two important catalysts for respiratory-related diseases (see Figure 2-2).

Retrofitting improves health by reducing exposure to "cardiorespiratory diseases, lung cancer, asthma and common mental disorders due to changes in indoor air pollutants, including second-hand tobacco smoke, PM2.5 from indoor and outdoor sources, radon, mould, and indoor winter temperatures" (Hamilton et al., 2015, p.1), lowering excess winter mortality (EWM) in cold climates as well as fewer deaths in heat extremes (IEA, 2014).

Studies have demonstrated that the incidence of colds and flu decreased by as much as 50% when indoor air quality is improved (Carnegie Mellong, 2005 as cited in Santamouris, 2016) while rehabilitating low-income homes resulted in a 50% reduction in the incidence of anxiety and depression (Gilbertson and Green, 2008). Similar estimates are made by Santamouris, (2016) who modelled the required investments to eradicate fuel poverty in Europe between 2015 and 2050 and estimated a 50% - 90% reduction in health problems (although this is for the whole of Europe).

Tenant health interconnects with fuel poverty discussed below. The reduction in energy use from retrofit ensures that the whole house can be heated adequately to maintain healthy indoor thermal comfort which in turn reduces the risk of the home falling into fuel poverty. In addition to direct physical health effects, housing quality also impacts mental health directly (Matte and Jacobs, 2000) through environmental characteristics such as noise, indoor air quality and light; and indirectly through altering the psychosocial relationships for developing supportive household interactions, creating psychological stress (Evans, 2003). Pevalin et al., (2017) have also shown that being exposed to persistent poor housing has a strong, long-term impact on a person's mental health.

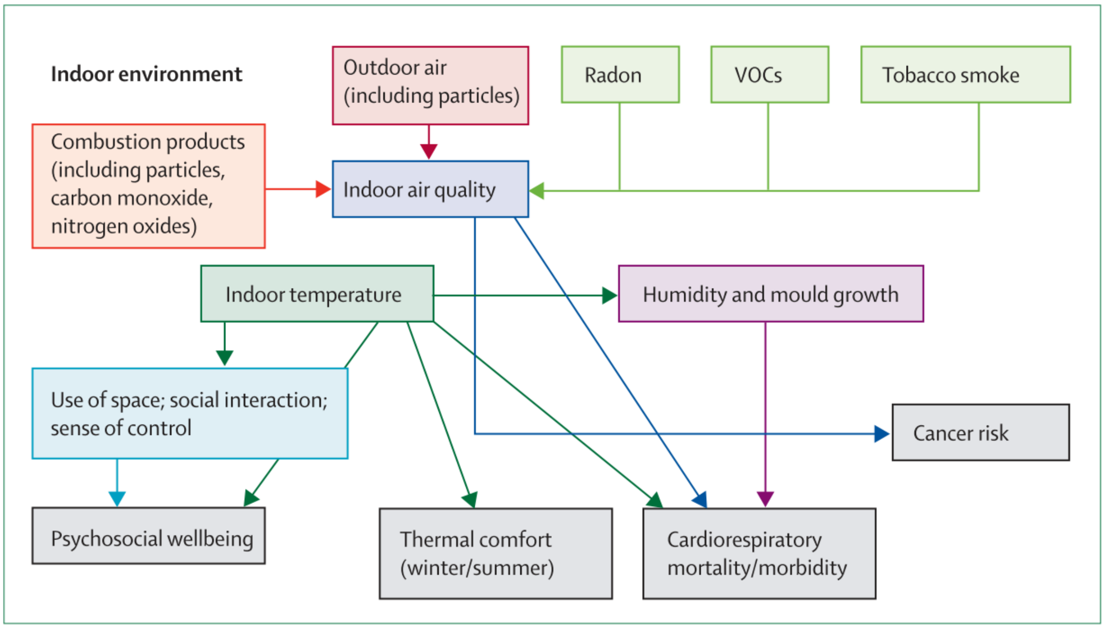

Figure 2-2 Linkages between energy efficiency and health in homes. Source: (Wilkinson et al.*, 2009).* Permission to reproduce this has been granted by Elsevier.

2.3.3.2 Fuel poverty.

High fuel prices, coupled with low incomes and poor energy efficiency lead to a situation where a household struggles to adequately heat their home, rendering them fuel poor. It has received widespread treatment in academic and policy discourse (Liddell and Morris, 2010; Thumim *et al.*, 2014; Walker *et al.*, 2014; Vilches, Barrios Padura and Molina Huelva, 2016; Monteiro *et al.*, 2017). In the UK, reducing the population in fuel poverty remains one of the key policy priorities of many government initiatives in the home retrofit sector. As of 2019, the UK had 13.4% (or 3.18 million) of its households living in fuel poverty, with each household requiring an average of 216 reductions in fuel costs for it to not be in fuel poverty. This figure is expected to increase given the record energy price hikes in the country, sending more homes into deeper fuel poverty (Bolton, Kennedy and Hinson, 2022).

Until 2013, a household was considered fuel-poor if it spent more than 10% of its income on adequately heating the home, an indicator first proposed and adopted in 1991 (Boardman, 1991) which is still used in many European countries and some devolved administrations in the UK. England has perhaps the highest developed measures for fuel poverty after the departure from the standard 10% indicator in 2013 following Hills', (2011) recommendation of the Low-Income High Cost (LIPC) indicator (Hills, 2011; Robinson, Bouzarovski and Lindley, 2018). Currently, a household is classed as fuel poor in the UK if, it has a fuel poverty energy efficiency rating (FPEERP) of band D or below and if it were to spend its modelled energy costs, it would be left with a residual income below the official poverty line (BEIS, 2021a). This is the LILEE (Low Income, Low Energy Efficiency) updated indicator for fuel poverty adopted in 2021 after the publication of the Government's Sustainable Warmth Strategy (BEIS, 2021c), replacing the LIPC indicator. The three main drivers for fuel poverty estimation are energy prices, the energy efficiency of homes and the income of households.

Social housing tenants are among some of the poorest households in the UK and an increasing proportion of them are unable to afford (ONS, 2017; Hickman, 2019) or heat their homes adequately (Hafner *et al.*, 2020). By investing in retrofits, such households are relieved from the financial burden and psychological choice of heating the home or eating. This is particularly significant for the social housing sector which is a vital part of the UK's housing system, representing 17% of the total stock (ONS, 2017).

2.3.3.3 Financial benefits to Landlords and Tenants

Retrofitting social housing has significant financial advantages for both landlords and tenants. One significant advantage is the potential for significant energy bill savings. Energy demand can be significantly reduced by implementing energy-efficient technologies such as improved insulation, modern heating systems, and efficient appliances. According to the Energy Saving Trust (2018), this could result in annual savings of up to £415 per household. The extent of the savings, however, can be influenced by the specific retrofit measures implemented as well as the tenant's energy consumption behaviour. Retrofitting may not always result in significant energy savings in some cases. For example, Rosenow et al. (2016) found that energy-efficient measures may not result in the expected savings in some cases due to rebound effects, in which tenants may use more energy because of lower bills or increased comfort levels. This emphasises the importance of taking individual behaviour and habits into account when implementing retrofit measures. Also, the initial cost of retrofitting social housing may be prohibitively expensive for some landlords and tenants, making long-term energy bill savings difficult to realise.

Furthermore, retrofitting can increase the value of the property. Fuerst et al. (2015) estimated that energy-efficient properties were valued approximately 14% higher than their less efficient counterparts in a UK-based study. This suggests that landlords may see an increase in the market value of their property following retrofitting. Nonetheless, it is critical to recognise that rent increases in social housing may not always be feasible due to tenant affordability constraints. Thus, social landlords may not benefit from such improvement values from rent. However, the increase in the stock or portfolio value unlocks the potential for accessing further funding and support to invest in more retrofits.

Another financial benefit of retrofitting is the reduction in maintenance and repair costs. A comprehensive retrofit can reduce the need for frequent repair calls, thereby extending the lifespan of building components and systems. While this indicates long-term cost savings for landlords, initial retrofit costs must be considered, which may necessitate effective financing schemes. The benefits discussed above are intertwined with a variety of other factors, including the building's age and condition, tenant behaviour, and the local housing market. However, retrofitting can provide financial benefits to landlords in the form of increased property value and lower maintenance costs. When deciding whether to retrofit a property, it is critical to consider the initial costs as well as potential affordability constraints for tenants.

2.3.3.4 Tenant Comfort and Satisfaction

The comfort and satisfaction of a building's occupants are heavily influenced by its internal conditions. This reality has grown more significant in recent times as our lives have become more sedentary, largely due to the COVID-19 pandemic and the shift to remote and virtual work. These changes mean we now spend more time in our homes than ever before. This, along with factors such as increased urbanisation with its associated noise and activity, changing weather patterns, the wear and tear of buildings over time, advancements in construction technology, and rising environmental concerns highlights the need for a re-evaluation of our buildings' internal conditions. Ensuring that these conditions meet certain standards, which include the quality of indoor air, ventilation levels, noise control, temperature, humidity, and the overall physical appeal of the space, is paramount for a comfortable and satisfactory living experience.

Air quality within a building significantly affects the health and well-being of occupants, especially those with respiratory conditions. Ventilation systems are vital in maintaining good air quality as they remove pollutants and allow fresh air in (Walker et al., 2014). Noise levels also significantly influence the living experience, as constant loud noise can cause stress and hinder concentration. Similarly, the control of temperature and humidity is crucial for comfort as extremes can lead to discomfort and health issues (Brown, Swan and Chahal, 2014). Therefore, designing optimal living conditions requires careful consideration of these and other factors to ensure occupant comfort and satisfaction.

Moreover, the design of a building's interior can influence the mental and emotional well-being of its occupants. Research suggests that natural lighting, access to outdoor views, and the use of soothing colours and materials can foster a more positive and productive atmosphere. Also, incorporating green spaces and sustainable materials can encourage a sense of environmental responsibility and contribute to a healthier living environment overall (Elsharkawy and Rutherford, 2018). As we continue to spend more time indoors, prioritising the internal conditions of our buildings to cater to our physical, mental, and emotional well-being becomes increasingly important.

These considerations are critical for a variety of reasons. Firstly, the internal conditions of a building directly impact the health and well-being of its occupants. Secondly, these conditions also influence the building's energy consumption, and subsequently, costs, highlighting their relevance for sustainability and cost-effectiveness. Also, by addressing these concerns through retrofitting, landlords can provide a much more comfortable living environment, ultimately resulting in happier residents and fewer complaints.

While it is true that improving internal conditions may be challenging, particularly in older buildings with limited resources for renovations or upgrades, neglecting these conditions can have detrimental effects. Poor internal conditions could compromise the health and well-being of occupants and could lead to increased energy costs in the long run. Hence, addressing them is crucial to fostering a comfortable, healthy, and energy-efficient living environment.

2.3.3.5 Environmental and climate change benefits

Retrofitting social housing offers significant environmental and climate change benefits, with energy and carbon savings being central to these. These savings form the cornerstone of most retrofit policies and programmes, propelling public policy initiatives towards the goal of an 80% reduction in carbon emissions by 2050. However, reaching this ambitious target necessitates reducing energy consumption across three crucial domestic energy services: heating, hot water, and lighting (Saffari & Beagon, 2022). Space heating, which is particularly responsive to retrofits takes up a significant proportion of home energy use. This area is a significant focus of retrofit investment, as it is sensitive to self-rationing and rebound effects (Saffari & Beagon, 2022). Thus, energy-efficient heating systems and enhanced insulation can considerably lower energy demand and carbon emissions.

Simultaneously, retrofitting can support the local energy supply chain, particularly renewable energy sources. By incorporating renewable technologies, like solar panels or heat pumps, into retrofit projects, the demand for such technologies, increases. This, in turn, can stimulate local markets and innovation in renewable energy, supporting sustainable economic growth. Besides retrofit has been shown to hold far-reaching benefits and advantages to demolishing. It is far quicker to retrofit a house which ensures housing is added to the stock at a faster rate than demolition and rebuilding from scratch. Environmentally, retrofitting avoids the destructive and disruptive effects of demolition eliminating construction wastes (Assefa & Ambler, 2017).

Moreover, retrofitting offers the opportunity to enhance a property's resilience to climate change. Retrofit measures that increase airtightness, such as external sealing of the building envelope, can make properties more watertight, reducing potential water damage and mould/rot risks from excessive rainfall events (Shrubsole et al., 2014; Williams et al., 2012). This is a vital climate change adaptation measure, strengthening homes against increasingly frequent and intense weather events due to global warming.

While these benefits are compelling, a careful and holistic approach to retrofitting is crucial. Not only must retrofits address immediate energy and carbon savings, but they should also factor in long-term resilience and sustainability considerations, contributing to broader climate change mitigation and adaptation goals. Furthermore, retrofitting should prioritize the needs and safety of vulnerable communities, such as low-income households and those living in areas prone to natural disasters. By taking these factors into account, retrofits can have a positive impact on both the environment and society.

In addition, retrofitting can support the transition to a low-carbon economy. An IEA report indicates that energy efficiency measures, including retrofitting, can deliver almost half of the carbon emissions reductions required by 2040 to achieve the Paris Agreement's target of limiting global temperature rise to 2 degrees Celsius (OECD/IEA, 2018). This highlights the importance of investing in retrofitting as part of a comprehensive strategy to address climate change and promote sustainable development.

2.3.3.6 Economic incentives to the broader society

The benefits of investments in retrofitting social housing extend far beyond individual households and landlords' energy/emissions savings and costs. Some benefits drive economic incentives that accrue to the wider society and national level governments, (and regional and local levels, depending on the scale of a retrofit activity). They include the 'activity and employment triggered by initial investments to enable energy efficiency improvements;' and in addition, "the impacts of improved energy efficiency itself that potentially delivers a greater and longer lasting stimulus to household incomes and the wider economy."(Turner et al., 2016, p1). This is mostly expressed in terms of economic growth or increase in GDP (with modelled estimates of £3.2 per £1 invested in energy efficiency by the government, (Washan, Stenning and Goodman, 2014) or employment generation.

Closely related to this is an increase in tax intake from the increased economic growth as well as an increase in employment due to the jobs created in the services and construction sectors (including the supply chain). Introducing retrofit investments also helps to develop and change market conditions and eliminate barriers to decarbonising the housing sector thus making the sector attractive, commercially, and environmentally. The partnership of Energiesprong with Nottingham City Homes to realise the first 10 net zero energy retrofits in the UK, has led to a stronger institutional relationship. This has attracted other partnerships and funding to implement subsequent phases of nearly 400 homes (Studio Partington, 2021) and created a ripple effect in the retrofit industry in the UK. These developments generate innovation in business models leading to the creation or enhancement of products, materials, processes, and services for other customers in the industry which is another macroeconomic benefit of investing in retrofitting. Other studies have mentioned increased industry or firm productivity, increased wages/income for workers and the generation of licensing, patents, and other intellectual property rights (Genovese, Lenny Koh and Acquaye, 2013; Killip, 2013; Mlecnik, Straub and Haavik, 2019; Lowe and Chiu, 2020).

Healthcare cost savings represent another economic advantage. Improved living conditions can alleviate health issues associated with poor housing, such as respiratory and cardiovascular diseases, resulting in decreased strain on healthcare services (Maidment *et al.*, 2014). A Cambridge Econometrics (2014) report suggested that for every £1 spent on retrofitting, the National Health Service (NHS) in the UK, saves approximately 42p in healthcare costs (Washan *et al.,* 2014). Furthermore, retrofitting investment can lead to a more secure energy landscape. By reducing energy demand, reliance on energy imports is decreased, which, in turn, enhances national energy security.

2.3.3.7 Built heritage and neighbourhood preservation (community impact).

The rich built heritage of the UK, accounting for approximately 20% of the country's housing stock, comprises structures designated as such due to their age, planning regulations, or distinctive features of interest (Mazzarella, 2015; Wise, Moncaster and Jones, 2021). This stock includes traditional and listed buildings, each identified for their unique architectural or historical significance. Such structures often act as tangible embodiments of local culture, identity, and aesthetic values, encapsulating the communal history and character.

Retrofitting these heritage buildings provides a sustainable pathway for preserving their distinctive architectural attributes. Additionally, it contributes to maintaining the character and infrastructure of the existing built environment (Power, 2008). Retrofitting initiatives serve as a harmonious avenue for integrating heritage and modernity, blending historical significance with contemporary innovation. This process epitomises sustainable development, effectively balancing the demand for energy efficiency and the preservation of cultural heritage. Moreover, retrofitting initiatives promote urban renewal, with investments in such projects indicating a region's readiness for further (re)investment. Such an indication can stimulate community or neighbourhood development, enhancing the area's desirability and value. In turn, this fosters a sense of community pride, leading to additional social and economic advantages.

The impact of retrofitting also extends to enhancing neighbourhood quality and safety. Well-maintained and improved properties signal occupancy and care, often reducing the occurrence of vandalism and graffiti as they portray less of a target for such activities (Foster, Giles-Corti and Knuiman, 2010). These enhancements contribute to a safer, more appealing neighbourhood environment, fostering positive perceptions and increased satisfaction among residents. Furthermore, such enhancements stimulate social and community participation. The sense of pride and ownership derived from a well-maintained neighbourhood can bolster residents' engagement in community activities and social interactions, enhancing neighbourhood solidarity (Kearns and Parkinson, 2001). Thus, retrofitting catalyses vibrant, cohesive, and secure communities, where residents contribute actively to the ongoing development and preservation of their neighbourhood.

2.3.3.8 Regulatory Compliance

Retrofitting social housing in the UK presents an opportunity to meet the demands of an evolving regulatory environment geared towards achieving national decarbonisation goals and regulatory compliance serves as a crucial driving force for the retrofitting of social housing (Lowe and Oreszczyn, 2008; Sayce and Hossain, 2020). Legal mandates such as the Energy Performance of Buildings Regulations 2012 which introduced the Energy Performance Certificate (EPC), and the Decent Homes Standard are key examples of this regulatory framework aimed at elevating homes to adequate occupancy standards. This regulatory environment imposes obligations on landlords to ensure their properties achieve the stipulated energy efficiency requirements.

They also encourage a proactive approach to retrofitting, as meeting regulatory standards not only ensures legal compliance but also offers additional benefits such as improved energy efficiency and enhanced property value (Fuerst et al., 2015; Sayce and Hossain, 2020). Moreover, non-compliance with these regulatory standards exposes landlords to risks such as financial penalties, reputational damage, and decreased property values. Undertaking retrofitting initiatives offers these housing providers a viable pathway to demonstrate compliance with regulatory requirements which provide benefits in terms of business continuity, profitability, and risk mitigation, enhancing the overall viability of their housing provision services.

Further, communicating compliance with these standards also serves as a source of pride for housing providers, affirming their commitment to enhancing living conditions for their tenants. This reinforces their reputation, adding to the array of benefits that retrofitting initiatives offer.

2.3.3.9 Reputation or Goodwill benefit

With growing awareness of environmental issues especially carbon emissions, the construction industry and the built environment in general have been nudged and continue to shift towards good environmental behaviour. Businesses now pride themselves in showcasing their environmental achievements and with carbon trading and various market structures and mechanisms in place to capture the value of these and reflect them in financial reports, the incentive is even bigger. We see such developments in the retrofit sector, and this is an important benefit that has received little mention in the literature.

The reputation or goodwill of local governments, social landlords or housing associations is greatly enhanced when they achieve carbon or other environmental targets. For example, there appears to be some form of race among councils to achieve carbon neutrality first with a flurry of ambitious targets and pledges (Lyons, 2019; Willcox, 2020). This is rightly so given that home energy retrofits are a key component of achieving carbon targets both for the national and local governments. Nottingham City Council for example has set an ambitious carbon-neutrality target for 2028, 22 years ahead of the national 2050 target (Nottingham City Council, 2020).

Further, financing for retrofit and housing has developed new products based on the Environmental, Social and Governance (ESG) criteria and award funding to businesses based on their ESG performance. Achieving a good ESG rating is now becoming a standard in the housing retrofit and general climate finance sector (Ameli *et al.,* 2020). Individuals and tenants also enjoy this benefit in the form of the psychological reward of the good feeling of being an environmentally responsible citizen of person (MacNaughton *et al.,* 2017).

2.4 **Categorising benefits**

2.4.1 Approaches to categorising home retrofit benefits/impacts.

To support the development of a retrofit benefits assessment framework, there is a need to categorise the benefits of retrofit in some meaningful and logical way. To achieve this, this section explores the literature identified in section 2.3.1 together with further literature search/review to identify and analyse the common categorisation approaches and establish a relevant one for this study.

Categorisation is a fundamental cognitive analytical process in any field of study useful for understanding, organising, and communicating (often) complex information. It offers structure by grouping related items based on shared characteristics and this is particularly important for a multi-faceted topic such as the benefits of retrofitting social homes.

Various studies have considered some form of categorisation for the benefits that result from the energy-efficient retrofit/renovation of buildings (Table 2-7). It is a focal point of academic and policy debates, and each categorisation approach offers unique perspectives for comprehending retrofit benefits. However, they all exhibit inherent limitations and underscore the need for a more comprehensive and nuanced system of categorising benefits.

Amongst these, the IEA's categorisation based on the multiple benefits framework (shown in Figure 2-3 below) is generally highly regarded and widely referenced in energy and policy research. The multiple benefits frameworks do cover a broad spectrum of potential benefits, including economic, social, and environmental aspects, and it recognizes the importance of multiple stakeholders, which aligns well with the complexities of home retrofitting projects and the aim of this study. Notwithstanding, there are concerns raised about the framework. It has been criticised for focusing only on positive outcomes, overlooking negative impacts, and insinuating a linear relationship between efficiency measures and their benefits (Sundell et al., 2016; Janda et al., 2016).

Further concerns arise from the difficulty of quantifying indirect or intangible benefits like improved well-being or social cohesion, leading to a possible underestimation of the full value of energy efficiency interventions (Fuerst et al., 2015). Moreover, the framework offers limited guidance on managing overlapping benefits and may not be fully applicable or sufficiently detailed for specific contexts such as retrofitting in social housing (Rosenow et al., 2016). These critiques necessitate the development of a more nuanced and comprehensive framework for categorising retrofit benefits (especially in social housing).

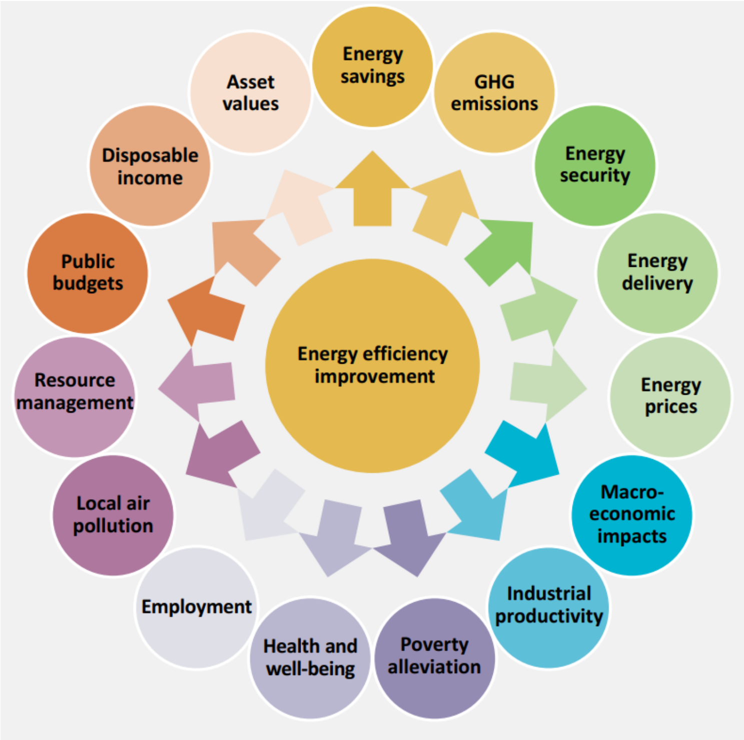

Figure 2-3 The IEA's multiple benefits of energy efficiency improvements framework

Source: IEA/ Campbell, N., Ryan, L., Rozite, V., Lees, E., Heffner, G. (2014) Capturing the Multiple Benefits of Energy Efficiency - January 2014.

Ferreira and Almeida, (2015), offer a conceptual framework that categorises benefits into two distinct types: direct and co-benefits (and these are catalogued further into "private" and "macroeconomic" based on the perspective of the primary beneficiary group associated with the benefit). Fundamentally, the purpose of retrofitting is to reduce carbon emission through energy use reduction (with its attendant life-cycle cost reductions) and the usefulness of their framework lies in calling these the direct benefits. However, it appears the classification lacks any logic or consistency, especially regarding the macroeconomic co-benefits.

Others have adopted the categorisation approach based on the nature of benefits and grouped them according to their intrinsic characteristics such as enhanced thermal comfort or energy savings. Despite the clarity and straightforwardness, it may fail to account for the interconnectedness and dependencies among different benefits. Conversely, the stakeholders-centred approach considers the multi-dimensional nature of benefits but could potentially overlook benefits that are collectively shared or unevenly distributed among stakeholders (Vine et al, 2015).

Several other frameworks such as direct versus indirect, short-term versus long-term, tangible versus intangible and monetary versus non-monetary benefits, introduce additional dimension to benefits categorisation. However, by dichotomising benefits into binary categories, these frameworks risk oversimplifying the complexities and nuances inherent in real-world projects (Rosenow et al., 2016). Similarly, the scale of impact and spatial categorisation approaches, while considering the extent and location of benefits, may conflate the reach of benefits with their importance and fail to account for benefits that transcend spatial boundaries or scales of impact (Sorrell, 2015).

Table 2-7 Various approaches for categorising home retrofit benefits.

Categorisation Approach	**Source(s)**
Nature of the benefits	(Fisk, 2000; Ürge-Vorsatz *et al.*, 2014)
Stakeholders benefiting	(Webber, Gouldson and Kerr, 2015);
Direct and indirect (Co-benefits)	(Geller *et al.*, 2006; Ferreira and Almeida, 2015; Ferreira, Almeida and Rodrigues, 2017)
Short-term and Long-term	(Cattaneo, 2019)
Tangible and Intangible	(J Peter Clinch and Healy, 2001; Galvin, 2014a)
Scale of impact	(Gillingham, Newell and Palmer, 2006; Wilson and Dowlatabadi, 2007)
Monetary and non-monetary	(Sunikka-Blank and Galvin, 2012; Rosenow and Eyre, 2016)
Technical and non-technical	(Hopper *et al.*, 2012; Killip, 2013)
Public and private benefits	(Levy, Nishioka and Spengler, 2003)
Process-based categorisation	(Gillingham, Newell and Palmer, 2006; Kelly *et al.*, 2012)
Retrofit-measure specific	(Guertler, 2012)
Policy-driven	(Fiona Porter, Rosenow and Porter, no date; Oreszczyn, Ridley, *et al.*, 2006; Wilkinson *et al.*, 2009; Rosenow and Eyre, 2016; Brown *et al.*, 2019)
Spatial categorisation	(Chiu *et al.*, 2014; Acre and Wyckmans, 2015)
Risk and vulnerability reduction	(Oikonomou *et al.*, 2009; S *et al.*, 2015; Sharpe *et al.*, 2015; Ranawaka and Mallawaarachchi, 2018; Brown, Sorrell and Kivimaa, 2019b)

Other approaches, such as technical versus non-technical, public versus private, and process-based categorisation, provide additional perspectives but might overlook the interactions and synergies among different types of benefits. Lastly, retrofit measure-specific, policy-driven, risk and vulnerability reduction categorisation offer more focused approaches. While useful in certain contexts, their applicability across various retrofit measures, policy landscapes, risk profiles, or sectors may be limited.

Given these considerations and the limitations of these approaches, a different proposal is to adopt a multi-stakeholder framework that integrates the nature of benefits and their scale of impact. This framework acknowledges the fact that different stakeholders perceive and experience benefits differently and that benefits can vary greatly in scale, from immediate, tangible impacts to long-term, systemic changes. By integrating the nature of benefits and scale of impact, this framework captures the diversity and complexity of home retrofit benefits more effectively than existing approaches. It recognises the interconnectedness and interdependencies of different benefits, the diversity of stakeholders, and the wide range of spatial and temporal scales at which benefits occur, providing a more nuanced and comprehensive categorisation.

2.5 A numerical scoring scale for the retrofit benefit

To aid the development of the retrofit benefits measurement tool development (later in chapters 6 and 7), a scoring scale and criteria needs to be established and defined. The actual scoring criteria is discussed in detail in chapter 6, section 3 (6.3). Here an overview is given to the literature review process followed in defining the scoring scale(s). A simple process, in Figure 2-4, is followed to specify the scoring scales. Following the identification of relevant literature sources, a synthetic review is carried out to identify and extract evidence for specifying scoring criteria for the indicators of all the retrofit benefits. Emphasis is placed on studies with a UK focus in the first instance, followed by those in Europe and then internationally. For indicators with no direct evidence in the literature, an extrapolation and interpretative analysis are carried out to define a scoring scale.

2.5.1 Extracting evidence for scale criteria from the literature

2.5.1.1 Identifying criteria sources

The systematic review reported in chapters two and three for the retrofit benefits framework and evaluation methods identified key and relevant literature sources and these sources formed the foundation for the search for criteria scale and thresholds. Where necessary, however, additional literature searches have been carried out especially when rationalising the criteria thresholds (because this was not the focus of the literature review in chapters two and three).

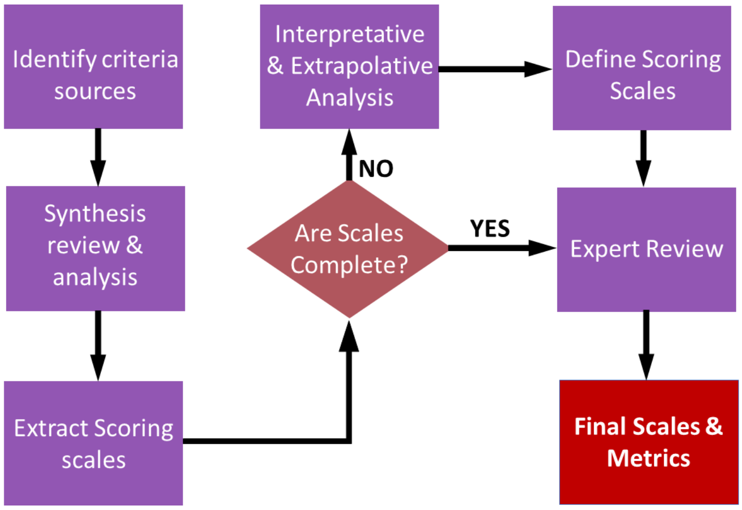

Figure 2-4 Process for establishing numerical scoring scales for the retrofit benefit indicators.

2.5.1.2 Synthesis and Interpretive Analysis

The literature sources were analysed synthetically to identify and define scoring thresholds for the various retrofit benefit indicators. This was accomplished in a spreadsheet which tabulated the indicators against their extracted thresholds, and the sources from which they were extracted (see an example in Table 2-9 below).

2.5.2 Defining the scales

The nature of the indicators is such that the definition of the numerical scale was done simultaneously with the establishment of the criteria. A Likert scale with 5 points (1 – 5) is used to score the indicators, where 1 is the lowest score and 5 is the highest score (see an example in Table 2-8 below in the column named Scale). To score each benefit indicator, the assessor is simply asked to consider the criteria for that indicator as well as the score thresholds and the associated scale of 1, 2, 3, 4 and 5 (explained in Table 2-8 below).

Table 2-8 Scale for retrofit benefits indicator/criteria scoring.

Scale	5	4	3	2	1
Explanation	Highest score	Intermediate score	Medium or Average	Intermediate score	Least score

Table 2-9 "Improved Physical Health" indicator and its scoring criteria and scale.

Indicator	Criteria	Metric/Unit	Scale/Threshold	Rationale
Improved Physical Health	% of occupants reporting improved physical health or well-being post-retrofit.	Occupant survey (Part VI)	1: Less than 30% 3: 30 – 60% 5: above 60%	Reduction of health problems between 50% and 90% - estimate (Santamouris, 2016) 69% reported general health as good/very good (Pedersen et al., 2021)

2.6 Chapter Summary

This chapter addresses the first objective of the study which is to review the literature on retrofitting, the benefits that are derived from it and the categorisation of benefits. It has reviewed and discussed the literature and background of home energy retrofits with a specific focus on the social housing sector. It has been established that retrofitting is a crucial development in the built environment with multiple stakeholders who all come at it with different objectives. This multi-stakeholder perspective is crucial when it comes to identifying the beneficiaries of retrofits and introduces complexities in categorising the benefits or impacts of retrofits. These benefits themselves are also diverse and cover a range of domains, namely social, environmental, and economic with different categorisation approaches. A multi-stakeholder perspective to categorisation is recommended to overcome this challenge and assist evaluations (which is the subject of the next chapter). Chapter 3 continues the literature review into the methods and tools for evaluating home energy retrofit projects, after which a conceptual framework of retrofit benefits is developed.

Chapter 3 : EVALUATING THE BENEFITS OF RETROFITS; EVIDENCE AND REVIEW

3.1 Introduction

It is one thing defining a concept, an idea or situation and another thing measuring it. Several important concepts exist which cannot unfortunately be measurable, at least by existing or known approaches or methodologies. One such concept is the benefits of retrofit activity. As shown in the previous chapter, benefits are multifaceted and multidimensional theoretically and conceptually. And while some attempts have been made to assess and evaluate them in some form, significant challenges persist. To maximise the benefits of retrofitting, "actions to gather data, quantify benefits" (Ferreira and Almeida, 2015), and apply the results to motivate the adoption of retrofit measures are needed.

To make any meaningful progress towards an evaluation/measurement framework, it is important to understand the nature and extent of what is already known about the measurement of retrofit benefits. This chapter's primary aim is therefore to evaluate existing methods, tools and frameworks used in identifying and measuring the benefits of retrofits. It will do so while analysing their strengths and weaknesses to inform the design of the proposed measuring framework.

The chapter opens with an overview of retrofit project evaluation covering the need for evaluation, when and what is evaluated. It then proceeds to assess the methods and tools from the literature highlighting the challenges in their use with a call for a more comprehensive approach and tools that can capture and evaluate the full benefits of retrofits. The chapter ends with a proposed conceptual multi-stakeholder framework for retrofit benefits.

3.2 Retrofit Project Performance Evaluation: An overview.

Several tools and decision support toolkits (both web-based and standalone) have been developed to support retrofit decision-making for various stakeholders (Crawley *et al.*, 2008; Lee *et al.*, 2015; Gonzalez-Caceres, Rabani and Wegertseder Martinez, 2019; Nima forouzandeh, Tahsildoost and Zomorodian, 2021). Some of these focus on specific stakeholders such as homeowners, and the design team such as architects, while others target the wider stakeholders such as policymakers, housing providers and local authorities or municipalities.

3.2.1 The need for evaluation.

Like every other project, retrofitting existing buildings requires not only an end-of-execution assessment to ascertain the achievements of claimed project objectives. A comprehensive evaluation strategy before and during the implementation stages is equally needed to validate the achievement of project objectives. Such a strategy is useful for establishing a clear baseline for future comparison and benchmarking, anticipating, and proactively addressing project challenges, and conducting cost-benefit analysis before and during the retrofits to achieve optimised outcomes. While it is recognised that such a thorough evaluation process, costs money and takes up a lot of time (The Retrofit Academy CIC, 2022), their strategic significance cannot be understated. It is therefore important to review the strategic organisational importance of evaluating home energy retrofits especially for social landlords to highlight the significance of robust evaluation processes in achieving cost-effective and sustainable outcomes for retrofits.

3.2.1.1 Benefits Measurement and Decarbonisation

Benefits measurement in the context of home energy retrofit projects is a critical analytical tool, providing a quantitative and qualitative evaluation of the outcomes resulting from implemented measures. These benefits often span multiple dimensions, from energy savings and reduced greenhouse gas (GHG) emissions to cost savings for homeowners and enhanced residential comfort (Payne et al., 2015; Ferreira and Almeida., 2015).

The importance of benefit measurement is multifaceted. On a micro level, it enables homeowners and project managers to make informed decisions based on expected outcomes. On a macro level, it helps to substantiate the business case for broader decarbonisation efforts, demonstrating the value and viability of energy efficiency measures as a strategy for GHG reduction (Seo et al., 2018; Marchand et al., 2015).

Several studies underscore the central role of benefits measurement in supporting decarbonization. For instance, research has shown that retrofit projects incorporating robust benefit measurement tend to achieve better outcomes in terms of energy savings, cost-effectiveness, and GHG reductions. These successes provide tangible evidence of the efficacy of decarbonisation strategies and contribute to a compelling business case for further action (Sorrell et al., 2004; Ürge-Vorsatz et al., 2012).

However, implementing benefit measurement is not without challenges. The multi-dimensional nature of benefits can make measurement complex, requiring a comprehensive and balanced evaluation of different outcomes. Additionally, there can be discrepancies between projected and actual benefits due to factors such as changes in occupant behaviour or unanticipated issues with the retrofit measures. These potential barriers necessitate careful planning, reliable data, and a flexible approach to benefit measurement (Gillingham, Newell and Palmer, 2009; Galvin, 2014a).

Several solutions have been proposed to overcome these challenges. Advanced modelling tools can provide more accurate predictions of benefits, while post-implementation monitoring can help identify and address discrepancies between projected and actual outcomes. Further, a holistic approach to benefits measurement, which considers not just energy and cost savings but also less tangible benefits such as improved comfort or health, can provide a more accurate and compelling representation of the value of retrofit projects.

3.2.1.2 Selection of Retrofit Measures and Project Performance Evaluation

The selection of appropriate retrofit measures is a critical step in home energy retrofit projects. A variety of retrofit measures are available, each with its unique characteristics, costs, and benefits. Common retrofit measures include improving insulation in walls, roofs, and floors; upgrading heating, ventilation, and air conditioning (HVAC) systems; replacing windows with energy-efficient alternatives; and integrating renewable energy systems, such as solar panels (Jenkins, 2010; Jafari and Valentin, 2017b; Dirutigliano, Delmastro and Torabi Moghadam, 2018; Favi *et al.*, 2018). The selection of retrofit measures typically depends on several factors, including the current state of the building, the climate zone, the available budget, and the homeowner's preferences. However, benefit measurement plays a critical role in this selection process. By quantifying the potential energy savings, cost savings, and environmental benefits of different retrofit measures, benefits measurement can help homeowners and project managers make informed decisions (Jafari and Valentin, 2017a; Kamari, Corrao and Kirkegaard, 2017).

Moreover, benefits measurement is crucial not only in selecting retrofit measures but also in evaluating project performance. After retrofit measures have been implemented, it's important to monitor and evaluate their performance to ensure they are delivering the expected benefits. This can involve tracking energy use, cost savings, and GHG reductions over time and comparing these outcomes to the expected benefits based on the initial benefit measurement. Such evaluation can provide valuable feedback, which can be used to fine-tune the implemented measures and inform the selection of retrofit measures in future projects. There is a growing body of research demonstrating the effectiveness of benefit measurement in the selection of retrofit measures and project performance evaluation. This is attributed to the more precise mapping of measures to benefits, enabling more effective decision-making and implementation (Clinch, and Healy, 2001; Gillingham et al., 2009).

3.2.1.3 Market and Financial Models for Retrofit Projects

Market and financial models play a crucial role in facilitating home energy retrofit projects. These models provide the mechanisms through which the costs of retrofit measures can be covered, thereby enabling homeowners to implement these measures despite the often-high upfront costs (Brown, 2018; Brown, Sorrell and Kivimaa, 2019b). There are several existing market and financial models for retrofit projects. One common model is the energy performance contract, where an energy service company implements retrofit measures and is paid from the resulting energy savings over a contractually defined period. Other models include green mortgages, which provide favourable terms for energy-efficient homes, and on-bill financing, where the costs of retrofit measures are added to a homeowner's energy bill and paid back over time from the energy savings (Rosenow and Eyre, 2016; Brown, 2018; Miu et al., 2018).

Benefit measurement play a key role in these markets and financial models. By quantifying the expected energy savings, cost savings, and other benefits of retrofit measures, benefits measurement can inform the terms of energy performance contracts, the conditions of green mortgages, and the payback periods for on-bill financing. It can also assist in attracting investment by demonstrating the value and return on investment of retrofit projects (Brown, Sorrell and Kivimaa, 2019b; Stirano, Lazzeroni and Olivero, 2019; Green Finance Institute, 2020; Tingey, Webb and Van Der Horst, 2021).

Several case studies illustrate the importance of robust benefits measurement in market and financial models for retrofit projects (Gilbertson *et al.*, 2006; Critchley *et al.*, 2007; Grey, Schmieder-Gaite, *et al.*, 2017). For example, the "Arbed" scheme in Wales employed a multi-faceted benefits measurement approach that considered energy and cost savings alongside social and health outcomes (Grey et al., 2017). This led to a 20% reduction in energy use and a 19% reduction in CO2 emissions across retrofitted homes. Similarly, the "Energiesprong" initiative (originating from the Netherlands) aimed at net-zero energy retrofits for residential housing also utilized a comprehensive benefits measurement system (Critchley *et al.*, 2007). Early findings indicate not just significant energy efficiency improvements but also high levels of tenant satisfaction These case studies clearly show that robust benefits measurement can significantly influence the success of retrofit projects, from both an energy-saving and stakeholder satisfaction perspective. They provide the evidence needed to justify investment, inform financial terms, and ensure that retrofit measures deliver the expected benefits..

3.2.1.4 Social and Economic Impacts

Home energy retrofit projects provide significant social and economic benefits that go beyond the direct impacts of energy savings and greenhouse gas reduction (Thorne Amann, 2006; Rasmussen, 2014; Freed and Felder, 2017). Socially, these projects enhance health and well-being by creating more comfortable and healthier living environments (Maidment *et al.*, 2014; Archer *et al.*, 2016; Sharpe *et al.*, 2019). This is achieved through measures such as improved insulation and heating systems, which ensure consistent indoor temperatures (Levy, Nishioka and Spengler, 2003; Calderón and Beltrán, 2018), and enhanced ventilation systems, which improve indoor air quality (Sharpe *et al.*, 2015; Broderick *et al.*, 2017). Economically, retrofit projects stimulate local economies through job creation in areas like retrofit installation, maintenance, and retrofit material manufacturing (Ürge-Vorsatz *et al.*, 2010; Billington *et al.*, 2012; Oliveira, Coelho and da Silva, 2014; European Commission, 2020) and by reducing energy costs for homeowners (Gilbertson *et al.*, 2006; Critchley *et al.*, 2007; Grey, Schmieder-Gaite, *et al.*, 2017). A significant area where social and economic impacts intersect is in addressing fuel poverty, a prevalent issue in countries like the UK (Hills, 2011; BEIS, 2021b, 2021a; Bolton, Kennedy and Hinson, 2022). Retrofit projects can alleviate fuel poverty by reducing energy consumption and bills, thereby enhancing living conditions and health outcomes.

Benefit measurement is integral in quantifying these social and economic impacts. Despite these impacts being more challenging to measure than direct energy savings, methodologies have been developed for their quantification. For instance, health benefits can be quantified through metrics like reduced healthcare costs or improvements in self-reported health status. Economic impacts can be measured through job creation metrics or reductions in energy bills. Fuel poverty reduction, straddling both social and economic dimensions, can be assessed through changes in energy affordability and related health outcomes (Healy and Clinch, 2004; Thomson, 2013; Grey, Schmieder-Gaite, *et al.*, 2017). Thus, social and economic impacts of home energy retrofit projects add further dimensions to their value. Benefits measurement plays a key role in quantifying these impacts, helping to provide a comprehensive view of the value of retrofit projects.

3.2.1.5 Benefits measurements and technological advances and future trends

Future trends in the larger energy and climate landscape and ongoing technological advancements are driving the field of home energy retrofitting to continue to evolve. These changes have significant implications for the measurement and evaluation of retrofit benefits (Tronchin, Manfren and Nastasi, 2018; Zhou *et al.*, 2018). In terms of technological advances, several innovations are enhancing the effectiveness and range of retrofit measures. For instance, advances in insulation materials are leading to higher energy savings and greater reductions in GHG emissions. Similarly, improvements in the efficiency and affordability of renewable energy systems, such as solar panels and heat pumps, are expanding the options available for home energy retrofits (Tronchin, Manfren and Nastasi, 2018; Zhou *et al.*, 2018; Wade and Visscher, 2021; Liu, Sharples and Mohammadpourkarbasi, 2023; Madushika *et al.*, 2023).

These technological advances are not only affecting the retrofit measures themselves but also the methodologies for measuring and evaluating their benefits. For example, the rise of digital technologies is enabling more precise monitoring of energy use and cost savings, facilitating more accurate and real-time benefits measurement. Advanced modelling tools are providing more reliable predictions of retrofit benefits, supporting better decision-making (Sandberg *et al.*, 2016; Ahsan *et al.*, 2019).

Looking to the future, several trends could shape the field of home energy retrofitting and benefits measurement. The growing urgency of climate change, as reflected in more ambitious policy targets, could drive demand for more comprehensive and robust benefits measurement. The ongoing digitalization of the energy sector, including the rise of smart homes and the Internet of Things (IoT), could provide new opportunities for monitoring and evaluating retrofit benefits. Furthermore, societal trends, such as the growing awareness of the health and well-being benefits of energy efficiency, could lead to a broader conception of retrofit benefits, encompassing not just energy and cost savings but also improved comfort and health (IEA, 2014; Dellaert *et al.*, 2018; Fawcett and Killip, 2018; C40 Cities, 2019).

3.2.1.6 Policy and Regulatory Considerations

Policy and regulatory decisions have significant implications for home energy retrofit projects, shaping the incentives, requirements, and standards associated with these projects. Benefits measurement can play a crucial role in informing these decisions, providing evidence of the value and impacts of retrofit measures. The role of benefits measurement in policy and regulatory decisions is multifaceted. By quantifying the energy savings, cost savings, and other benefits of retrofit measures, benefits measurement can help policymakers and regulators understand the potential impacts of these measures. This evidence can inform the development of policies and regulations that encourage retrofit projects, such as financial incentives or building codes requiring energy efficiency improvements (Brotman, 2017; Galvin and Sunikka-Blank, 2017; Kerr and Winskel, 2018; Hughes, Yordi and Besco, 2020).

In the UK, several studies have highlighted the importance of policies and regulations for the success of retrofit projects. For instance, research has shown that the introduction of the Green Deal, a policy providing loans for energy efficiency improvements, led to a significant increase in retrofit projects (Rosenow & Eyre, 2016). However, the effectiveness of these projects was varied, underscoring the need for robust benefits measurement to ensure that projects deliver their intended benefits (DECC, 2012a; M. Dowson *et al.*, 2012; Marchand, Koh and Morris, 2015; Rosenow and Eyre, 2016).

Furthermore, regulations such as the Minimum Energy Efficiency Standards (MEES), which require rental properties to achieve a minimum energy efficiency rating, have driven demand for retrofit projects. Benefit measurement has been critical in these contexts, providing a means of assessing compliance with the regulations and evaluating their impacts (RICS, 2018). Thus, benefit measurement plays a pivotal role in shaping these considerations and informing the development and evaluation of policies and regulations.

3.2.2 What is or should be measured?

Evaluating the performance of any building-related project is three-pronged covering the physical building space and its elements (comprising the indoor environment); resource consumption in the building, pre-, during and post-construction (comprising energy, water, and the associated carbon footprints); and lastly but importantly the lived experiences of the people in the building space and consuming the energy and water (people or occupants). In this section, an argument is made for the clear and deliberate positioning of people (occupants) at the centre of evaluations as opposed to the prevailing systems and building-focused approaches to evaluations.

A review by Carratt et al., (2020) into the methods used in evaluating the performance of residential thermal retrofits revealed four key drivers of these evaluations – namely a) energy reduction, b) thermal comfort and internal environmental conditions, c) environment and CO2-related metrics, and lastly d) economic (and financial) metrics. Of the four, energy reduction is the most evaluated metric followed by indoor environment quality, economic (financial) and environment (CO2 emissions) in that order.

While Carratt *et al.*'s, (2020) review focused on only passive retrofits, it nonetheless is very revealing of the state of retrofit evaluation practice and what the focus of measurements has been, a bias towards systems and physical building-related metrics and very little on contexts of building occupiers and other human stakeholders at the centre of the retrofit. There is indeed an inherent value in knowing the quantifiable performance of building and retrofit measures installed in homes, and such assessments are often accompanied by some form of monitoring the lived experiences of occupants, however, these are often as a means to an end and not an end in and of themselves. It is important therefore that retrofit building performance evaluations are holistic and place equal emphasis on all aspects of the evaluation at the minimum if occupants' experience cannot or should not take priority.

To satisfy the interests of the many stakeholders in retrofits, a multi-objective approach is necessary and recommended (Carrat *et al.*, 2020). Retrofit evaluations primarily form part of building performance evaluations (BPE), and there is reportedly very little of this happening routinely on projects, with new builds failing to attain minimum energy targets (Diamond and Godefroy, 2021). One can only speculate about the situation with retrofitted homes if this is the case with new builds.

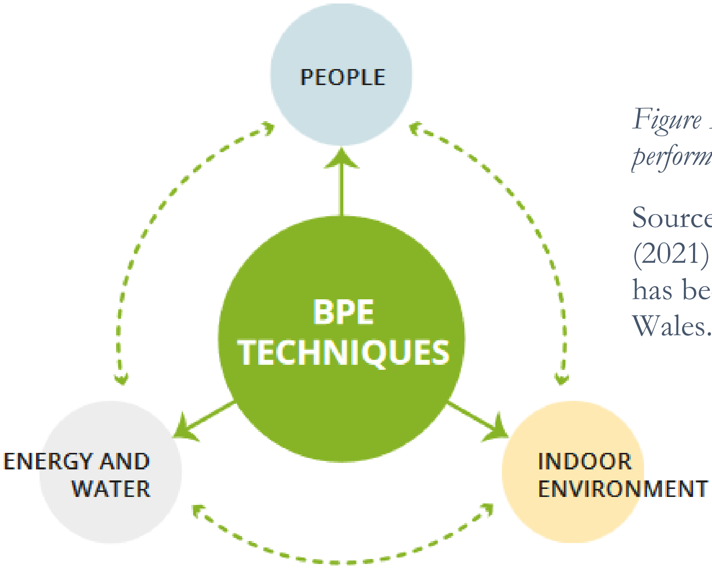

Figure 3-1 What holistic building performance evaluation should cover.

Source: Diamond and Godefroy (2021). Permission to reproduce this has been granted by Woodknowledge Wales.

The situation highlights the necessity for further retrofit evaluations and for learning more from earlier ones. A holistic approach to such performance evaluations is proposed by Diamond and Godefroy, (2021) to enable a good understanding of the performance of homes. They identify people, the indoor environment and energy performance (to include fabric & water), (see Figure 3-1). While this review and indeed the entire research is focused on post-construction/in-use evaluation, effective building performance evaluation should be integral to the entire project process from initial proposal to post-retrofit.

3.2.3 When to measure performance.

An often-overlooked aspect of retrofit benefit evaluation is the timing of performance measurements. Traditional methodologies primarily emphasize post-project evaluations. The evaluation of building retrofit performance in the UK (social housing sector), especially considering recent guidelines such as PAS 2035, has traditionally been anchored in ad-hoc, end-of-project assessments. While this endpoint perspective has its merits, it's becoming increasingly clear that a holistic approach to performance measurement might offer richer insights and more actionable data (Gupta and Gregg, 2020). This approach should follow the building process model and consider the various phases of the building lifecycle, because they are interconnected, and actions taken in one phase can have implications for other phases. This emphasizes the importance of adopting a life-cycle approach to ensure a comprehensive and accurate assessment of the building's energy and environmental performance during and after the retrofit (Sartori and Hestnes, 2007).

This section explores the strategic importance of the timing of these measurements and advances a case for their integration with project process models (The Retrofit Academy, 2022).

Historically, performance evaluations in retrofit projects have been somewhat linear or cyclical, typically commenced upon construction completion or initial occupation (depicted in Figure 3-2 below). Gupta and Gregg (2020) highlight that these evaluations can be initiated as early as the construction stage, offering a broader temporal canvas for assessment. Such evaluations might be set into motion either as a routine part of the project cycle or in response to concerns raised by residents or the client.

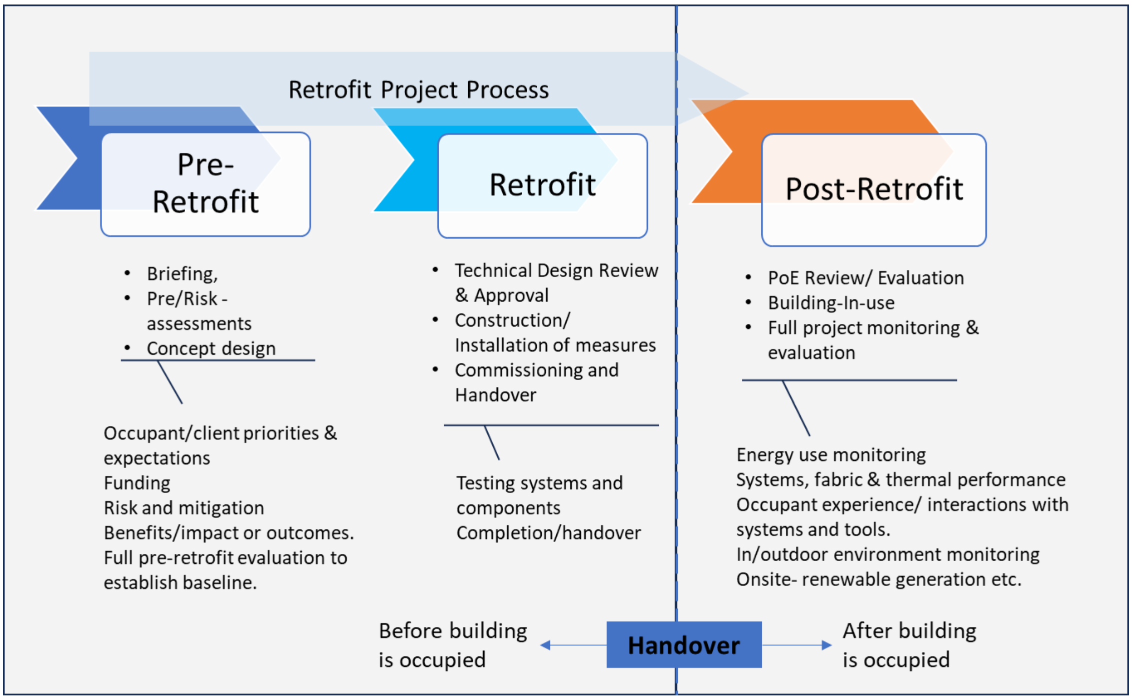

Figure 3-2 Retrofit Project evaluation stages.

Source: Adapted & adopted from (Gupta and Gregg, 2020; The Retrofit Academy, 2022)

3.2.3.1 Stages of Evaluation

As depicted in Figure 3-2 above, the evaluation stages can be split into three main stages following PAS 2035 principles. These are briefly outlined next.

Pre-retrofit evaluation,

Grounded in the principles of PAS2035, this is an indispensable stage, and it is important to set a clear baseline against which the post-retrofit outcomes can be benchmarked (Kelly *et al.*, 2012). Key elements of this assessment include:

- **Detailed Surveys:** A meticulous examination of the building's existing condition, structural integrity, and historical performance data.
- **Baseline Monitoring:** Establishing a clear baseline is instrumental for future comparisons. By monitoring the building's energy consumption, indoor air quality, thermal comfort levels, and other pertinent metrics, the industry sets the stage for a meaningful post-retrofit evaluation, especially when adopting a pre/post-comparison approach.
- **Occupant Feedback:** Even before retrofit interventions, understanding the lived experiences of residents provides invaluable insights into existing problems, expectations, and desired outcomes (Hong *et al.*, 2015). Occupants, equipped with their unique lived experiences pre- (and post-retrofit), offer invaluable insights into the tangible and intangible benefits of the retrofit interventions. While technical metrics and data-driven evaluations form a pivotal foundation, the human experience remains irreplaceable. From understanding the improvements in thermal comfort, indoor air quality, and noise reduction to gauging the enhanced sense of well-being, security, and satisfaction, the resident feedback transcends mere numbers, painting a holistic picture of retrofit success (this is a key point of this study further discussed in more detail in section 3.4 below).

During-Retrofit Assessment:

In deep retrofits, where occupants might decant for a period, the dynamic interplay between retrofit activities and building performance requires continuous monitoring (Galvin, 2014b). From tracking the efficacy of newly installed systems to understanding any potential disruptions in the resident's quality of life, this stage is essential to ensure the retrofit progresses as intended and any emergent issues are promptly addressed.

Post-retrofit Evaluations

This is broadly divided into two phases:

- **Immediate Post-Construction Evaluation:** Capturing the 'as-built' performance ensures the retrofit interventions align with the design intent (Oreszczyn, Hong, *et al.*, 2006). This stage comprises building fabric performance testing, system performance assessments, and a review of the handover process to ensure the building's residents are adequately informed and prepared.
- **Extended In-Use Evaluation:** Once the building's systems have stabilized post-retrofit and occupants have acclimatized to the changes, an extended evaluation phase ensues. This 'in-use' performance evaluation delves deep into energy consumption patterns (differences between expected and actual performance), system efficiencies, indoor environment quality, and, most crucially, occupant experiences post-retrofit (Sunikka-Blank and Galvin, 2012). The PAS 2035 breaks this evaluation stage into basic, intermediate, and advanced monitoring and evaluation (see Chapter 7, section 7.5).

3.3 Challenges in identifying and evaluating retrofit benefits.

Before proceeding to a discussion of the assessment or evaluation of retrofit benefits, it is necessary to lay down a background of some general challenges to the evaluation of benefits. This will provide a good context and introduction to why retrofit evaluation has developed the way it has and the general state of knowledge and practice in the field.

First, any rigorous analysis of the benefits or effects of retrofitting must be based on a thorough understanding of the net welfare effects of the project, programme, or policy and all the underlying interactions at play (Ürge-Vorsatz *et al.*, 2014). Theoretically, this is plausible and has been attempted with simulations, models, and frameworks (which will be discussed in the proceeding section). For instance, Guerra-Santin & Itard, (2012) used dynamic simulation models to assess the impact of energy performance regulations on social housing. Sunikka-Blank and Galvin (2012) introduced the concept of the 'prebound effect' to model actual energy use in retrofitted social housing, taking tenant behaviour into account. Kelly, et al., (2012) evaluated the adequacy of the UK's Standard Assessment Procedure (SAP) in the context of social housing. Hong et al., (2006) used statistical methods to model the impact of energy-efficient refurbishment in English Social Housing, and Galvin and Sunikka-Blank (2014) used household-level data to disaggregate the causes of falling energy consumption in German social housing post-retrofit.

It soon becomes apparent, however, that conducting such detailed analysis is exacting, and carries too high an analytical burden to practically implement or execute. This often comes from two major aspects, methodological complexity, and data requirements. To successfully address the various issues of interest in any retrofit benefit evaluation and attend to the interest of different stakeholders leads the analyst on a path of complexity. The lack of established methodologies and tools for some or most environmental and social-related benefits further complicates the methodological design requirements for the analyst.

Second, is the related challenge of data. A methodology, technique or tool is as good as the data fed into it (Eames *et al.*, 2018) and usually the detail and quality of data required is directly proportional to the complexity of the underlying methodological design. In the absence of detailed data (primary or secondary), an otherwise highly sophisticated methodology or framework is rendered practically irrelevant, notwithstanding its theoretical soundness and analytical utility. In many cases where some form of data exists from previous research or projects and programmes to allow some level of detailed evaluation of retrofit benefits, they are typically not collected considering present analytical requirements and often are not of sufficient granularity. In such instances, it is more efficient to collect new sets of data than attempt an update to existing data, due to comparability and compatibility issues amongst others. Such an undertaking wouldn't be a problem if one had infinite resources. However, competing needs for limited time, capital, and human resource, makes it difficult to gather data of sufficient quality. A related challenge concerns the apparent lack of clear guidance and information as well as oriented policies (discussed in Chapter 2).

A much broader challenge is the complexity and variability in the UK building stock. This cuts across the entire spectrum of the retrofit process, from designing projects through to completion. Mass or scaled retrofits are typically hampered by the uniqueness of the housing stock, coupled with traditional and listed buildings which present obvious challenges in implementing one-size-fits-all approaches. Having to deal with these and other challenges has meant that several studies that have attempted this sort of analysis have either had to compromise with far-sweeping assumptions of various variables of interest or the data requirements.

Some of these challenges arise from the significant initial expenses associated with investing in retrofitting (Klöckner and Nayum, 2016) and the uncertainty surrounding the time it takes to recover the investments made (Achtnicht and Madlener, 2014). These obstacles become more complex when homeowners do not possess the necessary financial means to cover the expenses(Klöckner and Nayum, 2016) , resulting in their inclination to invest in retrofitting projects only if financial subsidies are accessible.

3.4 Retrofit project evaluation research: methods and tools.

3.4.1 Review of Retrofit project evaluation methods and tools

There appears to be a strong divide between the two sets of measurement tools employed in retrofit evaluations, especially considering the precision and accuracy of what is measured. There are the traditional conservative assessments which tend to be indicative and repeatable performance checks and stock-level assessments such as standard post-occupancy evaluations. These are typically less obtrusive and disruptive to occupants and neighbours. On the other hand, there are more modern and often academic-focused approaches following fundamental science principles and applicable to single-home assessments. These include the Co-heat test, the QUB test and Heatflux tests which all measure whole house heat loss and are very intrusive and often require decanting, to enable full assessment of homes. The co-heating test for example can take an average of two to five weeks to complete and requires full access to the home.

Across both traditional and academic tools, the key metrics principally covered are around thermal and ventilation performance. Thermal performance-related tests include the Co-heat test, QUB tests, heatflux tests, and Veritherm, among others. Ventilation performance covers airtightness tests using the Blower door and Pulse tests as well as thermal bridging measurements using software tools such as TRISCO[1]. Other metrics covered include energy use over time from energy metering, temperature and humidity assessments, infrared u-value measurements (with thermography surveys) as well as indoor air quality monitoring and assessments.

[1] A steady state thermal simulation software applicable in thermal bridge analysis, thermal transmittances, thermal performance of windows, doors and shutters, heat transfer via ground and in masonry and masonry products (see www.physibel.be/en/products/trisco, for more details).

Other evaluation methods popularly used in buildings and specifically retrofits include Post-Occupancy Evaluations (POEs). POEs have been the staple of building performance evaluation dating back to the mid-1960s (Tsitnidis, 2016). They are a more technical systematic assessment of building performance during operation, dominantly used within commercial and industrial sectors, though they're gaining popularity within domestic sectors (Teasdale-St-Hilaire, 2013). They typically include some analysis of user perceptions, through occupant surveys, which are generally simplistic self-reported measures of building and element performance post-retrofits. As mentioned in section 3.2, this is important for contextualizing measured (often technical) quantitative data.

Further, as argued by The Retrofit Academy, measured data alone can present misleading impressions and conclusions about retrofit performance (The Retrofit Academy, 2022). For example, a home's measured data may indicate that its monitored CO2 levels are good, yet the occupants may complain about the room being stuffy and insist on leaving windows open. Similarly, a high energy use measurement doesn't always indicate a poorly performing home; perhaps the homeowner is just leaving a lot of inefficient energy appliances running, which itself needs addressing but in quite a different way than would be done for a poorly energy performing home. This is revisited in section 3.5 below.

3.4.2 Experimental/Monitoring methods for retrofit evaluation.

In building upon the foundational understanding of simulation and modelling tools in retrofit projects, it's imperative to consider complementary methodologies for a more comprehensive approach. Experimental and monitoring methods serve as crucial counterparts to computer simulations, providing empirical data that can validate, refine, or challenge simulated predictions (Chiu *et al.,* 2023). Poortinga et al. (2018) illustrate this by implementing a robust methodology that combined experimental designs with pre- and post-occupancy evaluations in UK social housing retrofits. This multi-method approach allowed for the capture of not just quantitative data on energy consumption and environmental performance but also qualitative insights into occupant satisfaction and well-being.

Similarly, the work of Carratt *et al.,* (2020) advocates for more integrative research methods that combine modelling, experimental design, and ongoing monitoring. Their study emphasizes the importance of real-time data collection through various monitoring

Table 3-1 Overview of retrofit evaluation methods used in literature.

Method	Use	Sources
Post-Occupancy Evaluations (POEs)	Assesses building performance and occupant satisfaction after retrofit implementation.	(Gupta & Barnfield, 2014b; Preiser et al., 2015)
Data Loggers	Using sensors and other smart devices to collect and store data on energy consumption, temperature, indoor air quality measurement, relative humidity, internal/external dry bulb air temp measurements etc. for analysis.	(Spataru *et al.,* 2010; Gupta & Barnfield, 2014b)
Smart Meters	Installing smart utility meters to log and transmit live or real-time data on energy consumption which is monitored remotely.	(Darby, 2010)
Occupancy surveys and interviews (questionnaires and diaries)	Gathers occupant feedback to evaluate comfort, satisfaction, and perceived benefits.	(Littlewood et al., 2017; TSB, 2014; Spataru et al., 2010; Gupta & Gregg, 2016; Gupta & Barnfield, 2014b; Leaman & Bordas, 2007)
Quick U-Building method	Short-term measurement of thermal performance of a building or indoor air temperature using electric heaters	(Alzetto *et al.*, 2018; A. Carratt, Kokogiannakis and Daly, 2020; S. Chen *et al.*, 2020; Deb *et al.*, 2021; Sougkakis *et al.*, 2022; Yang *et al.*, 2022)
Documentary Analysis including building design documentation analysis; and analysis of utility bills before and after retrofit.	Compares the actual performance of a retrofit to the intended design specifications in building documents. This may include inspecting the manufacturer's details and their execution on site, both visually and with thermography	(Littlewood et al., 2017; Spataru et al., 2010) (Albatici *et al.*, 2016)
Ventilation and Air permeability tests including air leakage tests	Before-and-after air permeability tests	(Spataru et al., 2010; TSB, 2014; Gupta & Gregg, 2016)
Thermographic Surveys (fabric condition & performance surveys	Thermography studies and imaging of building envelope including ex/internal wall insulation including fabric performance assessment – thermography surveys and photographic surveys	(Hopper et al., 2012; TSB, 2014; Spataru et al., 2010; Gupta & Gregg, 2016) (Albatici *et al.*, 2016)
SAP Analysis	SAP analysis of as-designed emissions targets	(Gupta and Gregg, 2016)
Geometrical Surveys together with structural material verification.	Site visits – geometrical surveys, structural material verification. This includes gathering precise data on the building's actual dimensions and layout and the validation of the actual materials used in a building	(Albatici *et al.*, 2016)

technologies, such as sensors and smart meters. For instance, experimental methods may include controlled studies where specific retrofit interventions are applied to a subset of buildings while leaving another set untouched to serve as a control group (Grey, Jiang, *et al.*, 2017). The performance of both sets can then be compared over a defined period, employing a variety of metrics such as energy consumption, indoor air quality, and occupant satisfaction.

On the other hand, monitoring methods generally involve the installation of various types of sensors and meters within the building to collect real-time data (Hargreaves *et al.,* 2010). For example, thermal sensors can measure indoor temperature variations, humidity sensors can provide data on moisture levels, and smart meters can track electricity and water usage (Sakuma and Nishi, 2019). Monitoring methods like these are also particularly beneficial when examining the human factors of retrofit projects. While simulations can guide and inform potential energy-efficient behaviours (Swan and Ugursal, 2009), monitoring allows for a real-time assessment of how these behaviours are manifesting and impacting energy consumption (Boardman*,* 2004).

Data from monitoring can also be combined with Building Management Systems (BMS) or Home Energy Management Systems (HEMS) to offer a comprehensive view of how a building is performing before, during, and after retrofit interventions (Ascione *et al.,* 2015). This is particularly useful for adapting to real-world scenarios, allowing for immediate adjustments to be made based on real-time performance data (Galvin, 2014). By employing experimental methods for initial validation and monitoring methods for ongoing evaluation, a synergistic approach is achieved that maximizes the benefits of each while providing a robust, multifaceted understanding of retrofit impacts (Oreszczyn *et al.,* 2010). This methodology becomes especially potent when paired with simulation tools, offering a holistic perspective that addresses both the physical and human elements involved in building retrofits (Kelly *et al.,* 2013).

In essence, by embracing a multi-method approach that combines the predictive power of simulations with the empirical rigour of experimental and monitoring methods, a more accurate and holistic evaluation of retrofit benefits can be achieved (Oreszczyn *et al.,* 2010). Such an approach aligns with recent shifts towards integrated research methodologies that consider both material and human aspects in building performance evaluations (Kelly *et al.,* 2013). This layered methodology not only corroborates or refines simulation-derived insights but also enables a dynamic adaptation to real-world conditions (Galvin, 2014). It confirms the need for a more integrated, human-centric approach to evaluating the benefits of retrofit projects, one that truly recognizes occupants as active participants in shaping and achieving energy efficiency goals (Gram-Hanssen *et al.,* 2013).

3.4.3 Modelling and Simulation methods for retrofit evaluation.

Computer simulations have been indispensable tools in the realm of building science for many years. Designers often employ dynamic thermal simulation programs to evaluate various performance aspects of buildings, such as energy consumption and indoor climate. This is particularly true in the UK, where simulation and modelling tools have been increasingly applied to evaluate and measure the benefits of retrofit projects in the social housing sector (Strachan, Kokogiannakis, & Macdonald, 2008). These tools, like EnergyPlus, EQUEST, ECOTECT, and TRNSYS, are actively adapted for retrofit projects in UK social housing, synergizing with appropriate optimization algorithms to identify the most cost-effective and least disruptive retrofit solutions (Clarke *et al.,* 2002; Wright, Loosemore, & Farmani, 2002).

However, traditional optimization methods often overlook the complexity of human behaviour, focusing more on technical parameters and less on human-centric factors like comfort and health outcomes (Hong *et al.*, 2018). This problem is not just limited to the context of social housing retrofits; it reflects a broader issue in building science.

Tsitnidis (2016) argues that the focus on energy performance and technology in building evaluations has often come at the expense of other crucial aspects like architectural design, construction quality, and especially human factors. While current simulations attempt to include human elements, they often do so by treating occupants as subjects for behavioural research. These approaches have yielded unreliable prediction models due to the inherent complexity and variability of human actions (Nicol, J. F., 2001; Nicol, J. F. & Humphreys, 2004; Hoes et al., 2009).

Table 3-2 Summary of modelling and simulation techniques for retrofit benefit evaluation.

Method/ Tool/ Technique	Overview/Description/ Area of Application	Studies or Sources
EnergyPlus Simulation	Evaluate the thermal performance and energy usage of the buildings helping to simulate various retrofit scenarios for energy savings and CO_2.	(Crawley *et al.*, 2001, 2008)
TRNSYS	Used for transient system simulation to model and assess the performance of renewable systems like solar heating and heat pumps in retrofitted homes and CO_2.	(Aragon, Teli and James, 2018; Rashad *et al.*, 2022)
Integrated Design Model (IDM)	Focuses on comprehensive building performance including energy usage, indoor environment quality, and cost analysis.	(Regnier *et al.*, 2018; Li, Xu and Fan, 2019; Yu *et al.*, 2023)
Stochastic Modelling Techniques - Monte Carlo simulations; Markov Chain; Real Options Analysis	Evaluate uncertainties and risks associated with retrofit projects in terms of energy savings, costs, ROI etc..	(Wang, Yan and Jiang, 2011; Fabrizio and Monetti, 2015; Lim and Zhai, 2017; Manfren, Sibilla and Tronchin, 2021)
Building Performance Simulation (BPS)	Evaluate whole-building performance, considering HVAC, lighting, and occupancy patterns.	(Hong *et al.*, 2018; Hensen and Lamberts, 2019; Di Biccari *et al.*, 2022)
SAP (Standard Assessment Procedure)	UK's methodology for assessing energy performance in homes and CO_2 emissions and for generating Energy Performance Certificate (EPC) rating.	(Kelly, Crawford-Brown, et al., 2012;BRE, 2014)
CFD (Computational Fluid Dynamics)	Utilized for evaluating indoor air quality and thermal comfort post-retrofit.	(Curado and de Freitas, 2019; Chowdhury, Rasul and Khan, 2022)
ESP-r	Evaluates energy consumption, CO_2., temperature, and indoor air quality, among other parameters.	(Baldoni et al., 2019; Di Biccari et al., 2022; Sdei et al., 2015)
Integrated Design Model (IDM)	Focuses on comprehensive building performance including energy usage, CO_2 indoor environment quality, and cost analysis for a holistic benefit evaluation.	Clarke *et al.,* 2002
Visualisation and Interactive tools - Virtual reality (VR); Augmented reality (AR)	Used typically at the design stages for immersive visualisation and enabling stakeholders to experience the retrofitted home pre-retrofit. Also useful for stakeholder engagement, energy & comfort simulations and training of both professionals and occupants.	(Liu, Lather and Messner, 2014)

Building Information Modelling (BIM) Techniques - Energy analysis with BIM; Lifecycle Costing with BIM; Visualisation & VR with BIM	BIM can be integrated with energy simulation tools to perform detailed energy analysis; assess the economic performance of retrofit measures over a building's life cycle; and evaluate aesthetic impacts, occupant comfort, or even for training purposes.	(Göçer, Hua and Göçer, 2016; Tzortzopoulos *et al.*, 2019; Feng *et al.*, 2020; Okakpu *et al.*, 2020)

Instead of attempting to predict human behaviour, simulations could serve as a tool to guide and inform occupants, acknowledging their role in energy consumption and building performance. This strategy aligns well with the call for a more human-centric perspective in building performance evaluations. Simulations could then not only evaluate technical performance but also shape sustainable practices among building occupants, adding a dynamic and adaptable dimension to energy-efficient behaviours (Yan *et al.,* 2015).

Recent research is beginning to move in this direction, pointing towards the development of more integrated tools that consider both material and human factors, indicating a promising shift towards a more holistic understanding of retrofit benefits (Yan *et al.,* 2015).

3.4.4 Framework-based methods and tools

Due to their structured approach, which facilitates systematic evaluation and quantification of retrofit outcomes, framework-based methods for evaluating retrofit benefits in social housing and domestic settings have gained popularity (Galvin, 2014). Such frameworks, such as the Building Performance Evaluation (BPE) framework and the Standard Assessment Procedure (SAP) in the United Kingdom, provide exhaustive tools for analysing retrofit interventions and their respective benefits (Lowe, 2007; Zero Carbon Hub, 2013).

Despite these established approaches, however, obstacles persist. While these frameworks strive for general applicability, they may neglect social housing-specific complexities. Studies on the SAP framework in the United Kingdom have revealed potential discrepancies when applied to historic and variable occupancy social housing, with challenges deriving from its generalist assessment approach (Boardman, 2010; Oreszczyk & Lowes). The dynamic nature of the building sector, influenced by evolving technologies and materials, can sometimes render elements of these static frameworks less relevant over time. A case in point is the United Kingdom's aggressive push towards green housing, which is driven by policy mandates and technological innovations that outpace the adaptability of some evaluation frameworks (Gupta & Gregg, 2016).

The dependability of these evaluations is supported by the integrity of their data. Despite its comprehensive approach, the BPE framework relies largely on consistent data collection. Inconsistent methodologies across the United Kingdom and the difficulty of acquiring data from older social housing units have the potential to skew evaluations (Hong *et al.,* 2016). The potential marginalisation of qualitative aspects such as occupant comfort and well-being is a drawback of predominantly quantitative frameworks such as SAP. (Shipworth *et al.,* 2010) These nuances may not be adequately conveyed, despite their importance for residents of retrofitted homes. Moreover, the time and money required for these comprehensive evaluations may seem excessive for minor retrofit projects (Killip, 2013). Certain frameworks may inadvertently favour retrofit measures, particularly if they were created or influenced by industry stakeholders. This bias could skew evaluations, according to a critique of the BPE's approach to retrofit interventions (Oreszczyn & Lowe, 2010).

3.4.5 Economic or Financial tools and methods (numerical methods).

Understanding the economic viability and long-term financial sustainability of retrofit projects is paramount for decision-makers, contractors, and stakeholders involved. While technical evaluations using simulations and framework-based methods are crucial, the economic aspect can often be the decisive factor in whether a project is approved or not (Amecke, 2012). Economic evaluation methods offer a rigorous approach to assessing the financial and broader economic implications of retrofitting projects. These models range from straightforward spreadsheet calculations to complex macroeconomic modelling, serving various stakeholders from individual property owners to policymakers.

Basic Financial Metrics: Payback periods, Internal Rate of Return (IRR), cost-benefit analyses, and Net Present Value (NPV) are often carried out using spreadsheet models (Sunikka-Blank and Galvin, 2012). These methods are particularly useful for assessing the immediate financial viability and short-term impacts of retrofit projects, such as bill savings and necessary investments. While seemingly basic, these spreadsheet calculations provide a quick, albeit limited, snapshot that is crucial for decision-making.

Comprehensive Economic View: For a more holistic perspective, Computational General Equilibrium (CGE) and macro-econometric models can assess economy-wide effects, including GDP impact, job creation, and trade balances (Clinch and Healy, 2003). Input-Output (I-O) tables and analyses offer another robust method for understanding how retrofitting activities interact with various economic sectors (Oliveira et al., 2014, (Chitnis *et al.*, 2012). Scott, 2011).

While economic models excel in providing quantitative assessments, they often have a narrow financial focus (Rosenow and Galvin, 2013). Some methods, like the Triple Bottom Line or Social Return on Investment (SROI), are starting to gain attention for their more holistic approach that includes human-centric factors like quality of life, comfort, and health outcomes (Martin *et al.,* 2021). They can also struggle with the multi-stakeholder nature of retrofit projects, especially in social housing contexts. The issue of split incentives (Gillingham, Harding and Rapson, 2012; Melvin, 2018) complicates the assessment, as building owners are responsible for the investment, while tenants' benefit from reduced energy bills. Mechanisms like green leases or shared savings agreements are starting to address this issue (Smith et al., 2020).

Another limitation is the lack of adaptability to local conditions (Urge-Vorsatz *et al.,* 2014). Some methods, like microsimulation models or localized CGE models, attempt to address localized impacts such as community-specific job losses or gains and gentrification risks (cite). Understanding the multidimensional impacts of retrofit projects requires a holistic approach blending technical, economic, and social factors (Schweber and Leiringer, 2012). Economic and financial models and tools are integral to this multidisciplinary approach, providing the financial lens through which the viability and sustainability of retrofit initiatives are scrutinized and justified.

3.5 Retrofit benefit evaluations beyond technical metrics.

Building users and their influences are thus integral to each building and should be incorporated throughout the design process and extended beyond the point of client sign-off, persisting throughout the building's lifespan, and more so in the residential sector, where a building's performance hinges on its utilisation. As the user demographics and needs shift over time due to factors such as changing occupant numbers, user occupation, and climate change, the building design and services must adapt accordingly. This reinforces the importance of this study's focus on occupant feedback, as it helps inform such adaptive measures (Walker *et al.,* 2014).

As seen from the discussion so far, the assessment of building performance, encompassing retrofits, has progressively shifted towards a predominant focus on technological and systemic aspects, often neglecting human perspectives. This phenomenon, which parallels the larger shift to Industry 4.0, has led to a notable lack of emphasis on user experiences and stakeholder perspectives.

Numerous evaluation methods currently in use serve as illustrations of this particular concern. For example, the emphasis on quantitative metrics such as energy consumption, thermal efficiency, and CO2 emissions, although of significant importance, may overshadow the subjective perceptions and experiences of individuals occupying a building. These methodologies frequently depend extensively on data derived from building automation systems and energy simulation software, which furnish a substantial amount of technical data but provide a limited understanding of the human experience within the built environment.

Furthermore, Post-Occupancy Evaluations (POEs), as noted earlier could potentially offer a more balanced view by incorporating user feedback, but often fall short doing so in practice. While these evaluations are intended to capture user feedback on comfort and satisfaction, the weightage given to this feedback, in the final analysis, is often minimal compared to the hard technical data. This practice tends to downplay user perspectives and reduce their influence on decision-making.

Similarly, Life Cycle Assessments (LCA), primarily centre on the quantification of the environmental ramifications associated with a building throughout its entire life cycle. Although the use of Life Cycle Assessment (LCA) is undoubtedly beneficial in evaluating the sustainability of building materials and technologies, it often overlooks the perspectives and experiences of the occupants who regularly engage with these materials and technologies. In effect, evaluations are more quantitative and technical as well and property/building focused and occupant feedback surveys meant to augment and provide a broader picture and give context to the quantitative measures mentioned become essential (Walker *et al.,* 2014). This is considered a very critical component of the retrofit evaluation and an area this study emphasises.

Considering these issues, a need to pivot towards a more human-centric approach in building performance evaluations is apparent. This is a core tenet of Industry 5.0, which emphasizes the need to harmonize human and machine interactions, bringing back the human element that was overlooked in Industry 4.0. In the context of building performance evaluations, this could involve giving equal weight to user feedback and technical data and striving for a balanced approach that truly represents the complexities of building performance. Integrating a human-centric approach into the design and retrofitting process, not only guarantees the fulfilment of technical and environmental objectives for buildings, but also ensures the provision of a pleasant, gratifying, and captivating environment for the individuals occupying them. This approach acknowledges that buildings encompass more than mere physical structures, as they also serve as dynamic environments that both influence and are influenced by human experiences.

This emphasis on occupant feedback doesn't culminate here. Considering its centrality, occupant feedback becomes the recommended method for this study's retrofit measurement toolkit tailored to score the performance of retrofit projects. By placing residents at the epicentre of evaluation, the tool not only reinforces the importance of human-centric insights but also charts a progressive trajectory for future retrofit assessments (more in chapters 6 & 7).

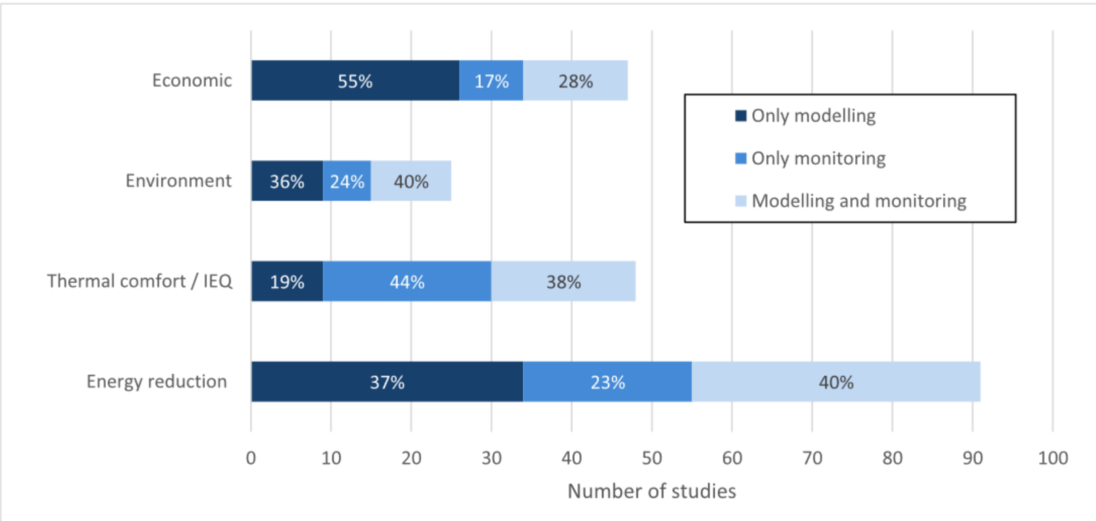

Figure 3-3 Evaluation methods used to evaluate some metrics of retrofit building performance

Source: (Carratt, Kokogiannakis and Daly, 2020). Permission to reproduce this has been granted by Elsevier.

3.6 Towards Occupant-Centred Retrofit Project evaluations

A recurring theme in this review so far is the fact that building (retrofit) evaluations have adopted a technocentric focus. In that context, the appeal of sophisticated technical modelling tools and simulation software can occasionally obscure the importance of the human factor. It's akin to an academic curiosity, a sincere desire to leverage these advanced tools to improve building performance and energy efficiency. Yet, this fervour should not detract from the fact that these tools and software must ultimately serve the needs of the building's occupants. Although it would be erroneous to assert that the human aspect is utterly ignored, it is crucial to critically assess the way it is incorporated and framed.

The relentless pursuit to enhance the predictability of models and simulations often is confronted by the inherent unpredictability of human behaviour. This discord can lead to the unfortunate characterization of these unpredictable behaviours as obstacles, an oversimplification that undermines the complexities of real human interactions. The discussion must evolve from framing occupants as 'barriers' to valuing them as key contributors to refining evaluation models.

The primary goal of these models should centre on improving human comfort and habitability, facets that are fundamentally subjective and diverse among individuals. The integration of such human diversity into models is indeed a formidable challenge, yet it is an endeavour that warrants embracement rather than evasion.

This analysis seamlessly aligns with an earlier proposition, the use of simulation results to guide and shape human behaviour instead of attempting to predict it. This strategic shift recognizes the vital role of human behaviour in determining energy consumption and overall building performance. Simulations, therefore, become powerful tools for not only assessing building performance but also cultivating sustainable practices among occupants.

Embracing this occupant-centric approach echoes the perspective that views humans as active contributors to energy use and building performance, as opposed to passive consumers. This tactic harnesses the predictive power of simulations to educate users, fostering building performance optimization that is adaptable, dynamic, and squarely focused on the occupants (Walker, Lowery and Theobald, 2014).

This fundamental shift holds the potential to instigate long-lasting changes in energy consumption behaviours by encouraging occupants to actively engage in energy conservation. The shift from predicting to informing fosters flexibility and adaptability, accommodating the diverse needs and preferences of building occupants. By blending technical proficiency with the nuanced complexities of human behaviour, this approach yields more robust, applicable, and occupant-centric results.

3.7 A multi-stakeholder retrofit benefits framework home retrofit benefits.

Following the reviews of literature in chapter two (section 2.4) and in this chapter, a multi-stakeholder matrix categorisation framework is proposed for this study to address the multiple-stakeholder interests in retrofit investment. However, a cross-cutting theme in several studies on retrofit benefits is the grouping of benefits into cost/financial, social, and environmental. This approach to categorising is more universal and allows the comparison of retrofit outcomes to investment outcomes in different sectors of society and policy areas, most especially as these benefits are multifaceted. It further provides a comprehensive and easily understandable framework for analysing and communicating the diverse benefits of home retrofits.

By capturing benefits across these three domains, this approach helps to highlight the interconnectedness of various outcomes and supports the development of integrated policies and strategies that address multiple objectives simultaneously. Adopting this approach, a multi-stakeholder triple-bottom-line sustainability framework for categorising retrofit benefits has been developed and incorporated for this study. In this approach, a hierarchical structure is proposed. Level 1 classifies benefits into social, economic, and environmental while level 2 classifies benefits according to the stakeholder of interest. Both levels acknowledge and reflect the nature and scale of the benefits.

3.7.1 The need for a multi-stakeholder benefits framework.

The development of a multi-stakeholder benefits framework is fundamental to the planning and execution of social housing retrofit initiatives. In the absence of such a comprehensive framework, retrofit project teams frequently experience uncertainty, which hinders their ability to identify and incorporate all relevant benefits into project designs. This gap, as highlighted by Jafari et al. (2019), demonstrates the urgent need for a comprehensive benefits framework capable of defining, categorising, and accommodating the multiple benefits associated with energy retrofit projects in existing buildings.

In addition, comprehensive evaluations of retrofit projects that encompass a variety of benefits are noticeably absent. Existing assessments are frequently limited in scope, predominantly through the lens of landlords, who are typically the decision-makers for retrofit investments. This narrow perspective may overlook the experiences and motivations of occupants and other stakeholders, resulting in a distorted understanding of the potential effects of retrofitting. Consequently, the proposed framework is a valuable tool for redressing this imbalance, shedding light on the frequently overlooked perspectives of occupants and other stakeholders. As these perspectives frequently diverge from those of landlords, landlords need to incorporate tenant perspectives when designing and assessing retrofit projects.

The proposed benefits framework also demonstrates the need for an inclusive approach to benefit evaluation, assuring a comprehensive understanding of the potential benefits of retrofit projects. The framework provides an invaluable road map for maximising the benefits of retrofitting for all involved stakeholders. In essence, the implementation of a multi-stakeholder benefits framework transforms from a desirable option to a fundamental component in social housing retrofit projects, thereby amplifying their social, economic, and environmental impacts. Figure 3-4 below, demonstrates how considering retrofitting (and benefits measurement) from a multi-stakeholder perspective combines benefits, strengthens the evidence base and helps create a strong business case for increased investments as compared to a single-stakeholder perspective approach.

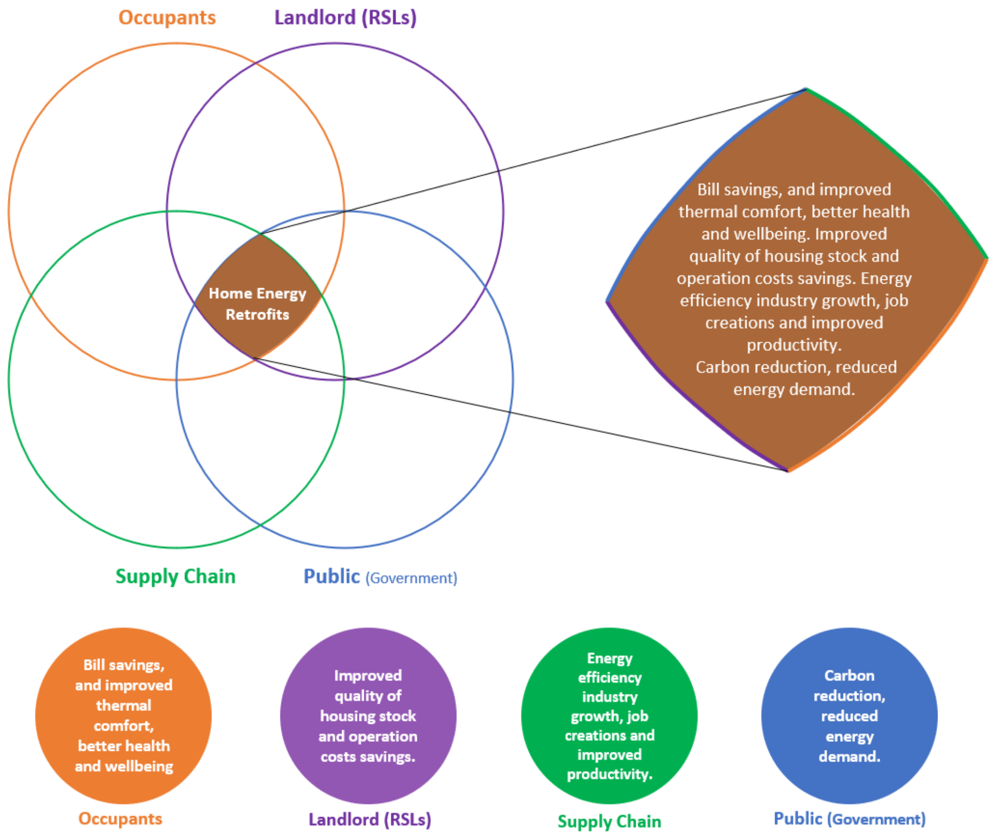

Figure 3-4 The benefits of home energy retrofits to different stakeholders (bottom) and the need to consider the benefits of retrofitting from a multi-stakeholder perspective (top).

3.7.2 Constructing the benefits framework

3.7.2.1 Structure of framework

The multi-stakeholder framework presents a comprehensive categorisation of the benefits of retrofits as identified in section chapter 2, section 2.2.2. The framework is constructed in a matrix table. Figure 3-5 below shows a condensed version of the draft framework showing only the benefits in the Economic category. From the figure, the left three columns present the benefits, their category, indicators, brief description, and metric/ unit of measure. These are followed by the stakeholder's section (with five stakeholders – occupants, landlord, SP partners, local authority, and society. The major stakeholders discussed in section 2.1.5 are considered here with some modifications. For practical purposes, the retrofit industry supply chain, energy suppliers and utilities, financial/capital providers and energy and building consultants stakeholders are merged and captured under

Table 3-3 Multi-Stakeholder Retrofit Benefits Categorisation Framework

BENEFITS-INDICATORS					STAKEHOLDERS					REFERENCES
Group	**Benefit**	**Indicators/Criteria**	**Description**	**Metrics/Units of Measure**	Occupant	Landlord	Local Authority	SP Partner	Society	
FB	Energy Costs savings	Cost savings or extra warmth from retrofitting	Reduced energy costs/expenditure due to decreased energy demand (Financial value of retrofitting)	£	X	X	X			Lilley, Davidson & Alwan (2017); EU (2019) Fingleton et al., (2021)
FB	Maintenance & repairs savings	Savings in repair and maintenance cost	Avoided or reduced costs of equipment maintenance and repair (from frequent breakdowns). Building life-cycle-costs reduction.	£	X	X	X	X		Seeley (2012) Colclough (2021)
FB	Property Value Improvement	Increased rental or market value	Observed increase in the rental/market value/sale price or transaction price of a house/rental in response to efficiency improvements.	£ Rental premium or market value due to retrofit	X	X				Fuerst et al., (2015); Stanley et al., (2016) Colclough (2021)
TCS	Improved Tenancy Management (Positive Tenant experiences)	Reduction in voids and vacancies	Avoided costs arising from dealing with regular tenant complaints and transfers as well as void periods - loss of rental income.	Nr. of voids avoided or rental income/revenue loss/gain from voids		X				Brown, Swan and Chahal (2014) Jansson-Boyd et al., (2017)
		Reduced Complaints		Nr. of complaints before/after.		X				
		Reduction in tenant transfers		Nr. of tenant transfer requests before/after		X				
EI	Innovations in Business, Products, Processes and Services	Investment in energy retrofitting	Increased investments in energy retrofits	million or billion of £					X	Fingleton et al., (2021)
		Construction products, services, and processes	Product and process innovations in retrofit works, that leads to new materials, products and services for other customers in the industry.	million £			X	X	X	Killip (2013); Fawcett and Killip (2018) Lowe and Chiu (2020)
		Local energy retrofit supply chain development (Energy efficiency of investment)	Developing and maintaining a highly competitive and competing home retrofitting sector (The amout of energy saved per pound invested in the energy retrofit. This indicator can be used to compare the cost-effectiveness of different retrofit projects)	kWh/m2 saved per year per £ invested			X		X	Genovese, Koh, & Acquaye, (2013). Fingleton et al., (2021)
		New or softer financing products and services created	Amount of new or softer financing realised or unlocked.	million or billion of £		X	X	X		Seeley (2012); Brown, Sorrel and Kivimaa (2019).
		New business models/opportunities	New market niches for new companies (like ESCOs) as well as innovations. Also consider businesses pushed out of the market by new ones Innovation	million or billion of £		X		X	X	Brown (2018) Mlecnik, Straub and Haavik (2019)
EI	Fiscal Benefits (Tax/Revenue/GDP/Growth)	Tax savings or Fiscal benefits	Tax and fiscal benefits accruing to homes, or firms or landlords or housing associations for investments in retrofit improvements. Efficiency investments also lead to increased GDP/growth in economy. Also includes avoided or decreased subsidies paid by government (most countries heavily subsidize energy for the population)	million or billion of £		X	X	X		Miu et al., (2018) Washan et al., (2014)
		Increased government revenue/GDP/Growth		million or billion of £			X			Brockway et al.,(2021; Colclough (2021); Katris & Turner (2019) Turner et al., (2016)
		Reduced subsidy payments		million or billion of £			X			
EI	Improved Productivity	Total value of improvement in productivity of business	Labour productivity	mn workdays	X	X	X	X	X	Thema & Wuppertal, (2018) Deffner et al., (2022)
			GDP/income/profit generated as a consequence of new business models, opportunities, products, services, innovation and job creation	million or billion of £		X	X	X	X	
EI	Supply Chain Development	Institutional relationships, partnerships & networks created	New and/or strengthening of existing relationships and networking between partners/business and cities (can lead to further activities, projects, and collaboration)	No. of partnerships, collaboration or consortia created for the project		X		X	X	Brocklehurst et al., (2021)Owen (2023) Killip, Owen and Topouzi (2020)

Building Level	Community level	Society level

the umbrella group "supply chain partners". The landlord represents all social and housing association providers, while "local authority" represents all public and government authorities up to the city level. A fifth stakeholder group 'society' is introduced to represent the general society at the regional and national level as well as any other stakeholder that may not be captured in the existing stakeholder groups. An "X" indicates whether a benefit accrues to a stakeholder group. This is updated in the final framework following expert review to also indicate the level of importance or relevance to each stakeholder group (in chapter 5, section 5.2.4).

Within each benefit category (that is, social, economic, and environmental), the benefits are classified into three different levels, which is the building level (the direct benefits to occupants; the local or community level, which are the indirect benefits to the neighbourhood and surroundings of the property; and society level, which address the indirect benefits to governments and wider society at regional and national levels including utility companies (Jafari *et al.,* 2019; Department of Energy, 2015).

3.7.3 Indicators & metrics

The indicators and metrics for measuring the selected retrofit benefits can generally be grouped into quantifiable or measure-based ones and qualitative or self-reported metrics. These will be discussed later in chapter 6. It thus suffices for the framework to only mention some of the metrics identified and used in the framework. Occupant survey is the main method or approach used to generate data to assess the self-reported indicators and applies mostly to the social and some environmental benefit indicators such as indoor environment quality (IEQ), health and well-being, fuel poverty, community impact and regulatory compliance.

3.8 Chapter Summary

Following the review of retrofitting, its benefits identification and categorisation in chapter two, this chapter set out to address the second research objective which was to understand from the literature, the various methods, and tools available for evaluating and assessing the benefits (especially the wider benefits) of home energy retrofits. The review first examined the need for retrofit evaluation and highlighted the managerial and strategic importance of the effective monitoring and evaluation of projects, what is or should be measured and when to conduct evaluations. The review then delved into some of the challenges in evaluating projects and the central argument presented is that the assessment of retrofit investments especially in social housing remains challenging, with little methodological guidance, more technically inclined and missing the human component necessary for home energy retrofit projects. A case for a human-centred and multi-stakeholder holistic approach to evaluations that follow the building process model is also made.

Chapter 4 : RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

The method(s) by which data is collected, analysed, and interpreted by the researcher is fundamental to all scholarly or scientific inquiry. It is important that the researcher states clearly and provides appropriate justification for the choices made for each piece of research. Embedded within research methodology are assumptions that a researcher holds or makes regarding the nature of reality at the start of his research. These notions of research philosophies and paradigms – whether reality is knowable or not, and how – together with the various research approaches that underpin, and orient social research, constitute the focus of this chapter. The chapter additionally provides an overview and rationale for the research design, outlining the selected methods, as well as the approaches employed for data collecting and analysis. This is preceded by a review of the research philosophies and approaches and philosophical orientation of this study.

4.2 Research Perspectives and Paradigms

4.2.1 Perspectives on (social) research

Researchers investigate and examine societal realities and issues from a variety of perspectives. The goal of all social scientists/researchers remains similar, to produce scientific knowledge, even though different worldviews have evolved alongside social research. These worldviews or perspectives represent interpretations of reality and a particular manner of knowing it, and every method or tool used in research has an inherent commitment to one perspective or another. Hughes (1980) further observes that "no technique or method of investigation ... is self-validating: its effectiveness, its very status as a research instrument ... is dependent, ultimately, on philosophical justification (Hughes, 1980, p.13). Therefore, it is essential to establish a clear philosophical stance in addition to stating one's conceptual and theoretical frameworks for research before making any knowledge claims. Research methods should not "be viewed in isolation from the ontological and epistemological position(s) adopted by the researcher" (Knight & Ruddock, 2008, p.3).

The researcher must first address a few fundamental issues of his study, which his philosophical perspective aids in resolving. They comprise:

a) what is the researcher's view of reality (ontology) – does it exist?
b) how does the researcher know reality (epistemology) – is reality knowable?
c) what value stance does the researcher have (axiology)? and
d) what procedures are used to generate and verify knowledge (methodology)?

Turning now to addressing these questions, we begin with the ontological question, which addresses the nature of being or reality. As Potter, (1996) puts it, ontology "is the concern about whether the world exists, and if so, in what form". The inquiry at hand pertains to the ontological nature of social phenomena, specifically whether they possess an inherent reality and objectivity that exists independently of human cognition and interpretation (Corbetta, 2015). The researcher's comprehension and convictions regarding reality hold significance since they influence the nature of inquiries posed to it. Researchers have the option to conceptualise the realm of reality in two distinct manners: firstly, as a tangible entity that can be observed and quantified, commonly referred to as matter; or secondly, as a construct of the human mind, where reality is shaped by the mind's perception, categorization, and interpretation of the external world (Glesne, 2014).

These two fundamental ontological views are what Easterby-Smith *et al.,* (2015) refer to as "realism" and "relativism" ontology, although she highlights two further ontological positions "internal realism" and "nominalisation" which extend from the original two. Realists believe that social phenomena are objective facts that exist independent of our knowing. They do acknowledge that some concepts may be difficult to quantify but contend that we cannot change the reality of their effects or deny their existence (Xian and Meng-Lewis, 2018). Quantitative research ascribes to this ontological position. Relativists on the other hand assert that what we know or believe to be reality depends largely on a person's background, their societal upbringing and class. In essence, they argue that reality is socially constructed – a product of what we already know, and 'what counts for the truth varies from place to place and time to time (Collings, 1983, cited in Easterby-Smith *et al.,* 2015). This is the principal argument of qualitative research procedures which seek to understand the social and personal meanings that people give to observed facts and patterns.

Epistemology, on the other hand, highlights issues regarding the nature of knowledge and how we know what we know about our social and physical environments. Dubberly et al

(2012) suggest that epistemology examines the criteria by which we distinguish between knowledge that is justified or scientific and that which is not. It seeks to know the relationship between the researcher and what is known, because one's ontological position influences their epistemological position. It is justified for a researcher who believes reality exists independent of our knowing to desire to comprehend the social world in a detached, objective manner without worrying that the learning approach would change it.

Closely connected to the debates in ontology, there are two broad positions in epistemology: positivism and interpretivism (constructivism) (Antwi and Hamza, 2015). Positivists hold the view that social phenomena should be subjected to the precise empirical observations of the natural sciences and that science seeks to obtain the most accurate representation of reality by developing the most objective methods possible (Knight and Ruddock, 2008; Ulin *et al.,* 2004). In other words, the researcher can maintain neutrality in the research process. The alternative orthodoxy of interpretivism posits that social constructs need to be interpreted – and not necessarily whether social reality exists or not. It rejects deterministic 'natural laws' and their cause-and-effect categories (Corbetta, 2003); finds subjective meanings in the objects studied and acknowledges that interpretation is critical to understanding human interactions (Glesne, 2014). A key feature of constructivism is the recognition that the researchers' insights & emotions feature in their work as they are actively involved in the process (Corbetta, 2003), which is in direct contrast to the positivist's position of maintaining researcher neutrality.

The third question, what value stance does the researcher have relative to his research refers to the role of values and ethics in the research process. Both the researcher and the researched hold value positions, and axiology questions, how to deal with these values, and answers to these questions are critical to the credibility of research results (Saunders, et al., 2016). Heron (1996) contends that selecting a specific area of investigation and determining how to explore it shows the researcher's axiological skills. In other words, implicit assumptions of value are made by the researcher throughout the research process, from selecting a research philosophy to choosing specific data collection and analysis techniques. Equally, a researcher articulates his notions of value for the subject of inquiry chosen, suggesting it to be of higher value than other topics/subjects.

Moving onto the last question of methodology, this deals with how the research proceeds to practically discover what they believe is discoverable. Methodology transforms all the ontological and epistemological assumptions and principles into directions and guidance on how the research should be conducted (Antwi and Hamza, 2015; Bell, Bryman and Harley, 2019). It addresses the technical instruments, tools and techniques that aid the cognitive process (Corbetta, 2003), helping the researcher to investigate the concepts, hypotheses, and fundamental principles of reasoning on a topic (Aha, 2022).

4.2.2 Research philosophies and paradigms.

A research paradigm refers to a cluster of beliefs and dictates that influence what should be studied, how research should be conducted, and how results should be interpreted (Bryman, 1988, p. 4). Paradigms "make assumptions about the nature of reality and truth" (Glesne, 2014); and they guide research by specifying the object of study; formulating hypotheses and determining the most appropriate techniques for empirical research

However, in the social sciences, the popularity of paradigms fluctuates over time. Unlike their counterparts in the natural sciences, these paradigms do not follow a strict progression from obsolete to state-of-the-art; rather, they shift in their usefulness and applicability depending on the area of study and research context (Babbie, 2014, p.33; Corbetta, 2003). In other words, they act as lenses through which we view the social world, each offering different perspectives and insights while overlooking other aspects. This section discusses four such paradigms: positivism, realism, interpretivism, and pragmatism. This section discusses four such paradigms: positivism, realism, interpretivism, and pragmatism which are employed in research to investigate truths and facts about the real world (Saunders, et al., 2016).

Positivism follows the realist ontology and objectivist epistemology emphasising the need to test hypotheses with observed facts or data. Positivists posit the existence of a point of neutrality from which the researcher can observe the external world objectively (Johnson and Duberley, 2000). Thus, positivism aims to isolate and distance the researcher from his subject of investigation. That way social reality can be measured, evidence examined, and research of others replicated in a way that results are not biased (Neuman, 2014); Johnson *et al.,* 2006). For instance, a positivist studying workplace productivity might use statistical methods to identify patterns and correlations between variables such as working hours, breaks, and output. Creswell and Creswell, (2018) further show that positivist researchers hold a deterministic philosophy, with the need to identify and assess the causes that influence the outcomes we observe. They add that such an approach to research is reductionist and empirically oriented, interested in reducing ideas into numbers and categories. Methodologically, positivism adopts quantitative approaches and techniques in collecting and analysing data and in doing so, developing numerical measures of observations, and studying individual behaviour is paramount (ibid).

Conversely, interpretivism (also called constructivism) posits that social reality is subjective and complex, Interpretivist researchers believe that the social world is diverse and individuals in their quest to understand the world they live and work in develop subjective meanings of reality and generate such rich experiences that cannot be capture by positivist methods and approaches. According to Creswell and Creswell, (2018), the researcher's goal is therefore to heavily rely on the opinions and views of the researched and to focus on "the complexity of these views rather than narrowing meanings into few categories and ideas" (p. 46).

Interpretivists tend to follow the ontological belief that reality is socially constructed, complex and constantly changing and this should form the starting point for developing our knowledge about the world. It also emphasises the role of the social researcher as one of making sense of other people's construction of social reality, formed through their interactions with others and their own cultural and historical experiences (Glesne, 2014). In pursuing this role, interpretivists recognise that the researcher's background and cultural norms shape their interpretations and hence they need to acknowledge this by positioning themselves in the research (Creswell & Creswell 2018). A study on workplace productivity from an interpretive perspective might involve in-depth interviews to understand employees' perceptions of their work, their motivation, and their experience of workplace policies. Interpretivism is typically associated with qualitative research methods, which capture the depth and complexity of individuals' experiences. From the foregoing, it is evident that interpretivists associate with qualitative research approaches.

Siting between paradigmatic extremes of positivism and interpretivism is realism. Following on from positivism and interpretivism, realism asserts itself as a paradigm comfortably positioned between these extremes. Much like positivism, realism accepts the presence of a reality independent of our thoughts or perceptions (Saunders, *et al.,* 2016). However, it concurrently recognises the complex and subjective nature of human interpretation and experience, not dissimilar to the interpretivist perspective.

There exist two main forms of realism: direct and critical. The former proposes that our senses provide us with an accurate representation of the world, while the latter suggests a disconnect between our perceptions and the 'actual' reality, citing the complex interplay between various phenomena and our perceptual mechanisms as the cause (Bryman, 2006). From a methodological standpoint, realism is open to employing both quantitative and qualitative research methods. It aims to capture not just the surface of occurrences but also delves into the 'why' and 'how' beneath the surface. Often, realist researchers adopt mixed methods to gain a comprehensive understanding of the research context, mirroring the blend of perspectives offered by their philosophical stance (Johnson *et al.*, 2006)

Finally, pragmatism takes a different route from positivism, interpretivism, and realism. Pragmatism renounces the idea of a single observable reality. Instead, it purports that reality is a fluid concept, continually renegotiated, debated, and interpreted, manifesting as a spectrum of diverse and subjective experiences (Creswell & Creswell, 2018).

Table 4-1 Summary of key features of research paradigms

Research paradigm	Ontology	Epistemology	Methodology	Example
Positivism	Objective reality	Knowledge gained through observation and measurement	Quantitative	Simulating of modelling performance of home retrofit measures
Interpretivism	Subjective reality, shaped by human experiences and interactions	Knowledge gained through understanding individuals' experiences and interpretations	Qualitative	Interviews about the lived experiences of occupants in a retrofit project.
Realism	Independent reality, but human understanding is subjective	Knowledge gained through observation, but an acknowledgement of subjective interpretation	Mixed methods	Combination of simulation, modelling and occupant interviews
Pragmatism	Reality is constructed and negotiated	Knowledge gained through practical problem-solving	Dependent on the research question	Combination of methods, possibly including case studies, experiments or interventions.

Pragmatism accentuates the primacy of the research question and argues that it should determine the method, freeing the research from the strictures of preordained epistemological and ontological positions. As a result, pragmatism often aligns with mixed methods research, integrating both qualitative and quantitative techniques. This approach yields practical and action-oriented outcomes, favouring 'what works' over strict adherence to any single philosophical stance. Such an approach is especially useful for applied research areas where the objective extends beyond understanding phenomena to solving specific problems or effecting change (Johnson and Duberly, 2000).

In sum, the paradigm chosen for a study largely hinges on the research questions at hand, the character of the subject matter, and the researcher's philosophies. Thus, a deep understanding of these paradigms, their strengths, and their limitations, is critical for making an informed choice of approach in any given study. The next section discusses the philosophical orientation of the present study.

4.2.3 The philosophical orientation of this study

This study by its nature and objectives, is disposed towards a pragmatist philosophy. The pragmatist paradigm allows the researcher to draw on objectivist and subjectivist epistemologies without the need to stick to one perspective (Xian and Meng-Lewis, 2018) because different philosophies are suited to different research needs or objectives. Pragmatists generally reject both notions of the existence of predetermined realities (positivism) and the ability of people to construct meaning out of nothing (interpretivism) (Rorty *et al.*, 2004) and rather argue that the researchers' questions (should) determine the methods he adopts.

The subjects of the study are mainly people (occupants) and landlords (social institutions). It will be conducted considering specific cases and/or examples with the participation of a restricted number of specialists. These research subjects are active participants in the knowledge creation framework around them and influence the meanings of the interactions they have. Their behaviour is therefore not a passive one, and not outside their influence or control, and these transverse conditions imposed by the positivism paradigm.

Moreover, the research involves the investigation of opinions and perspectives of experts on retrofit project benefits. Thus, the overall design does not follow a particular philosophical position. Creswell and Creswell (2018) point out that the pragmatist philosophy is not committed to any one system of reality but is concerned with the practicalities of research. Consequently, emphasis is put on the research questions and problems rather than the methods or their philosophical underpinnings. This way, the researcher is free to draw liberally on all methods and approaches necessary to understand the question(s). This study subscribes to this position as the questions to be answered involve both qualitative and quantitation dimensions.

Further, given that the objectives of this study are to understand and measure the benefits of retrofit projects (quantitative) and to investigate the opinions and perspectives of home occupants and experts using group decision-making techniques (qualitative), a mixed-methods deductive/inductive approach is deemed most appropriate for achieving the aims of the research and aptly justifies the choice of pragmatism – the philosophical foundation of mixed methods research – as a paradigm.

4.3 Research Approaches

Researchers in the social sciences generally belong to a 'community of researchers' (Teddlie and Tashakkori, 2009) or adopt a 'research strategy' based on their methodological stance or their approach to theory development. Three fundamental communities exist using the former (qualitative, quantitative, and mixed), and the latter – induction, deduction, and abduction. These are the research approaches and they each necessitate a variety of data collection strategies, regardless of the underlying notion. For research undertaking to be considered successful, it must demonstrate the existence of significant research questions and an appropriate approach for addressing them.

4.3.1 Quantitative, Qualitative and Mixed-Methodology approaches

The debate between proponents of the two major methodological movements – qualitative and quantitative has its roots in the 'paradigm wars' or 'paradigms debate' in the 1970s and 80s that raged over the superiority of the two worldviews of positivism and constructivism (Tashakkori and Teddlie, 1998). The quantitative movement is generally associated with the positivist paradigm while the qualitative movement subscribes to the constructivist paradigm.

The distinctions in both approaches can also be looked at in terms of what they measure, their philosophical orientations as well as the history of their evolution (see Tashakkori & Teddlie, 1998). Qualitative research is generally interpretive where the researcher tries to make sense of social phenomenon from a constructionist perspective and often begins with a deductive approach (Saunders *et al.,* 2016). The subjectivity of qualitative research lies in its interest in investigating less quantifiable aspects of a research subject such as the values, perceptions, and attitudes. Creswell and Creswell (2018) define qualitative research as "an approach for exploring and understanding the meaning individuals or groups ascribe to a social or human problem" (p.41). To do well and be confident in the interpretations and claims of a qualitative study, qualitative methodologies rely on "*triangulation*" – the practice of using multiple methods of data capture (Glesne, 2014). Qualitative research methodologies include action research, case studies, ethnography, narrative research, and grounded theory (Saunders *et al.,* 2016). In terms of data collection techniques, qualitative researchers employ mainly interviews, documents and texts (reports), field observations, focus group discussions, and participant observations among others.

The quantitative research approach on the other hand is primarily objective, concerned with experimental and survey research strategies using a deduction approach, where the focus of testing theory with data. While quantitative research is known to collect and analyse numerical data with structured and detailed techniques, it is important to note and distinguish between data about attributes of the researched subjects and data about their opinions – which are numerical, yet in qualitative terms. Saunders et al., (2016) refer to them as 'qualitative numbers.

With an end to the paradigm wars following pragmatism, (Tashakkori & Teddlie, 1998), Brewer and Hunter (1989) rightly conclude that the tremendous growth in the social sciences means, "…there is now virtually no major problem area that is studied exclusively within one method" (p.22). Creswell and Creswell (2018) echo the same admonishing that, both approaches should not be seen as necessarily 'rigid, distinct categories, opposites, or dichotomies', but rather as 'different ends on a continuum'. With this view, instead of categorising a piece of research as qualitative or quantitative, it can be more accurately described as being more qualitative than quantitative or vice versa.

Researchers now increasingly agree that adopting an approach that best suits a particular research's objectives seems more sensible than following entrenched approaches. Therefore, a mixed methodological approach has emerged wherein researchers combine the strengths of both quantitative and qualitative approaches (Tashakkori and Teddlie, 1998; Bryman, 2006; Creswell and Plano Clark, 2017; Creswell and Creswell, 2018). The power and usefulness of mixed methods research stem from the acknowledgement that all methodologies possess inherent limitations, and that combining qualitative and quantitative data helps to address these limitations and optimise the strengths of each methodology.

4.3.2 The Deductive and Inductive Approach

Deductive and inductive reasoning are two opposing approaches to research reasoning. This tells readers about how clear the researcher is about theory at the start of the investigation, and this Saunders, et al., (2016) note raises a vital question about the research project's design. The deductive approach relates to quantitative methodologies and is more aligned with the positivist paradigm. It begins with the development of a theory, conceptual model, or framework, which is then tested logically to obtain a conclusion (Xian and Meng-Lewis, 2018). The inductive approach on the other hand allows general principles to be developed from specific observations, (Babbie, 2014). Inductive reasoning also has limitations which critics identify as the inability to build theory out of empirical data irrespective of the amount of it.

Also, deductive approaches are typically 'top-down' starting at the top with a sweeping theory and working down to finer more specific details of hypotheses which are subjected to testing. The opposite applies to inductive reasoning. It is considered a 'bottom-up' approach, where first observations and/or experimentations are carried out and moved up to large generalisations and theory building. While both approaches involve the use of data, the inductive reference uses data (measurements and observations) to explore a phenomenon, identify patterns, create a hypothesis, and conclude with a theory. The deductive reference instead uses data to evaluate given propositions of an existing theory to either verify or falsify the theory (Saunders *et al.,* 2016).

4.3.3 The research approach for the study

As mentioned in section 4.2.3 above, this study adopts a pluralistic approach to answering the research questions. The overall research design follows both inductive and deductive approaches. The inductive approach allows general principles and inferences to be developed and drawn from specific observations while the deductive approach enables conclusions to be derived logically from a set of premises as well as establishing and explaining causal relationships between concepts and variables (Babbie, 2014; Bell et al., 2018; Saunders, e al., 2016). The use of mixed methods research is also an attempt to bridge the ideological divide between qualitative and quantitative adherents. Rather than adopting one approach, the practical significance of each approach could be thoroughly investigated to provide additional value to the research (Creswell and Plano Clark, 2017).

At the initial stages of this research, reviews, and synthesis of published literature (inductive/qualitative) were conducted to identify and classify the various benefits that result from a home retrofit investment, as well as establish their respective indicators and criteria. Similar techniques were implemented to define the numerical scoring criteria for the retrofit benefit indicators. To augment the literature reviews, interviews, and reviews (inductive/qualitative) were used to elicit the views of experts and practitioners on their understanding of the existing evaluation and measurement approaches for retrofit project benefits. Experts also reviewed frameworks and tools for relevance, quality, and appropriateness.

Table 4-2 Summary of the research design for this study.

Theme	**The choice for this study**
Philosophy	Positivism and Interpretivism
Approach	Pragmatism
Strategy(ies)	Mixed method
Data Collection	Surveys and Interviews; Analytical Hierarchy Process; Delphi Technique
Data Analysis	Thematic analysis

4.4 Research methods adopted for the study.

Social science researchers can choose from a large pool of research methods to accomplish their research endeavours. What matters, in the end, is whether those methods chosen are appropriate and able to generate the right data to answer the questions posed. This study adopts several methods spanning both qualitative and quantitative approaches. They include 1) literature reviews and synthesis, 2) Interviews (semi-structured), 3) focus group discussion and 4) AHP-Dephi techniques. These are explored further in the following sections.

4.4.1 Literature reviews

After making decisions about approaches and methods, a key initial activity that also needs to be done is a review of the literature. Such reviews help with the question of whether a study *can* and *should* be researched (Creswell & Creswell, 2018). It also helps the researcher to set out a limit for the scope of his inquiry. Beyond this, literature reviews also serve to connect research to the findings of prior studies and enable the researcher to critically evaluate concepts and theories, contribute to the greater ongoing debates in the particular field of inquiry, as well as to fill potential gaps or extend previous studies (Marshall and Rossman, 2016). This study uses literature reviews for the following:

i) The initial review is to understand and identify the gaps in the existing body of knowledge on social housing retrofit project benefits and their categorisation as well as the extent of their evaluation and measurement. Chapters 2 and 3 present the results of these reviews.

ii) Literature is also reviewed in Chapter 3 to identify and establish the retrofit benefit measurement framework tool which details the relevant benefits of retrofitting for social housing retrofits and maps these to relevant stakeholders.

iii) Later in Chapter 6, the literature is again analysed to establish the retrofit benefits scoring tool criteria and score thresholds for evaluating the performance of a retrofit project. The tool derives from the retrofit benefits framework developed in Chapter 3 and presents scoring criteria and thresholds for the indicators of retrofit project benefits.

4.4.1.1 Systematic review methodology and search protocol

To produce a comprehensive literature review, it is necessary to develop a technique that ensures completeness and reproducibility, hence preserving the study's integrity (Nađa, 2020). This procedure, like primary data gathering, should be carried out with a focus on quality, rigour, and accountability. It is critical to include any modifications in the procedure to strengthen the study's validity.

To meet the systematic review's inclusive criterion, evidence is chosen based on its relevance and contribution to the understanding of the benefits of retrofits in UK social housing. Inclusivity does not imply including all evidence, but rather selecting what is appropriate for the purpose (Nada, 2020). The evidence base may include a range of sources from relevant websites to academic/journal papers, selected to provide a comprehensive understanding of the topic.

The review’s aim in terms of data synthesis is to interpret, code and synthesise data from multiple studies. The initial task will be to organise the data into tables, which will aid in the development of preliminary findings. To create final insights, study attributes such as 'important issues assessed in research' will be contrasted and synthesised. This review also acknowledges the heuristic principle, recognizing that while there may not be a universal solution to a problem, conclusions drawn from the review could inform guidelines and suggestions (*ibid*). Given that solutions vary greatly depending on the setting, the findings of this study will concentrate on identifying mechanisms that operate in the unique context of UK social housing.

The protocol for this study was derived from Pawson (2006), Tranfield *et al.,* (2003), and Denyer and Tranfield (2009), as adopted in Nada, (2020). It will direct the review process by identifying review questions, searching for primary studies, assessing evidence quality, extracting data, synthesising findings, and communicating the findings. Following this, the study developed a protocol to identify the benefits of retrofits in social housing in the UK. Using the CIMO logic recommended by Denyer, *et al.,* (2008), specific research questions derived from this objective have been formulated and presented in Nada (2020). Similar questions are posed for the present study in (Table 4-2) below.

The CIMO model (Context-Input-Mechanism-Output) serves as a structured framework commonly utilized in systematic reviews, especially within the domains of social sciences and management research (Denyer *et al.,* 2008; Wong, 2013). The model delineates four principal components to guide the synthesis of evidence:

1. **Context**: This element characterizes the specific setting in which the intervention or phenomenon under study takes place. It can involve a myriad of variables such as the type of organization, social conditions, geographical area, and timeframe. Understanding the impact of these contextual factors is crucial for interpreting the outcomes (Pawson *et al.,* 2005).

2. **Input**: This refers to the resources or interventions that are deployed within the given context. In a systematic review focused on educational interventions, for instance, the input could be a new teaching methodology (Biesta, 2010).

3. **Mechanism**: Mechanisms articulate the processes through which inputs generate outputs. They explore the causative aspects, often entailing human behaviours like motivation and reasoning, that drive the changes brought about by the input (Wong, 2013).

4. **Output**: These are the effects or results that manifest as a consequence of the interactions between context, input, and mechanism. Outputs may be either intended or unintended and offer valuable insights into the efficacy of the intervention (Denyer *et al.,* 2008).

The CIMO framework facilitates the formulation of precise research questions, the identification of pertinent studies, and the coherent synthesis of findings (Pawson *et al.,* 2005; Biesta, 2010). It aims to not only describe the efficacy of an intervention but also delve into understanding how and why such efficacy is achieved, for whom, and under what conditions.

Table 4-3 CIMO model identified keywords for literature search strategy.

CIMO component	**Question**	**Response**
Context (C)	What is the population of interest?	Social housing in the UK
Intervention (I)	What is the intervention of interest?	Retrofitting, energy retrofit, building retrofit, home retrofit
Mechanisms (M)	What are the mechanisms of the interest?	Policy, legislation, techniques, incentives
Outcomes (O)	What are the relevant outcomes?	Energy savings, cost savings, health benefits, carbon reduction. Alternatively, this can be captured as benefits, impacts, additional or wider or multiple or co-benefits

Adapted from Naa and Milivojevi (2020), the search strategy will focus on connecting the CIMO-identified keywords. The objective is to identify literature in which context (C) and interventions (I) influence outcomes (O) via mechanisms (M). The search encompassed two databases, Web of Science and Scopus, using a combination of keyword searches conducted in each.

The final search strategy adopted was:

> ((social AND housing OR domestic OR homes OR residential)) AND ((retrofitting OR energy retrofit OR building retrofit OR home retrofit)) AND ((benefits OR impacts OR co-benefits OR additional benefits OR wider benefits OR multiple benefits)) AND ((UK OR United Kingdom)).

A slightly modified version of the above search was used on Scopus to fit with the search operand requirements of Scopus.

> (social AND housing OR domestic OR homes OR residential) AND (retrofitting OR "energy retrofit" OR "building retrofit" OR "home retrofit") AND (benefits OR impacts OR co-benefits OR "additional benefits" OR "wider benefits" OR "multiple benefits") AND (UK OR "united kingdom")

See Chapter 2, section 2.3.1 for the presentation and discussion of the CIMO search results.

4.4.2 Evaluation of search results and inclusion and exclusion criteria.

Robust inclusion and exclusion criteria drove the systematic literature evaluation, ensuring a rigorous selection of relevant articles for review. The review of relevant sources was conducted in two stages to discover appropriate literature based on a set of established criteria. The following generally guided the evaluation of data and sources (adapted from Nada, 2020):

1. Study context
2. Study research design
3. Relevance of study to current research
4. Key findings and
5. Conclusions from the study.

Initially, screening was done by reading and assessing the titles and abstracts. Relevant sources were those that identified any benefits of retrofitting that agreed with the research goals. This preliminary assessment enabled the identification of possible studies that gave useful insights into the advantages of retrofitting in the UK residential sector.

The entire texts of the shortlisted studies were appraised for relevance and quality in the second stage. Studies were omitted if the whole text was not available online, ensuring that the review was based on complete data. When there was significant overlap between a journal and a conference paper, the journal version or the most recent version was chosen to eliminate redundancy and to ensure the use of the most up-to-date information. Studies were also omitted if they did not focus on residential, domestic, or home-related advantages. This allows for more focused research into the benefits of retrofitting in the context of the housing sector in the United Kingdom.

The selection process has been enhanced further by incorporating best practices from prior relevant systematic reviews. In examining the costs and benefits of energy efficiency, Rasmussen's (2017) methodology for analysing additional benefits was used, as were methodological insights from Thomson, Petticrew, and Morrison (2001) and Kamal, Al-Ghamdi, and Koc (2019). These tactics not only enabled a thorough search but also provided a solid framework for synthesising the material. The review ensured a robust and thorough collection of literature through this methodical methodology. This organised and open approach reduced bias and ensuring a broad coverage of relevant papers, improving the review's validity and reliability.

4.4.3 Evaluating Research Findings: Approaches adopted in this study.

Evaluation is a critical aspect of research, enabling researchers to scrutinize both the methodological rigour and the practical applicability of their study's findings. In the context of this dissertation, the term "evaluation" encompasses the systematic appraisal of the retrofit scoring tool's methodological soundness and practical usability. According to Patton (2000, pp. 426-427), evaluation involves "the systematic collection of information about the activities, characteristics, and outcomes of programs to make judgments about the program, improve program effectiveness, and/or inform decisions about future programming." This definition captures the essence of what this chapter aims to achieve—establishing the credibility, reliability, and validity of the retrofit scoring tool.

The empirical validation of frameworks and tools is an integral part of scholarly research, providing the necessary bridge between theoretical development and practical application. It helps ensure that research outputs are not just academically rigorous but also practically useful. According to Yin (2018), empirical validation is vital for the credibility, generalizability, and utility of research findings. In the case of this study, empirical validation serves to lend credence to the REBAT tool, increasing its potential for adoption in the industry. This phase of empirical validation is especially crucial given the novel nature of the REBAT tool. As highlighted by Creswell and Creswell (2018), research instruments need to undergo a meticulous evaluation process to confirm their reliability and validity. Empirical validation of the tool allows for an evidence-based critique of its performance, providing insights that can be critical for its refinement, thereby ensuring it effectively meets its intended purpose (Bryman, 2016).

The Tool was designed as a practical implementation of the retrofit benefits framework to evaluate the benefits of housing retrofit projects (in social housing), emphasizing a human-centric approach. It aims to fill existing gaps in the literature and industry practice, as identified in earlier chapters (2, 3 and 5). While theoretical rigour was applied in its development—drawing from extensive literature reviews, stakeholder interviews, and expert consultations—empirical validation is what ultimately provides a holistic examination of its utility and efficacy. It answers critical questions about the tool's real-world applicability, its ease of use, and its relevance in addressing the complexities involved in retrofit project evaluations.

Moreover, empirical validation situates the tool within a broader ecosystem of existing methods and tools, offering insights into how it complements or diverges from them. It provides an avenue to verify the theoretical underpinnings of the tool and its functional effectiveness, as argued by Neuman (2014). By doing so, it does not merely confirm the tool's intrinsic value but also provides evidence for its comparative advantages or limitations. It serves to triangulate the findings derived from other research methods employed in this study, thereby enhancing the overall robustness and credibility of the research (Nowell *et al.*, 2017).

Various types of validity are often considered within the context of construction management research. Construct validity involves ensuring that the tool's operational measures accurately represent the theoretical constructs. This is an essential step to show that the criteria and thresholds used in the tool are grounded in robust theoretical foundations and that they represent the constructs they are intended to measure (Creswell & Creswell, 2018). Content validity, meanwhile, assesses how well a measure represents all facets of a given construct. For this study, the question is whether the retrofit scoring tool adequately covers all elements crucial in evaluating retrofit benefits. Content validity ensures that the tool is comprehensive and omits nothing significant, which is pivotal for any evaluation tool to have a broad utility (Carmines and Zeller, 1979). Face validity is more subjective and relates to the degree to which a procedure appears effective in terms of its stated aims (Carmines & Zeller, 1979). For this research, face validity would mean gathering feedback from industry experts and stakeholders who can affirm that the tool seems to be a practical and applicable measure in real-world settings.

Although these are the primary foci of this research's evaluation, it is worth noting that other types of validity like external and criterion validity are also essential but are not addressed here due to the research's scope and limitations. External validity refers to the generalizability of the research findings (Shadish, *et al.,* 2002). Criterion validity involves the comparison of the tool against some 'gold standard' (Bryman, 2016), and both remain areas for future research. In focusing on construct, content, and face validity, this study aims to build a solid foundation of methodological rigour and credibility. It also opens avenues for future research to focus on aspects like external and criterion validity for a more comprehensive evaluation of the retrofit scoring tool.

4.5 The Integrated AHP-Delphi benefits prioritization, ranking and weighting methodology.

4.5.1 The Delphi Method

The retrofit benefits framework developed (see Chapter 5) identifies the indicators and criteria for the various retrofit benefits. When evaluating indicators or lists of project benefits, it is established that benefits do not possess equal levels of value to stakeholders therefore it is important to assign different weights to different indicators to reflect these different levels of importance (cite He *et al.,* 2015). To generate the weightings for the benefit indicators needed to contextualise the computations and outputs of the measurement tool, a combination of Delphi and Analytic Hierarchy Process (Delphi-AHP) is recommended and used (Berghorn and Syal, 2016; Kian Manesh Rad, Sun and Bosché, 2017a; Jafari, Valentin and Bogus, 2019). Using the Delphi method allows data to be collected from diverse experts in a way that time, distance, and logistical issues will not permit the convening of such expert panels for an in-person event (Yousuf, 2007). Furthermore, (Powell, 2003) mentions that the Delphi method is particularly applicable in contexts when source agreement is desired through a refereed process that collects, aggregates, and organises knowledge from possibly unique or divergent information sources.

The Delphi method, defined as 'a method for structuring a group's communication process so that the process is effective in allowing a group of individuals, to deal with a complex problem' (Linstone and Turoff, 2002, p3), was originally designed by Rand Cooperation as an expert group consensus and forecasting tool in the 1950s. It has since grown in popularity beyond forecasting studies into a ranking technique (see Linstone & Turoff, (2002)) for the evolutional history of the technique). This "ranking-type" variant of the method is now used in group decision-making to shape the consensus of a group about the relative importance of issues (Schmidt, 1997). It has received wide application in information systems research, social work education, operations management, health research (Vernon, 2009) and more recently in construction (engineering management research) (Hallowell and Gambatese, 2010).

The ranking-type Delphi method or survey is designed to 'elicit the opinions of a panel of experts using a controlled feedback process (Schmidt *et al.*, 2001). The controlled feedback process is 'systematic and interactive' and the goal is to obtain the judgements of a group of independent experts on a specific topic (Hallowell and Gambatese, 2010). From the foregoing, implementing a Delphi survey involves 1) identifying and selecting an expert panel (assuming research questions and strategy are already determined), 2) designing and executing the survey (controlled feedback system) to elicit opinions 3) collecting, interpreting, analysing, and concluding findings. The Delphi process typically involves two or more rounds of questionnaire circulation to gather the judgements of experts. Panellists are encouraged to revise their responses after each round of questionnaires relative to the responses of other panel members, with the process repeating until the group reaches a consensus. It also appears that the selection of the experts is at the heart of any Delphi study and Okoli & Pawlowski, (2004) outline very detailed guidelines to aid this process.

Two other very important challenges in implementing a Delphi method in any study relate to achieving uniformity in individual experts' judgement or ranking of issues (*consistency*) and the agreement of opinions among different experts in the panel (*consensus*). Consistency checking (which also relates to the Analytical Hierarchy Process) will be dealt with in section 6.2.3 while section 6.2.4 will address the consensus challenge. Schmidt, (1997) also identifies three critical issues to the success of applying the Delphi techniques in ranking issues or factors: 1) when to stop the polling of opinions, 2) how many items to carry over to subsequent Delphi rounds and 3) the statistical techniques used to analyse Delphi data and support conclusions. These issues will also be discussed in detail in chapter 6.

4.5.2 Analytical Hierarchy Process (AHP) methods

The Analytical Hierarchy Process (AHP) forms part of a broad group of techniques for decision-making in situations where selecting and prioritizing options is not simple and involves a multitude of factors or variables. One such specific method is the multi-criterion decision-making (MCDM) which is a 'process to assist organisations [and individuals] to evaluate the available information, weigh all of the possibilities and reduce the risk of disappointment after a decision is made' (Salvia *et al.*, 2019). As an MCDM approach or method, the AHP, developed and popularised by Saaty (1987; 1988; 1991; 1994; 2002; 2008) helps to quantify relative priorities for any given set of alternatives using a ratio scale and everything solely based on the judgements of the decision maker (Ghazali, Rashid and Mohd Sadullah, 2017). When faced with any decision-making task, a person needs to understand what the purpose of that decision is, the problem for which the decision is to be made, any criteria or sub-criteria of the decision as well as stakeholders or groups who will be affected by the choices made (Saaty, 2008).

All these can soon become complex and difficult to deal with, and a process which formalises the thinking used in decision-making becomes needful. Such a process brings transparency into what we must do to make better decisions in all its aspects (Saaty, 2008). The AHP provides this system, helping to organise the criteria/sub-criteria (tangible and intangible) involved in decision-making in a systematic way. This provides a structured way to find solutions to the decision problem. A decision hierarchy is generated which breaks down the decision in a logical fashion from the broad perspective of the decision goal down into intermediate levels, descending gradually into smaller levels of the actual alternatives to be compared. This way, paired comparison judgements can be made between the alternatives from the smaller levels to the large (Al-Harbi, 2001) resulting in a ranking of the criteria or factors.

In this study, the AHP is adopted to help stakeholders in a retrofit project make decisions regarding the benefits that can accrue from investing in retrofitting. As mentioned in the previous chapters (2 and 3), a multitude of benefits are available to different stakeholders and for each stakeholder, different preferences exist for these benefits. In measuring and evaluating these benefits, it is important to reflect these preferences and priorities through a ranking and/or weighting methodology. The purpose is to understand which benefits or sets of benefits are important to a stakeholder's decision to invest or not. The AHP accomplishes this by basically asking, for example, an occupant or householder to choose between two benefit indicators, the one that is more important to the goal of retrofitting his/her house, and by how much. The next section further details the AHP methodology and its developments and justifies the choice of the AHP to elicit group weights/rankings for retrofit benefits. The actual tool and how it is implemented is however addressed chapters 6 & 7.

4.5.3 The AHP: Process and Justification

Retrofit investments yield multiple impacts or benefits for diverse stakeholders requiring a systematic approach to prioritise and rank these benefits. The methodology for implementing this is built on an integrated AHP-Delphi method. The AHP, arguably one of the best-known multicriteria decision aid (MCDA) approaches available is thus adopted (Tavana, Soltanifar and Santos-Arteaga, 2023). This section gives an overview of the methodology, its theoretical underpinnings and rationale for its adoption and use as the preferred technique.

> "Several MCDM methods have been developed (e.g., ELECTRE, MacBeth, SMART, PROMETHEE, UTA,… [VIKOR and TOPSIS] and all are based on four steps: problem modelling, weights valuation, weights aggregation and sensitivity analysis." (Ishizaka and Labib, 2011, p.14336).

For studies and comparisons of various MCDM methods, see (Zanakis et al., 1998; Triantaphyllou, 2000; Wallenius et al., 2008; Belton & Stewart, 2002 and Figueira, Greco, & Ehrgott, 2005). The AHP was chosen over these methods mainly because, while these methods only provide a 'final ranking of decision elements' (ordinal information), the AHP and its variants provide both ordinal information and 'final weights' for decision elements (cardinal information). This capability is crucial in group decision making processes, as it allows the aggregation of a consensus decision among group members, enhancing the robustness and accuracy of collective outcomes (Srdjevic *et al.*, 2022).

As an approach for multi-criteria decision-making, the analytical hierarchy process (AHP) offers a means of breaking down a decision problem into a hierarchy of more manageable sub-problems. Using a paired comparison approach, decision-makers compare criteria and choices in pairs. Alternatives are individually evaluated, and weights are derived for the criteria, building an overall ranking of the alternatives, and choosing the best one (Alonso & Lamata, 2006).

The four main steps involved in the AHP are.

1) Problem modelling and criteria hierarchy
2) Weight calculation (judgement scales and pairwise comparisons)
3) Weights aggregation (derivation of priorities, consistency checks, final aggregation) - (Ishizaka and Lusti, 2006)
4) The fourth step involves sensitivity analysis, but this is not discussed as it falls outside the remit of the present research.

The widespread use and popularity of the AHP methodology are linked to its unique advantages of being versatile and effective in addressing complex decision-making scenarios. Tavana, Soltanifar, and Santos-Artega (2023) summarise the advantages of the AHP (as outlined by Saaty 1980) as follows:

> "… unity in providing a model for problem-solving, analytical and systematic approach to solving complex problems, problem-solving power dealing with the interdependency of criteria, observance of hierarchical structures in decision making, measurement of intangible and qualitative cases, examination of consistency in priorities, synthesis desirability for alternatives, the trade-off in preferences, judgment, and consensus, and the possibility of improvement through repetition." (Tavana, Soltanifar and Santos-Artega, 2023 p881).

Since its introduction in the late 1970s, the AHP has seen widespread use and application across multiple disciplines and subjects, including engineering, business, health, science, education, and policy. This section only aims to outline the main developments in the methodology and versions. For a detailed review of the AHP and its applications, however, the reader is referred to the reviews of Madzik and Falat (2022) who distil the state-of-the-art of the AHP methods for the past 40 years to establish its usage and research impact in various subjects, trends in its popularity, and common topics related to the method. See also Ishizaka and Mu (2023) also describe what makes the AHP special, relevant, and resilient after over 40 years.

Beyond simplifying decision-making, the AHP methods also serves as weighting method and this is the other main reason for adopting it for this study (to help establish the weightings for the wider retrofit benefits among the different stakeholders. As a weighting method, it has been used together with other methods such as COPRAS, ARAS, CMBA, ELECTRE, DEA, including GIS, to improve the performance of decision making (Tavana, Soltanifar and Santos-Artega, 2023).

Following the original AHP methodology outline by (Saaty, 1977, 1980), several variations, modifications and extensions have been proposed to deal with specific issues with the methodology (e.g. *revised AHP* – (Triantaphyllou and Mann, 1994); *modified-AHP* – (Nefeslioglu *et al.*, 2013); *AHP with OWA* – (Yager and Kelman, 1999); *SMAA-AHP* - (Durbach, Lahdelma and Salminen, 2014)) , and it is not possible to discuss all the individual variations as this falls outside the scope of this dissertation. However, to support the methodological choices of this thesis and establish its rigour, we will review only the major developments.

Generally, these modifications or variations address challenges with group decision making dynamics, dealing with uncertainty or ambiguity and reducing the cognitive burden of the AHP process on decision makers. The initial set of variations dealt with incorporating uncertainty and imprecision in decision judgements (e.g. imprecise data) and have led to what is now known as Fuzzy AHP (Van Laarhoven and Pedryczt, 1983) and reported to be the second most widely used technique (in a stand-alone mode) after the original AHP (Mardani, Jusoh and Zavadskas, 2015; Kubler *et al.*, 2016). However, the complexity of managing fuzzy numbers and the requirement of more sophisticated calculations are major drawbacks to its adoption in this study, especially in the context of social housing retrofit stakeholders.

Another group of variations that emerged in the 1990s to early 2000s are the interval AHP (Sugihara Kazutomiand Maeda, 1999) and the AHP which is strictly an extension of the AHP developed by (Saaty, 1996, 2001) to address criteria dependency – situations when alternatives and criteria in a decision-making process depend on each other. Interval AHP on the other hand introduces flexibility by enabling the use of interval judgement scales in place of precise comparisons to accommodate the imprecision in a decision makers evaluation of alternatives or criteria. Interval AHP is also fraught with the same problems of Fuzzy AHP while ANP is does not fit the context of the current decision-making problem.

In its original form, however, the AHP was designed to deal with a single decision maker, without the necessary support for complex group decision-making that involved multiple stakeholders. In 1989, following the need for collaborative decision-making tools, (Saaty, 1989) introduced a variant of AHP applicable in a group setting – Group AHP. This was in response to the trend of political and technical complexities of organisation decisions which require group meetings to solve, which trend is very much prevalent today than ever. Group AHP mimics the democratic and inclusive decision-making process necessary in today's organisation settings and allows diverse viewpoints to be synthesised thus enhancing the robustness and acceptance of the resulting decisions arrived at using the process (Huang, Liao and Lin, 2009; Srdjevic *et al.*, 2013). Group AHP is considered more applicable and relevant, given the public policy implications of retrofit decisions involving multiple stakeholders and requiring a harmonisation of viewpoints. The criticality of maintaining this group dynamic in the decision process is further underscored by the recommendations to use a modified Delphi approach in the integrated AHP-Delphi proposed for the prioritisation of benefits weights in this thesis (more on this in section 7.2.3).

Table 4-4 Recent developments in the AHP methodology

Timeline	Major Developments
1970s	**Original AHP** developed by Thomas L. Saaty as the fundamental framework for decision-making.
1980s	**Fuzzy AHP:** this era saw the rapid emergence and development of fuzzy set theory based AHP variants that integrated fuzzy set theory to solve uncertainties in decision-making. 109 articles related to AHP registered in Scopus's citation database. **Group AHP** became the most popular variant of AHP in response to the increasing need for collaborative decisions and the version adopted for this study.
1990s to 2000s	**Interval AHP** gained prominence in the late 1990s to early 2000s. This variant used interval scales to address the uncertainties in pairwise comparisons. **Analytical Network Process (ANP)** also developed around this time by Thomas L. Saaty strictly not a variant of AHP, but rather an extension to it. ANP allowed interdependencies and feedback between decision-makers. Scopus bibliographic and citation database also records about 604 articles on AHP and its applications
2010s	**Best-Worst Method (BWM)** was developed around 2015 to simplify the pairwise comparisons

[a] *Voting AHP developed by Liu and Hai (2005)*

Sources: compiled from (Emrouznejad and Marra, 2017; Madzík and Falát, 2022; Tavana, Soltanifar and Santos-Arteaga, 2023)

4.6 Qualitative Inquiry

4.6.1 Expert (Practitioner) Interviews

Interviews allow the researcher to generate open-ended forms of data containing the shared views, ideas, and opinions of participants unconstrained by predetermined scales or instruments (Creswell and Creswell, 2018), although interviews can be structured (and unstructured). Structured interviews entail pre-established questions created by the researcher that remain unchanged throughout the interview and for all other participants in the study. When during the fieldwork, the pre-established questions are amended or replaced by emerging questions, it is called a semi-structured interview. There are unstructured interviews where the researcher develops his questions on the go during interviewing and is only guided by the aims of his research.

Given the qualitative nature of the study and the research approach chosen, the interview technique was deemed appropriate for data collection, and these comprised both expert and focus group interviews. This method allows for a thorough understanding of people's experiences, perspectives, and impressions (Proverbs and Gameson 2008: 75 as cited in Knight and Ruddock, 2008). The interview allows participants to express their opinions in their own words and authentically convey their feelings about the subject (compared to online surveys or closed-ended questions). The use of open-ended questions encourages participants to contribute insights regarding identified theoretical factors, potentially introducing new ideas. As a result, interviews with open-ended questions to capture a deeper understanding of the topic constitute the core of this study (Table 4-5 below provides an overview of the empirical data collected for this study). Four separate empirical data collection exercises were conducted involving one focus group interview.

However, completing the data collection proved difficult and at some point, impossible. The study's planned data collection period coincided with the global Covid-19 pandemic with enforced lockdowns and restrictions on physical interactions. To circumvent this challenge, the study resorted to virtual or online interviews using a combination of Microsoft Teams and Zoom to facilitate the interactions.

Table 4-5 Overview of empirical data collected for this study.

Data Collected	Purpose	Sample Size (participants)	Chapter covered	Responds to Objective
Semi-structured interviews	To understand the on-the-ground challenges in retrofit evaluation	11	5	2
Semi-structured interviews	To review the multi-stakeholder matrix retrofit benefits framework	7	5	3
Semi-structured interviews	To review the scoring criteria and thresholds of the Retrofit Benefits Scoring tool	5	6	5
Focus Group Interview	To evaluate the final Retrofit Scoring Toolkit	1 (4 participants)	8	6
Total Interviews		**27** (including the 4 focus group participants)		

Elite interviews can present some challenges, such as participant accessibility, time constraints, and willingness to share information. Given their roles or positions of authority, interviewees may find it difficult to divulge extensive information (Milivojević, 2020). Bogner, Littig and Menz, 2009b), on the other hand, identified several reasons why experts may choose to share their knowledge with others, including a genuine interest in the research, a willingness to assist, and a shared industry background. To address these issues, interviewees were given the freedom to choose a suitable time for the interview, and consent forms outlining study details, data confidentiality, and ethical considerations were provided. Another potential issue is interviewees' subjective interpretation of questions, which is inherent in qualitative research in the social sciences (Jennifer. Brown, 2018). To mitigate this disadvantage, a meticulous and structured approach to data collection and analysis was used.

4.6.1.1 Interview design.

This study adopted a mixture of semi-structured and focus group interviews to understand the views and opinions of experts. In this study, these experts or participants are social housing landlords and industry practitioners who have directly been involved with housing retrofit works. These may include Asset Managers, Capital Works Officers, Property

Managers, and Heads of Sustainability among others. These interviews augmented and contextualised the findings of the literature review on retrofit benefit evaluation methodologies and helped to understand the challenges and needs of participants in assessing the impacts of retrofit projects.

The interview was designed in line with the aims of the study and covered questions on the practices of organisations in evaluating retrofit project benefits in terms of the methods, approaches, frameworks, systems, or tools employed, as well as how to understand emerging issues and/or challenges in using such approaches and establish and confirm the need for a comprehensive framework approach to retrofit benefit assessment. The study adopted a semi-structured form of interviewing over a fully structured form because it was deemed appropriate for answering pre-investigated topics (King, Horrocks and Brooks, 2019) as well as when dealing with expert participants (Bogner, Littig and Menz, 2009a). Semi-structured interviews introduce flexibility in the questions, which allows the generation of new ideas and eliminates the need to clarify questions with experts. Besides, a structured approach is not recommended for studies investigating the perceptions and beliefs of participants.

Given the diverse backgrounds of the intended participants, the interview questions were prepared in advance and designed such that they could fit the multiple contexts of the various participants to ensure ease of comparing answers across participants. In other words, the questions were capable of being modified to suit the circumstances of a particular respondent, while allowing for some questions to be entirely skipped or omitted (where necessary). This intentional design was to help create a smooth flow in the conversation with interviewees and enable them to respond more freely without coercion and maintain a level of respect for their opinions, in fulfilment of ethical considerations in interview research. Additionally, the open-ended nature of the questions allowed for a more comprehensive understanding of the interviewee's perspective and experiences, providing valuable and nuanced insights for the study. Even though the interviews were not fully structured, they were neither unstructured nor incomplete. This was to ensure that they were not unwieldy, and losing focus on the objectives, which could result in a loss of data consistency, and complicate the analysis process.

The questions were also designed to follow the issues emerging from the literature review as well as the first objective of the research. An initial draft of questions (Appendix A3.1) was developed with background questions on the area of expertise of interviewees, years of experience, and specific roles in retrofit work. The questions addressed areas such as the benefits considered for retrofit projects, the stakeholders, the current trends in retrofit evaluation, the evaluation process, who is responsible when it is done, and the challenges. There were also questions on the need for a measurement framework and the key characteristics it should have. Following a pilot run of this guide and consultations with the supervisory team, a second draft was developed (presented in Appendix A3.2), which was subsequently used in the final interviews. The second draft maintained the background questions at the top and added a brief overview of the guide and research project, while the questions placed more emphasis on the evaluation process and the challenges encountered.

4.6.1.2 Participants and Sampling

Participants for this study were sampled purposively. Interviewing experts requires that people with the right knowledge and experience are recruited, to ensure the credibility of the answers generated. These experts are expected to share their individual experiences and reflect on their practice. Table 4.4 below indicates the professional roles of the interview participants and their experience demonstrating why their answers are useful in addressing this study's objectives.

The experts were selected following guidelines by Okoli & Pawlowski (2004). A Knowledge Resource Nomination Worksheet (KRNW) was developed (see Table 4-3 below) and populated with a list of experts collated mainly from literature reviews, personal contacts, and networks as well as recommendations from the supervisory team. The process provided details of individual authors and their organisations, such as the UK Green Building Council, C40 Cities and Nottingham Energy Partnerships. A final list of about 25 potential experts was generated based on their familiarity with retrofit projects and benefits measurements.

Following the identification of experts, the actual number of experts to include in the study/interview had to be determined. Sample size in qualitative research is often informed by three strategies: specific objectives and design of the research, literature recommendations and saturation point. All three approaches informed the selection of the sample size for this study. Several studies have recommended different sample size selection guidelines for qualitative interviews and more specifically expert interviews.

Creswell and Poth (2017) outline a range of sample sizes used for various qualitative research from a low of one or two individuals (in narrative research) to a high of 325 in phenomenology studies (Polkinghorne, 1989). Others have suggested and used 3 to 10 participants, while some also recommend 20 to 30 individuals. Patton (2015) observed that most qualitative dissertations used between 20 and 30 participant interviews. Following the literature, this study targeted to collect 10 to 15 interview responses (the main empirical analysis discussed in Chapter 5). A range was chosen instead of a specific number to introduce flexibility and to also recognise the awareness that sample sizes can change throughout the research phase.

Table 4-6 Expert Knowledge Resource Nomination Worksheet (KRNW)

Disciplines or skills	Industry /Organisation	Related Literature
• Academic − Published literature. • Government Official − Local Government Councils • NGOs and Charities − Organisations lists	• Housing Associations • Construction Industry Groups − Construction Excellence − The Housing Forum − National Housing Federation − Regulator of Social Housing − Social Housing UK − Construction Industrial Training Board • Retrofit Academy • Retrofit Works	• Academic: • Conferences, Workshops & Seminars. • Journals of, − Energy and Buildings − Applied Energy − Energy Policy − Energy Economics − Energy Efficiency − Economics of Energy & Environmental Policy • Industry reports and publications − Department for Business, Energy & Industrial Strategy

Another equally viable approach to sample size selection used in this study is the saturation point. Saturation refers to a state in qualitative data collection when "gathering fresh data" or interviews "no longer sparks new insights" or reveal any new themes or categories, which signals the need to stop collecting more data (Creswell, 2014). Given the diverse nature of survey participants, saturation appeared to differ for different exerts. Averagely, though, saturation for this study occurred around the seventh interview and the subsequent interviews were used to further explore the themes or categories that had emerged.

This study conducted 11 interviews[2] with various experts and professionals in the home retrofit industry in the UK for the main empirical round of data collection. All experts, except one, are UK-based. All the interviews were approximately between 40 minutes to 1 hour and 20 minutes providing rich data for this analysis. The inclusion of an international participant enabled a comparison of experiences in the UK and internationally.

Table 4-7 Interview participants for the empirical review of the state-of-the-art of retrofit evaluation (chapter 5).

Interview code	Professional role	Organisation Type	Sector
1923	Director of Property	Housing Association	Public
1924	Sustainability Manager	Housing Association	Public
1925	Domestic Energy Assessor	Energy Assessor	Private
1926	Research Fellow/ Asst. Prof.	Academic/ Research	Education
1927	Retrofit Coordinator	Consultancy/ Supply Chain	Private
1928	Senior Project Manager (Retrofits)	Consultancy/ Supply Chain	Private
1929	Director	Consultancy/ Supply Chain	Private
1930	Technical Consultant	Consultancy/ Supply Chain	Private
1931	Product Manager	Housing Association	Private
1932	Lecturer/Researcher	Academic/ Research	Education
1933	Head of Sustainability & Carbon Reduction	Housing Association	Public

In addition to the main round of interviews to establish the empirical knowledge on the benefits measurement and retrofit project evaluation (discussed in Chapter 5), three other rounds of interviews were conducted as part of this study. The first one was to solicit feedback on the conceptual benefits framework (see Chapter 5, section 5.2 for more details); the second one was to review the final list of scoring thresholds and criteria for the benefits scoring tool (discussed in Chapter 6, section 6.4), while the final one is the individual and focus group interview conducted as part of the evaluation of the final retrofit benefits scoring tool (discussed in chapter 8).

[2] These are only the interviews about the challenges of the retrofit benefits measurement and project evaluation in general, discussed in chapter 5. There are two further rounds of expert interviews conducted as part of this study. One of them was to solicit feedback on the conceptual benefits framework (see chapter 5, section 5.2.1 for more details); while the second one was to review the final list of scoring thresholds and criteria for the benefits scoring tool (discussed in chapter 6, section 6.4.1).

In all these interviews, the KRNW described above were followed and all experts identified using this process were qualified to participate in all interviews. However, because participants should not have been involved in earlier phases of a study (Bryman, 2012), when sending interview invitations or questionnaire forms for data collection, each round of interviews excluded individuals who had already participated in a previous round of interviews. The exception was with the final evaluation focus group interview where one participant had been part of the previous interviews, and this was purposely done to introduce an element of 'expert validation' (Lincoln and Guba, 1985) to ensure that the researcher's understanding aligns with the participants' perspectives and expert knowledge.

4.6.1.3 Interview data collection; engaging participants and limitations.

Nearly all the data collection for the study was conducted virtually. Limitations of traditional face-to-face interviews together with the COVID-19 pandemic informed this approach. Face-to-face interviews are time-consuming and expensive to conduct (Milivojević, 2020). Besides, according to Cresswell and Pott (2017), web-based qualitative data collection saves time and money on travel and transcribing. It also gives participants time and space to ponder and respond to information requests. Thus, they can deepen reflection on the topics and establish a safe, comfortable space for delicate discussions (p. 227). James and Busher (2009) also argue that participants who are hard to reach due to some practical constraints, disability, language, or communication barriers can be easily reached using online data collection (as cited in Cresswell & Pott, 2017).

However, online qualitative data collection comes with its challenges and introduces new requirements for both interview participants and interviewers. First, the researcher needs to acquire or improve skills in online interviewing, including engagement, interactivity, and online etiquette. It also includes being able to troubleshoot any technical glitches (hardware and software) that may affect the success of or frustrate the interviews that arise. Additionally, skills in handling audio data and transcribing and interpreting textual data need to be strengthened.

Another important requirement for interviewers and participants is the need to have technical proficiency in using online communication tools and platforms as well as access to a stable internet connection. There is also the need for a quiet environment to interview to minimise or eliminate noise in audio recordings of the interview, which affects data quality or even causes data loss. Protecting interview participants' privacy and the confidentiality of their information is yet another crucial requirement in online data collection. To achieve this, very clear guidelines and data management protocols were established that address issues such as data storage, sharing, and disposal to protect participants' sensitive information.

4.6.2 Expert review/validation/consultation

A research's design, findings and outcomes need to be scrutinized for quality. The researcher needs to show that his evidence and conclusions can stand up to scrutiny and that all efforts have been made to reduce the possibility of making errors or obtaining wrong results. The researcher achieves this by assessing the reliability and validity of his research (Saunders, Lewis and Thornhill, 2016; Bell, Bryman and Harley, 2019). Validity serves to check the quality of a research's data, the results and the researcher's interpretation of the same, by asking whether the research has observed, identified, and measured what it intended to measure (Bryman and Bell, 2011). Creswell and Plano Clark (2018), identify four strategies for determining validity including 'asking others to examine the data' or outputs of the research. The others they recommend may be people external to the research (external auditors) who are called upon to review the results of the research. Reliability on the other hand deals with the repeatability of a study's findings or results and is more of a concern in quantitative research than in qualitative ones (Bryman and Bell, 2011). In other words, if other researchers followed the same process and strategy, would they achieve the same results as the current study?

This study adopts expert review combined with a focus group as a strategy to check reliability and validity. Experts reviewed and revised the retrofit benefit framework and heavily inputted into the in-exclusion of benefits and indicators in the final framework. During the evaluation of the numerical scoring criteria, experts were also involved in revising the scales through a 'yes' and 'no' closed-ended questionnaire survey.

4.6.3 Focus Group Interviews/Discussion

Focus groups are very useful for validating and refining purposes especially following individual interviews (Creswell and Poth, 2017). Focus groups also offer a different set of benefits, such as the generation of collective insights that cannot be easily obtained through one-on-one interviews. They are particularly useful for exploring group norms, uncovering multiple perspectives, and understanding complex behaviours and motivations (Krueger and Casey, 2015). Focus groups are employed in the final evaluation of the retrofit benefits scoring tool discussed later in Chapter 8. During the review of the multi-stakeholder benefits framework in Chapter, 3, two of the interviews took the form of focus group discussions as the participants were in both cases from the same organisation.

4.6.4 Qualitative Data Analysis

4.6.4.1 Thematic Analysis

Given the complexity and multifaceted nature of evaluating the benefits of retrofit projects in the social housing sector in the UK, qualitative data analysis is essential for capturing the nuanced perspectives of stakeholders. Thematic Analysis, a widely recognized qualitative research method, is particularly well-suited for this task (Braun & Clarke, 2006) and therefore chosen for the analysis of the qualitative data for its flexibility and capacity to provide a rich, yet complex, account of the data (Braun & Clarke, 2006). The adaptable nature of the thematic analysis is compatible with the multi-dimensional impacts and diverse stakeholders that characterize the UK's social housing retrofit projects (Gues et al., 2012).

Thematic Analysis follows a structured series of steps including data familiarization, initial coding, identifying themes, reviewing themes, and defining and naming themes (Braun & Clarke, 2006). This iterative approach ensures that themes are derived from the data in a way that aligns with the research objectives, contributing to the identification of overarching and subsidiary themes (Fereday & Muir-Cochrane, 2006) and the development of a robust framework (Joffe, 2012) that balances academic rigour with practical applicability (King, 2004) for evaluating retrofit projects. As a qualitative analysis technique, it is however without limitations. The key is the potential for researcher subjectivity to influence results and thus miss important perspectives (Braun and Clarke, 2012). Moreover, the validity of the themes generated may require empirical validation for broader application in the UK’s social housing sector.

Notwithstanding, it remains a robust method for understanding the intricate context of social housing retrofit projects. Through this method, this research aims to identify, explore, and rank themes essential for a comprehensive evaluative framework (Patton, no date). According to Braun and Clarke (2006), thematic analysis is performed through a systematic process that generally includes six phases: familiarization with data, generating initial codes, searching for themes, reviewing themes, defining, and naming themes, and producing the report. The first step involves immersing oneself in the data to understand its depth and breadth. This is followed by the coding phase, where significant patterns in the data are marked. Initial themes are then generated based on these codes. These themes undergo several rounds of review and refinement before they are finalized, defined, and named. The last phase involves tying everything together in a coherent and logical report.

4.6.4.2 Transcription of the Expert and Focus Group Interview Data

In analysing qualitative research data, especially audio-taped interviews, the researcher is typically faced with two choices either supporting the analysis with their field notes derived from the interview (and supplemented with a review of the audiotapes or relying entirely on the transcripts of the interview (McLellan, MaCqueen and Neidig, 2003). The analysis of the qualitative data from the expert interviews was based on the transcripts from the audio-taped interviews, while fully recognising the inherent limitations of transcripts as captured aptly by (Emerson, Fretz and Shaw, 1995) that 'a transcript cannot ever produce a verbatim record of discourse, given the ongoing interpretive and analytical decisions that are made" (p 9). Elements of the interview such as tone of voice, facial expressions and other non-verbal forms of expression are automatically lost in transcripts.

Other researchers have argued for the need to include contextual information such as silence, pauses and speech fillers to adequately reflect the interview itself. For this study however, it is determined that while what is not said in an interview is equally or sometimes more important than what is said, the omission of such contextual information will not affect the quality of the transcribed data. This is also partly because most of the interviews were concerned with the professional opinions of experts. However, effort was put into making sure that such contextual information was not deliberately ignored or removed during the transcription.

To further ensure the quality of the textual data (which is as good as the transcription process) a systematic process was followed in transcribing interview audiotapes. First, all texts selected for transcriptions were considered based on their analytical contribution to the overall study. In the first instance, all audiotapes were saved to a password-protected

Microsoft OneDrive account of the researcher. Following this, the audiotape was replayed to ensure the quality was good enough for automated transcription. After this, Microsoft Office 365's online transcription feature which is embedded in the Office Word 365 online version of their software was used to automatically transcribe each audio file within a few hours after the interview took place. The focus group for the evaluation in Chapter 8 was transcribed directly from within the Microsoft Teams app used for the interview call. Thus, there was no audio/video recording of the interview, nonetheless, participants were informed, and their consent was obtained before initiating the automatic transcription of the interview.

The raw transcript is then saved with a unique interviewee code. In some instances, a particular interview had multiple audio files; these were individually transcribed and then the transcripts were combined into a single Word document (with clear transition points indicated to identify the various parts).

4.6.4.3 Familiarisation, Coding and Themes Identification

The transcripts from the various interviews were all read thoroughly multiple times to ensure familiarity with the content and nuances as well as a comprehensive understanding of the content. Notes were made of potential developing codes for the first read of the transcripts, after which an initial coding structure was developed which was then applied subsequently to complete the first coding to identify significant patterns in the data. Additional codes were identified and added to this list to further expand on them while organising them into some form of loose structure towards identifying themes. Coding was done both manually for one transcript initially and then transferred to NVivo 12 to expand on the codes and organise the structure.

Following the initial coding, some themes began to emerge. The initial coding structure developed was reviewed and revised using an iterative process, which merged similar codes and/or nested some codes to establish linkages between them and identify potential themes. These potential themes were also revised which involved, revisiting the coded data and the proposed themes to ensure they encapsulate the dataset adequately. Where needed, themes were refined, split, combined, or discarded (Braun and Clarke, 2006). The final set of themes was clearly defined, with subthemes. At this stage, it was important to ensure that each theme accurately reflects the corresponding dataset, or insights being captured. The final themes, their descriptions, and subthemes (codes) can be seen in Chapter 5, section 5.3.2.

4.6.5 Ethical considerations

4.6.5.1 Ethical Approval

This study has been conducted in full compliance with ethical standards and received ethical clearance from the Schools of Art, Architecture, Design and Humanities Committee (AADH REC), the ethics body responsible for the School of Architecture, Design and Built Environment on January 1, 2021.

4.6.5.2 Informed Consent

All experts participating in this study were provided with an informed consent form which outlined the scope, objectives, and confidentiality measures associated with the research. This informed consent ensured that all participants were fully aware of the extent of their involvement and their rights, including the right to withdraw from the study at any stage.

4.6.5.3 Confidentiality and Data Security

To protect the privacy and intellectual property of the experts involved, all interviews were conducted confidentially. The data collected during these interviews have been securely stored and will only be used for the purposes outlined in the consent form.

4.6.5.4 Participant Withdrawal

Participants were explicitly told they had the freedom to withdraw from the study at any point should they choose to, without facing any repercussions. Contact details for the researcher were provided to facilitate communication of any concerns or questions during or after the research process.

4.6.5.5 Professional Integrity

Given the specialized knowledge of the expert participants, the researcher ensured that the interviews were conducted in a manner that respected their expertise and professional standing. All questions were carefully designed to be respectful of their professional and ethical boundaries. By adhering to these ethical guidelines, this study aims not only to uphold the highest standards of academic integrity but also to respect the professional and personal integrity of all participants involved.

4.7 The Research Process

A three-stage iterative research process, (made up of 7 components) was followed in completing this study. Figure 4-2 depicts this process. The first and second stages are mostly theoretical/conceptual while the last stage is empirical.

4.7.1 Conceptual Stage: Literature reviews and synthesis

Step one employed a combination of scoping and systematic reviews, and documentary/content analysis techniques to critically examine academic and industry literature. The reviews borrowed from (Maxwel, 2013). The outcome of this stage is the detailed current understanding of wider benefits, their key indicators, criteria and metrics and tools/approaches of measurements which are covered in Chapters 2 and 3.

4.7.2 Development and review of framework and tools

Stage two involved the design of the retrofit benefits measurement framework from the synthesis of literature from stage one combined with empirical data collection and analysis on indicators, metrics, and their weightings from expert perspectives. Data collection comprised one-on-one semi-structured interviews with practitioners from social housing providers and academics to understand the current challenges of retrofit evaluation. Interviews followed an open-ended discussion framework with participants sampled through non-probabilistic purposive techniques given the uniqueness of the targeted respondents (Yin, 2018). The resulting data was thematically analysed using NVivo. Criteria of selection included participants in retrofit programmes. A benefit weighting for different criteria is also established using a combination of the Delphi and Analytic Hierarchy Process (AHP) techniques (Kian Manesh Rad, Sun and Bosché, 2017a).

4.7.3 Reviews and Evaluations

The last stage involved the empirical review of the developed framework and tools against their intended delivery/expectations through stakeholder and expert reviews to gain some insights for improvements. The finalised framework & tools were also evaluated through a focus group interview to understand their empirical practicality, robustness, and contextual nuances. This stage also provides a discussion and interpretation of all the key findings from the study including conclusions and recommendations for future research and potential policy implications.

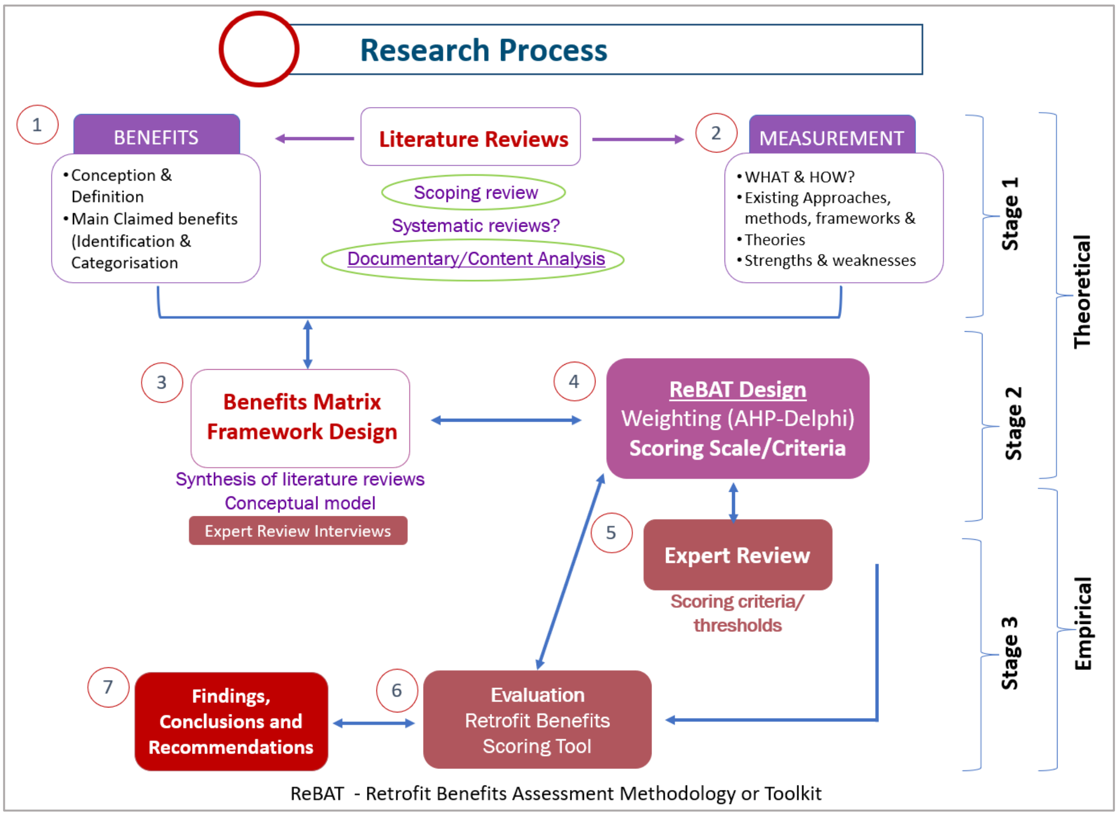

Figure 4-1 Overview of the research process.

4.8 Chapter Summary

In undertaking this research, a thoughtfully planned and integrated methodological design was adopted to ensure robust and comprehensive findings. The chosen methodological spectrum for this study spans both positivist and interpretivist philosophies, drawing from their strengths to provide a nuanced understanding of the research questions. Philosophically, the research is anchored in both positivism and interpretivism. Positivism, with its objective and empirical stance, facilitates the collection of quantifiable data and ensures the reliability of findings. On the other hand, interpretivism, with its subjective lens, aids in understanding the lived experiences, perceptions, and interpretations of the study participants, especially during interviews and focus groups.

The research pivots on a pragmatic approach, which allows for the integration of both quantitative and qualitative methods. This pluralistic stance makes it possible to explore phenomena from multiple dimensions, ensuring a richer and more holistic understanding. By integrating both inductive and deductive processes, the research endeavours to generate new insights while also testing existing hypotheses.

A mixed-method strategy was adopted, encompassing both qualitative and quantitative techniques. Surveys and interviews were employed to gather in-depth insights and contextual data. The Analytical Hierarchy Process (AHP) and the Delphi Technique, both robust and well-regarded methods, were used particularly in the development of the weighting tool. Data collected were rigorously analysed using thematic analysis methods, with the assistance of software tools like NVivo and MaxQDA. These tools allowed for systematic coding, categorization, and identification of emergent patterns and themes, ensuring the depth and rigour of analysis. In essence, this research design, characterized by its pluralistic stance, ensures a comprehensive exploration of the topic, drawing from the strengths of both quantitative and qualitative traditions.

Chapter 5 : EMPIRICAL ANALYSIS: REVIEW OF MEASUREMENT FRAMEWORK & HOME RETROFIT EVALUATION EXPERT INTERVIEWS.

5.1 Introduction

This chapter presents the empirical analysis of data collected for this study. As discussed in the previous chapter on methodology, the empirical data collection strategy has been predominantly structured interviews with experts or practitioners involved in home retrofitting. Following the literature review analysis of retrofits and their evaluation methods and the conceptual multi-stakeholder framework, the study then progressed to an empirical data collection to triangulate the findings of the literature review and solicit feedback on the framework. The chapter therefore opens with the analysis of the expert practitioner interviews on the retrofit framework and the resulting refined framework. It then proceeds to present an analysis of the interviews on the state-of-the-art retrofit evaluation with specific emphasis on the challenges. The results of this empirical analysis together with the two literature reviews then inform the development of the retrofit benefits measurement toolkits discussed in the next two chapters (6 & 7).

5.2 Expert review and refinement of the Benefits Framework

The conceptual multi-stakeholder matrix framework of retrofit benefits developed from Chapter 3 (section 3.7) was subjected to a review by experts and practitioners to further refine it to reflect industry perspectives. The process and outcomes of this engagement are discussed in the proceeding sections.

5.2.1 Selecting the experts

The experts were selected following guidelines set out in section chapter 4, section 4.6.1.2). The process provided details of individual authors and their organisations, such as the UKGBC, C40 Cities and Nottingham Energy Partnerships (NEP). A final list of about 40 potential experts was generated based on their familiarity with retrofit projects and benefits measurements. An initial list of 12 experts was generated and used as the sample for this review. All 12 were contacted via email invitations (a sample of the invitation is provided in Appendix A3.3. Out of the 12, only 7 participated in the framework review (see Table 5-1 below). They included 1 academic; 3 supply chain partners involved in the delivery of retrofit projects and 3 professional or research consultants with high-level familiarity and knowledge about retrofit projects in the social housing sector in the UK.

Table 5-1 Information on participants in the expert review of retrofit benefits framework.

Industry	*No of Respondents*	*Experience (years)*	*No of Respondents*
Academic	1	Under 3	1
Supply Chain Partners	3	5 - 10	3
Professional Research/ Consultancy	3	10 – 15	1
		15+	2
TOTAL	7		7

5.2.2 Design of the questionnaire

The list of benefits, their indicators and metrics/units of measurement were put into a spreadsheet questionnaire format. This was shared with experts to review from an expert perspective. The questionnaire had three sheets each containing the relevant benefits, indicators, and metrics for social, economic, and environmental. Experts were asked to indicate the relevance/appropriateness of the benefits, indicators, and metrics by answering *Yes/No*. Suggestions and changes were also requested where they did not agree. Lastly, experts were also asked to comment on the attribution of benefits to stakeholders. The spreadsheet questionnaire was shared with the expert in advance before the interview. The interview either discussed an expert's feedback which was received in advance, or their feedback was taken as part of the interview.

5.2.3 Results analysis and refinement of the final framework

The assessments from the five reviewers have been analysed and used to refine the framework. There was general agreement among the experts in terms of the relevance of benefits/indicators for most of the benefits. Some mergers and re-categorisations were also recommended. The following summarises the suggestions received which formed the basis for refining the framework.

5.2.3.1 Social Benefits

1. *"Health and wellbeing"*: The benefit had 7 indicators covering personal health, morbidity and physiological effects, asthma, winter deaths, healthcare cost etc. with most of them having DALYs (Disability-Adjusted Life Years) or YOLLs (Years of Life Lost) as metrics. The suggestions were in two parts – the metrics used and the sub-indicators themselves. One expert recommended avoiding DALYs as metrics since they're not always clear to individuals. Percentage (%) reduced risk (e.g., % improved mental

health; % reduction in asthma cases, % increase in life expectancy) was suggested as better metrics that will be more sensitive to individuals who are the targets of these measures.

Please indicate your review and agreement on the benefits, indicators, description, and metrics by clicking on either **Yes** or **No**. If your answer is No, please present your suggestions in the comment box.

Also indicate your review and agreement on the relevant stakeholder to whom the benefit accrue by **putting an "X"** in the corresponding box for the stakeholder.

If you agree with the already assigned stakeholder, then you don't need to do anything.

BENEFITS-INDICATORS							STAKEHOLDERS					
Economic Benefits		Indicators/Criteria	Description	Metrics/Units of Measure	RELEVANT/ APPROPRIATE?	COMMENTS	Occupant	Landlord	SP Partner	Local Authority	Society	COMMENTS
Econ. 1	Energy Costs savings	Cost savings or extra warmth from retrofitting	Reduced energy costs/expenditure due to decreased energy demand (Financial value of retrofitting)	£	☐ Yes ☐ No		X	X		X		
Econ. 2	Maintenance & repairs savings	Savings in repair and maintenance cost	Avoided or reduced costs of equipment maintenance and repair (from frequent breakdowns). Building life-cycle-costs reduction.	£	☐ Yes ☐ No		X	X	X	x		
Econ. 3	Fiscal Benefits (Tax/Revenue/GDP/ Growth)	Tax savings or Fiscal benefits	Tax and fiscal benefits accruing to homes, or firms or landlords or housing associations for investments in retrofit improvements. Efficiency investments also lead to increased GDP/growth in economy. Also includes avoided or decreased	million or billion of £	☐ Yes ☐ No			X	X	X		
		Increased government revenue/GDP/Growth		million or billion of £	☐ Yes ☐ No					X		
		Reduced subsidy payments		million or billion of £	☐ Yes ☐ No					X		
Econ. 4	Improved Tenancy Management (Positive Tenant experiences)	Reduction in voids and vacancies	Avoided costs arising from dealing with regular tenant complaints and transfers as well as void periods - loss of rental income.	Nr. of voids avoided or rental income/revenue loss/gain from voids	☐ Yes ☐ No			X				
		Reduced Complaints		Nr. of complaints before/after.	☐ Yes ☐ No			X				
		Reduction in tenant transfers		Nr. of tenant transfer requests before/after	☐ Yes ☐ No			X				
Econ. 5	Property Value Improvement	Increased rental or market value	Observed increase in the rental/market value/sale price or transaction price of a house/rental in response to efficiency	£ Rental premium or market value due to retrofit	☐ Yes ☐ No		X	X				
Econ. 6	Improved Productivity	Total value of improvement in productivity of business	Labour productivity	mn workdays	☐ Yes ☐ No		X	X	X	X	X	
			GDP/income/profit generated as a consequence of new business models, opportunities, products, services, innovation and job creation	million or billion of £	☐ Yes ☐ No			X	X	X	X	

Table 5-2 Snapshot of the framework review questionnaire for the Environmental benefit category.

Two experts also thought that figures for morbidity, life years lost to PM2.5, and excess winter deaths are typically very low and therefore underwhelming when reported. Besides, there is the problem of attribution to deal with. The revised framework omitted the two sub-indicators.

Also, healthcare cost savings from reduced hospitalisations and visits are considered very relevant to England, given the state-sponsored healthcare system. It has been moved to the economic benefits category where it is properly aligned.

2. "*Tenant comfort and satisfaction*": The indicators here included thermal comfort, acoustic comfort, and indoor air quality as well as aesthetics, quality, and safety/security of the home. Following the suggestion of one expert and further literature review, these were merged into a new benefit 'indoor environment quality' (IEQ). Useful building space was omitted – the literature agrees with one expert's suggestion that retrofits typically

'reduce the useful area in a home with thickened walls from insulation (Malka et al., 2022; Dong et al., 2023). Any space gains from heating system change are assumed to be offset by such losses from insulation.

Related to this is the quality of the retrofitted space, which one expert predicts is shifting more towards the 'flexibility' of retrofitted space.

3. "*Tenant awareness and agency*" around energy efficiency and climate change in general also had mixed reactions. Retrofitting does not correlate directly with occupant behaviour unless catalysed by some additional intervention and/or guidance. Even in such instances, any observed behaviour changes are temporal and short-lived – 'there is no long-term effect'.
4. "*Jobs/ employment created*": This has moved now to the economic benefits category as this is fundamentally an economic metric.

5.2.3.2 Environmental Benefits

2. "*Building Physics*": This has been replaced by a broader "Indoor Environment Quality" benefit with specific indicators for indoor air quality, acoustic/noise comfort etc. Some of these extra indicators are pulled from the "Tenant Satisfaction & Comfort" benefits in the social benefits category. In addition, an occupant survey has been adopted to collect the data for these indicators (in the basic evaluation/monitoring stage) and reserve physical measurements which is more accurate (but often very expensive to implement) for the intermediate/advanced evaluation. Besides such physical measurements will still require some qualitative judgements from occupants to give context to their analysis and interpretation.
3. "*Building quality/home upgrade*": This benefit has been modified to read "Improved home or building aesthetics" to include such issues as improved quality, look and feel of the home, security/safety of home as well as any addition of usable areas or spaces in the building.
4. "*Air pollution reduction" (local air quality)*: Two experts thought it wasn't relevant for retrofit. It is also "*hard to bring it down to a single building if energy is generated elsewhere*". One expert while agreeing it is relevant highlighted it is "*super difficult to measure*". Given the foregoing, this indicator has been excluded from the framework due to difficulty in measuring and attributing to retrofit projects, especially at the project scale and for social housing retrofits.

5. "*Waste reduction*": Only two experts commented. Both suggested removing it since it's not a direct result of retrofitting, but rather "a consequence of clean construction" and that it also applies to all construction projects and not just retrofits. The indicator has thus been excluded from the framework.
6. "*Local energy supply chain development (Renewable energy production)*": One expert while agreeing it is a relevant benefit/ indicator, commented that this is "not depending on retrofit itself, but more depending on a separate choice for doing clean building". However, many recent retrofit works are increasingly adding renewable generation as a standard measure to achieving net zero. Therefore, it has been maintained in the framework, but renamed as "Local energy supply improvement".
7. "*Carbon savings*": One expert suggested rephrasing the description to emissions saved from energy generation and use. The question of whether to consider embodied carbon also came up. In principle and practice, it should be included, and some studies have investigated this generally (Chitnis *et al.*, 2012; Wuni, Shen and Osei-Kyei, 2019) and in the case of social housing retrofits (Makantasi and Mavrogianni, 2016). Consequently, the current framework aggregates operational and embodied carbon. Where a project estimates and includes embodied carbon, it must indicate this. Where no indication is given, the default assumption will be emissions saved from operational energy use.
8. Some of the benefits and indicators that are deemed too high level and thus not immediately relevant for local level retrofit projects are not included in the final retrofit assessment tool, even though they remain in the framework. They include "Resilience or adaptation of retrofitted homes to climate change"; and "Improved environmental & resource management".

5.2.3.3 Economic Benefits

1. "*Energy costs savings*": One expert suggested the "need to specify that this potential [is] more for the occupant". No other expert shared a similar opinion, so no action was taken. Another suggestion to include the general Society as a beneficiary of this benefit was not adopted. The name was also modified to "energy bill savings".
2. "*Fiscal benefits (Tax/GDP/Revenue Growth)*": There is clear evidence (mostly from modelling studies) that increased spending in retrofit results in higher tax revenue for the government from net increases in employment and general fiscal returns (Washan,

Stenning and Goodman, 2014; Hanna, Heptonstall and Gross, 2022). However, these arguably are high-level indicators as suggested by two experts and "hard to measure and to link to a specific action", hence have been reserved for the advanced iteration of the framework and assessment tool.

3. "*Energy Security*": Defined as 'ensuring uninterrupted availability of energy sources at an affordable price (IEA, 2022) this indicator, like fiscal benefits above - is a high-level one typically considered at the state or national level (see Stavytskyy et al., 2021) and one not immediately relevant to local level social housing retrofit. It has therefore been reserved for the advanced iteration of the framework and tool.
4. "*Improved productivity*": This indicator was considered relevant to commercial retrofits and not applicable to homes. It has been removed.
5. "*Improved tenancy management*": This benefit with three indicators – reduced voids, complaints, and tenant transfers – was thought to be wrongly classified. When tenants are not happy, they can move out or protest with delayed rent payments which creates costs for landlords and retrofitting can fix this. However, this is generally not the case with social housing, hence it's more appropriate to put a social lens on this indicator rather than an economic one. To address these issues, a revised single indicator "Reduced tenants' complaints" has replaced this indicator and moved into the social category of benefits.
6. "*Property value improvement*": While no changes were suggested for this indicator, one expert thought that an increase in property values also creates revenue for the state, and just hasn't been assessed yet. This is already captured by the framework under "fiscal benefits – tax/GDP growth".
7. "*Innovations in business, products, processes and services*": There was mixed reaction on this benefit/indicator, although the general agreement was that this was considered a high-level indicator which does not tie "to the retrofit of single homes…it may only get relevant if you look at the big scale." It has been excluded from the framework and tool. In its place, a new benefit which assesses the cost efficiency of the retrofit investment has been established.

Table 5-3 In/Exclusion implemented on the original list of retrofit benefits.

	Benefit	In/ Exclusion	Changes effected
Social	Health and Well-being	(✓-)	Originally had 7 indicators covering different aspects of health and well-being, many of which had attribution issues. Health cost savings which is one of them moved to the economic category. It's now split into two "Personal health & well-being" and "Improved mental health/well-being"
	Tenant Comfort & Satisfaction	(✓?)	Some original indicators such as air quality, noise pollution reduction etc., have moved to "Indoor Environment Quality". Thermal comfort is now a standalone benefit
	Tenant Awareness (and Agency)	(✗)	Some mixed reactions. As retrofitting does not necessarily correlate with occupant behaviours which can be often temporal and short-lived
	Goodwill and Reputation	(✓)	
	Jobs/Employment Generation	(✓?)	Moved into the Economic category with emphasis placed on additional jobs.
	Neighbourhood Quality or Regeneration	(✓-)	Now "Neighbourhood quality improvement"
	Fuel Poverty Reduction/ Improved Social Welfare	(✓-)	Now "Fuel poverty reduction"
Environmental	Building Physics	(✗)	Introduced "Indoor environment quality" to capture all indoor related benefit
	Building Quality/ Home Upgrade	(✓?)	Now "Improved home or building aesthetics"
	Energy Savings	(✓)	
	Regulatory compliance	(✓)	
	Air pollution reduction	(✗)	Excluded as it is hard to bring it down to a single building and it is also hard to measure and associate with retrofits.
	Waste Reduction	(✗)	Not unique to retrofits, but a result of better construction techniques

	Local energy supply chain development	(✓-)	Modified to read "Local energy supply improvement"
	Carbon savings	(✓)	No change. The default assumption is savings from operation use. Where embodied carbon is measured, this should be clearly stated.
	Resilience or adaption of homes to climate change	(✓)	Maintained in framework, but excluded from measurement toolkits as these are higher order.
	Improved environmental & resource management	(✓)	Maintained in framework, but excluded from measurement toolkits as these are higher order.
Economic	Energy Costs savings	(✓-)	Modified to "Energy Bill savings" for clarity, as this relates to occupants
	Maintenance & repairs savings	(✓)	
	Fiscal Benefits (Tax/Revenue/GDP/Growth)	(✓)	Maintained in framework, but excluded from measurement toolkits as these are higher order, national level benefits.
	Improved Tenancy Management (Positive Tenant experiences)	(✓-)	Modified to read "Reduced tenant complaints" and moved to social category. Social tenants may not necessarily vacate when not happy with their homes, hence there may be minimal or no change in rental income/losses for landlords.
	Property Value Improvement	(✓)	
	Improved Productivity	(✗)	More relevant to commercial retrofits
	Innovations in Business, Products, Processes and Services	(✗)	High level and captured in parts across other benefits such productivity improvement as well as wider economic growth effects.
	Supply Chain Development	(✓?)	Moved into the Social category

(✓)	Maintained
(✗)	Excluded
(✓-)	Included (with modification)
(✓?)	Moved to another category

5.2.4 Final Retrofit Benefits Framework

Following the expert review of the framework and some further reviews, a final framework with 23 indicators resulted. Table 5.3 above summarises the end benefits with inclusion (✓) and exclusion (✗) from the final framework and gives a brief reasoning for the in-/exclusion. In the final framework (Figure 5-1, 5-2, 5-3 below), some layout changes were implemented. Each benefit was immediately followed by the indicators and description. The positions were in reverse in the earlier iterations of the framework. This list of indicators is considered to show the most relevant aspects of a retrofit project assessment or evaluation in general, social housing retrofit, or both. The full framework is in Appendix A1.2).

Table 5-4 Comparison of the number of benefits (and indicators) before/after Framework review.

	Original Draft before review	**Final benefits after Expert Review**	**Difference**
Social	7	7	0
Economic	8	8	0
Environment	11	8	-3
TOTAL	**26**	**23**	**-3**

A look at Table 5-4 above, shows that the number of benefits in social and economic categories did not change, which is not quite the reality. While the absolute numbers remained unchanged, the make-up or the actual list of benefits did change. This is demonstrated by the inclusion/exclusion details presented in Table 5-2. From that table, it is observed that a total of 2 of the benefits (*Improved productivity* and *Innovations in Business, products, and services*) were excluded, while another *Improved Tenancy Management*, was moved to the social category, leaving only 5 benefits. However, 3 other benefits - *Energy Security* originally in the Environmental category; *Jobs/Employment Created* and *Healthcare cost savings*, both originally in the social category, were moved into the Economic category bringing the total benefits back to the original 8.

	Benefit Indicator	Criteria/Metric	Description	Evaluation Level: Building	Evaluation Level: Project	Occupants	Landlord	Supply Chain	Local Auth.	Society
Social	Improved Physical Health	% of households with reported improvement	Reported personal health and well-being improvements of residents from retrofit measures installed	✓	✓	+ + +				
Social	Improved Mental Health	% of households with reported improvement	Reduction in anxiety and distress or depression to improved building characteristics	✓	✓	+ + +				
Social	Fuel Poverty Reduction	Households removed from risk of fuel poverty (in %)	Reduced household expenditure on fuel and electricity	✓	✓	+ + +	+ +			+ + +
Social	Reduced tenants complaints	Reduced number of tenant complaints	Satisfied tenants with less complaints. Also avoided costs associated with handling tenants' complaints	✓			+ + +			
Social	Reputation and Goodwill	Recognition for energy efficiency achievements	Demonstrated recognition awarded to the retrofit project for achievements made in energy efficiency		✓		+ + +			+
Social	Neighbourhood Quality Improvement	Reported improvement in safety and livability of the neighbourhood	General improvements in social relations and sense of safety and crime rates in a neighbourhood following renovation or retrofits	✓	✓	+ + +	+ +		+ + +	
Social	Supply Chain Development	Reported improvement in safety and livability.	New and/or strengthening of New or strengthened existing relationships, networking and collaborations between retrofit supply chain		✓			+ + +		+ +

+ + + More relevant
+ + Moderately relevant
+ Less relevant

Figure 5-1 Final Retrofit Benefits framework for Social Benefits

	Benefit Indicator	Criteria/Metric	Description	Evaluation Level: Building	Evaluation Level: Project	Occupants	Landlord	Supply Chain	Local Auth.	Society
Environmental	Energy Savings	Reduction in energy consumed (in % or kWh)	Total energy saved from reduced energy use/demand through retrofit project.	✓	✓	+++				+++
Environmental	Indoor Environment Quality (IEQ)	% of homes with improved IEQ	Improved indoor air quality as reported by occupants. Noise reduction, improvement in the lighting conditions or levels in occupants' homes.	✓	✓	+++				
Environmental	Thermal Comfort (Warm in winter/cool in summer)	% of homes with improved internal temperatures	Improved thermal comfort due to better control of room temperatures, lower temperature differences, air drafts and air humidity	✓	✓	+++				
Environmental	Improved home or building aesthetics	Improvements in the aesthetics, spatial quality, safety and security of home.	Aesthetic improvements to the home, Satisfaction with internal arrangement space and privacy within & out of the house.	✓	✓	+++				
Environmental	Carbon Savings	Reduction in CO2 eq/yr. (in %)	Carbon emissions (CO2 equivalent) savings achieved through the retrofit project (to embodied carbon of retrofit products and materials if assessed).	✓	✓		+	+	++	+++
Environmental	Local energy supply improvement	Enhanced local energy supply (renewable energy production)	Production from local renewable sources or by-products that further strenthens sustainability of local energy supply.	✓	✓	+			+++	+++
Environmental	Resilience or adaption of homes to climate change	No. of buildings retrofitted to meet vulnerability to climate change guidance	Energy systems (Buildings/homes) better response to faults and/or interruptions, can increase their efficiency & safety		✓				+++	+++
Environmental	Improved environmental & resource management	Material footprint or Unused resource extraction	Reduced negative effects and impacts on biotic and abiotic components of the environment; as well as reduced environmental footprints in		✓				+++	+++

+ + +	More relevant
+ +	Moderately relevant
+	Less relevant

Figure 5-2 Final Retrofit Benefits framework for Environmental Benefits

	Benefit Indicator	Criteria/Metric	Description	Evaluation Level: Building	Evaluation Level: Project	Occupants	Landlord	Supply Chain	Local Auth.	Society
ECONOMIC	Energy Bill Savings	Annual reduction in energy costs (in % or £)	Reduced energy costs/expenditure due to decreased energy consumption, i.e. £ equivalent of the total energy saved from reduced energy consumption.	✓	✓	+ + +	+ + +			+
	Property Value Improvement	% Increase in the rental premium or market value of retrofitted property	Observed increase in the rental/market value/sale price or transaction price of a house/rental in response to efficiency improvements.	✓	✓	+ + +	+ + +			
	Maintenance & repair savings	£ savings in repair and maintenance cost	Avoided or reduced costs of equipment maintenance and repair (from frequent breakdowns). Building life-cycle-costs reduction.	✓	✓	+ + +	+ + +	+ +	+ +	
	Fiscal benefits (Tax/Revenue/GDP Growth)	million or billion or 1000s of £ (in Tax savings or fiscal benefits)	Tax and fiscal benefits to firms, landlords or government for investments in retrofit improvements. Increased GDP/growth in economy.		✓		+ +	+ +	+ + +	+ + +
	Jobs/ Employment Created (New/Additional)	Additional FTE jobs per £1million invested.	New or additional direct and indirect jobs/vacancies due to retrofitting (emphasis is on direct jobs).		✓			+ + +	+ +	+ + +
	Cost Efficiency of Retrofit	kWh/yr/£1000 invested.	Energy saved per 1000 pound invested in the energy retrofit. Can be useful for comparing the cost-effectiveness of different retrofit projects	✓	✓		+ + +		+ +	+ + +
	Health Care Cost Savings	£ per person per year million £	Public health budget savings (e.g. to NHS) reductions in hospitalisations and visits as well as improved health.		✓				+ +	
	Energy Security	Security of energy supply and delivery (Energy Security Index)	Safety and security of energy delivery from reduced or dependence on imported energy		✓				+ +	

+ + + More relevant
+ + Moderately relevant
+ Less relevant

Figure 5-3 Final Retrofit Benefits framework for Economic Benefits

5.3 Empirical analysis of Interview data on challenges of retrofit evaluation.

5.3.1 Overview of empirical data.

This interview was initiated to gain a practitioner's understanding of the existing evaluation and measurement approaches for retrofit project benefits. (Section 4.6.1.2 in Chapter 4 provides more details on the expert selection process implemented). In total, 11 individuals from 10 organisations were interviewed. This is made of four participants from Housing Associations or Registered Social Landlords, and three from Supply Chain partners or Consultancy firms. Two participants were from Academic institutions with expertise in project management and retrofits, while one participant was an Energy Assessor and the other a private tenant and project consultant who has had experience retrofitting their home. One interview took the form of a focus group involving 2 respondents from the same organisation. The semi-structured nature meant that each interview was a little different in terms of the focus. Table 5-5 below gives summary statics of the interview participants (the professional roles and type of organisations these participants belong to are in Table 4-7 in Chapter 4).

Table 5-5 Summary statistics on interview respondents.

Industry	*No of Respondents*	*Experience (years)*	*No of Respondents*
Academic	2	Under 3	1
Private Tenant (Project Consultant)	1	3 – 5	2
Housing Association	4	5 - 10	3
Supply Chain Partners/ Consultancy	3	10 – 15	2
Energy Assessor	1	15+	3
TOTAL	11		11

Regarding the evaluation of retrofit projects and existing measurement techniques, there was consensus that there's a lack of comprehensive measurement tools for evaluating retrofit benefits/impacts. One respondent remarked that some landlords,

"…might find it useful to have some software that perhaps guides them and helps them identify what's next, what are going to be the benefits of what's next…" – 1923.

Moreover, the social housing respondents intimated that the lack of tools is particularly with those that can interface with existing systems of landlords & translate their data into more readily accessible metrics, which is what many local authorities will have an interest in. Supply chain partners interviewed all expressed keen interest in comprehensively understanding the impacts of retrofitting investments and being able to adequately advise their clients on the same. One of them intimated that while they're actively involved in a lot of retrofitting and general building renovation works, one of their key priorities is to be able to demonstrate that they're out there doing it and be able to measure and model their impacts.

Also, broader benefits are acknowledged in decision-making, though nothing more happens beyond that in terms of allowing them to drive investments in their measurement. Besides, the standard economic techniques such as payback estimates are favoured by budget officers in decisions involving retrofitting which typically form part of the capital programmes of social landlords. The effect is that capital programme decision-making processes do not favour broader benefits of retrofits which are considered externalities, without direct paybacks to landlords.

5.1.1 Overview of thematic analysis

The thematic analysis presented here follows the qualitative analysis strategy discussed in Chapter 4, Section 4.6.4. therefore, only the result of the analysis is presented and discussed here. Refer to the referenced section in Chapter for the methodological details. Following the final review of the codes and themes as well as those that emerged from further review, a final list of six major themes was concluded and these are summarised below in Table 5-6, while Figure 5-4 shows the thematic structure and the final codes making up these themes. The rest of this section provides a discussion of these themes and how they relate to the literature to extract further insights to support the development of the toolkits in the next two chapters.

5.1.2 Challenges in retrofit project monitoring and evaluations

Following (L. Miu *et al.*, 2018), the challenges are grouped as presented in Table 5-6 below and discussed in detail in the next sections.

5.3.1.1 Retrofit project evaluation process, technology, and systems.

This section combines the first two themes (retrofit evaluation process and technology and systems) for the purposes of the discussion. Project evaluation is a key aspect of any successful retrofitting program, enabling organizations to assess the impact of their interventions and identify areas for improvement. Retrofitting projects pose significant challenges, particularly in terms of technological and project evaluation aspects. A lack of consistent evaluation methodologies has been identified as a significant challenge within the sector (Janda, Killip and Fawcett, no date).

Table 5-6 Summary of the final 6 themes from the thematic analysis.

Themes	Definitions
Project Evaluation process	The approaches that are taken to assess the impact and success of home energy retrofitting projects including challenges in evaluation.
Tools and Systems	Various tools and systems are used for monitoring and evaluating home energy retrofitting projects, their strengths, limitations, and requirements.
Tenants/Occupants Engagement	How tenants or occupants are engaged before, during, and after retrofitting project evaluation
Costs related challenges	Costs associated with evaluating retrofitting projects and the challenges encountered in their execution.
Regulation and Policy	Regulatory landscape and policy factors that influence retrofitting projects and their evaluation.
Workforce and Training	Role of the workforce in retrofitting projects, including their skills, qualifications, and training needs and costs involved.

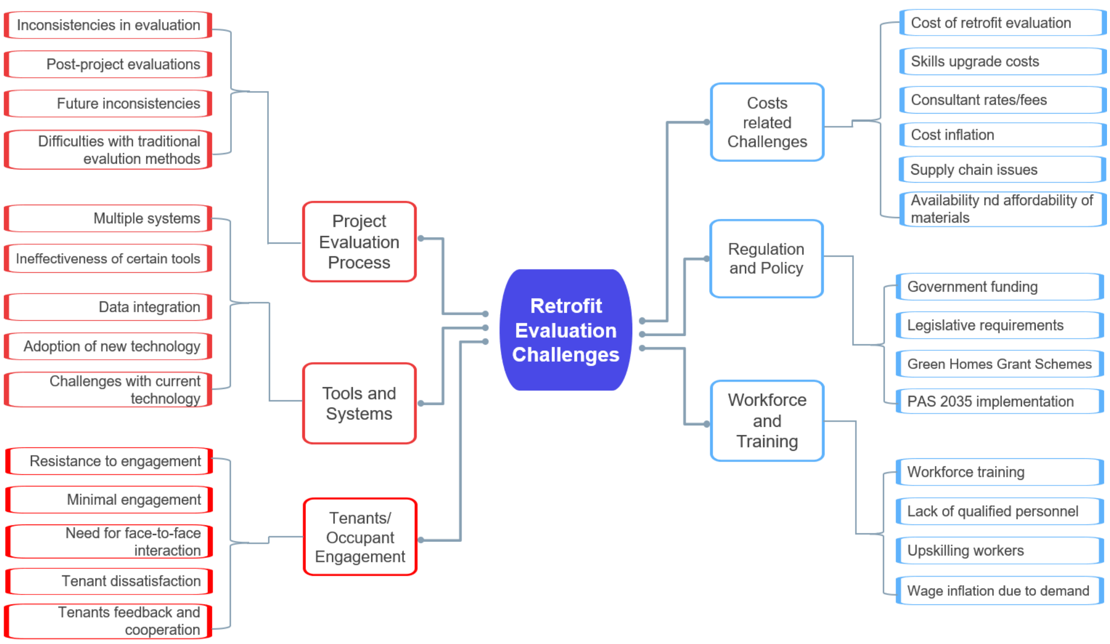

Figure 5-4 Theme and Code structure from the thematic analysis.

Interview findings indicate a pressing need for standardization in evaluation methods. The lack of a consistent approach makes it difficult to compare outcomes across different projects and undermines the overall effectiveness of the retrofit initiatives. This aligns with literature emphasizing the importance of standardized evaluation methodologies to ensure accurate and fair comparisons between interventions (RICARDO-AEA, 2015). The introduction of PAS 2035, an industry-recognized standard for the evaluation of retrofit projects, is viewed as a positive step towards a more standardized assessment of retrofit interventions (The Retrofit Academy, 2020). However, the cost implications of implementing such a standard, largely due to the inflation of rates in the jobs market, pose another layer of challenge.

Furthermore, the role of technology in retrofitting projects, especially in terms of monitoring and evaluation, is highlighted. A common underlying methodology for estimating energy savings is the government-backed SAP/RDSAP which also establishes the EPC ratings for dwelling stocks. The interview also revealed a variety of technological and proprietary housing management tools used to handle the general asset management of stocks for landlords while supply chain partners relied more on project performance measures. These include Switchee, Home Link, Wonderwall, and bespoke systems.

While these technologies can provide valuable data for project evaluation, their effectiveness varies depending on property archetype and other factors. This inconsistency aligns with research highlighting the complexities of applying a 'one-size-fits-all' approach to technology use in retrofitting (Brown, Swan, & Chahal, 2014). Additionally, the integration of data from various technologies into a central system for analysis and decision-making remains a major challenge, indicating the need for improved data management and interoperability in retrofit projects (Hargreaves, Nye and Burgess, 2013). Lastly, these approaches and techniques lack robustness and the reach to show evidence for the broader benefits/ impacts of retrofitting. A respondent observed that,

"…monitoring of improving the energy efficiency has not been particularly robust and is more anecdotal than factual, i.e., upgrading an element of insulation and assuming it's made improvements, but not testing or modelling that." – 1924.

Emerging from the interviews is the need for new techniques and measures in project evaluation, such as assessments of airtightness and thermal bridging. This underscores the multifaceted nature of retrofit projects, and the necessity for a holistic approach to evaluation that encompasses energy performance, comfort, and overall building quality

(Aghamolaei and Ghaani, 2020). Moreover, post-project evaluations, although inconsistent, are acknowledged as vital to the continuous improvement of retrofit programs. They provide invaluable feedback on the success or failure of the implementation process and guide future projects (Dixon and Eames, 2013).

It is established that the success and efficacy of retrofit projects hinge heavily on the robustness of project evaluation mechanisms and the reliability of tools and systems utilized in monitoring project outcomes. Thus, the evaluation of project impacts, alongside the effective use and integration of various technological tools, has emerged as central themes from the interviews conducted.

Project evaluations in retrofit efforts, as revealed through the interviews, lack a consistent methodology. This inconsistency makes it challenging to compare different projects or to determine the factors that led to a project's success or failure. Notably, this finding aligns with a wider consensus in literature: (Bright, Weatherall and Willis, 2019) underscore the importance of having robust evaluation frameworks in place to ensure the success of retrofit projects and contribute to the broader retrofit literature.

However, effective project evaluation is inherently tied to the reliability of the tools and systems employed in retrofit projects. A variety of tools and systems such as Switchee, Home Link, Wonderwall, and bespoke systems are utilized to monitor and evaluate project outcomes. The effectiveness and the interoperability of these systems, however, pose significant challenges. The findings corroborate with Brown, Swan, and Chahal (2014), who emphasize the complexity of a 'one-size-fits-all' approach to retrofitting.

Importantly, these two themes are intrinsically linked: the efficacy of project evaluation is often contingent on the reliability and integration of various monitoring tools and systems. As such, addressing the challenges in both areas - by establishing a consistent evaluation methodology and refining the usage of various tools and systems - is critical to enhancing the success of retrofit projects. By doing so, stakeholders can not only ensure the effectiveness of individual projects but also contribute valuable knowledge and insights to the broader field of retrofitting.

5.3.1.2 Tenants or occupants' engagement

Customers remain central to the success or otherwise of retrofit projects and thus hold considerable sway. It is therefore important they are engaged strategically throughout the process. Customer engagement emerged as a recurring theme in the interviews, revealing itself as both a cornerstone for the successful implementation of retrofit projects and a complex challenge that needs to be addressed (Maduka, Udeaja and Greenwood, 2015).

The interviews indicate that tenant engagement or the lack thereof is a significant factor influencing the progress and outcomes of retrofit projects. Respondents discussed various issues regarding tenant participation in these projects, including resistance to project work, reluctance to complete surveys or provide feedback, and a general desire for minimal engagement. Moreover, tenants seemed to prefer face-to-face interaction, although the practicality of maintaining such a high level of personal contact is questionable as projects scale up. Another area where a lot of inconsistencies occur in retrofit evaluations is tenant feedback. No consistent approach is adopted to evaluate tenant feedback across projects within the same organisation as well as across projects. Even in terms of questions asked, there is no consistency in questions asked, who is it asked to and the options. This impacts the overall evaluation effectiveness of a provider who is not able to compare their retrofit investment projects side by side to highlight successful projects which could become test beds for improvements in the delivery of subsequent or future retrofits [see 1934b, 00:00:52].

Such findings are consistent with the wider body of literature on retrofit projects. For instance, (Luo, Li and Sun, 2022) affirm that customer engagement is vital in implementing energy-saving measures, and a lack of effective engagement could hinder the successful execution of such projects. Similarly, IEA (2022) underscores the importance of direct engagement with customers, noting that it is an effective way to encourage energy-saving behaviours and participation in retrofitting efforts.

However, the literature also suggests that finding an effective balance between direct (face-to-face) and indirect (digital) engagement strategies is a nuanced challenge in energy retrofit projects. As per (Janda and Parag, 2011), while direct engagement can lead to higher satisfaction levels, its scalability is limited. Therefore, integrating and balancing both approaches while addressing customers' preferences and needs can contribute significantly to retrofit projects' success. Occupants' engagement presents both a critical element and a complex challenge in retrofitting projects. Therefore, strategies aiming to balance direct and indirect engagement, considering customer preferences and practical considerations, are essential to enhance the effectiveness of such projects.

5.3.1.3 Workforce and Training

The topic of workforce and training was highlighted in the interviews, pointing towards its significance in the context of retrofit projects. The insights provided by the interviewees echo the observations in existing literature regarding the impact of workforce quality, training programs, and the availability of qualified professionals on the outcomes of retrofit projects. During the interviews, one participant discussed the workforce's role in achieving consistent project evaluations, underlining the need for a trained workforce capable of applying the PAS 2035 standard uniformly across projects. This aspect has been supported by the likes of Shove and Walker (2014), who argued that the quality and effectiveness of retrofit projects are largely determined by the skill level and expertise of the workforce.

A shortage of qualified professionals in the retrofitting field has led to wage inflation, according to interviewee '*1931*'. This observation aligns with the findings of Rosenow and Galvin (2013), who note that insufficient numbers of trained retrofit professionals can lead to cost overruns and schedule delays. This lack of workforce can also lead to increased reliance on external consultants, further driving up project costs. Furthermore, the interviews touched upon the challenge of retaining upskilled employees. There is a risk of in-house training or upgrading existing employees. After investing in their training, these employees may move to another firm. In their study, Janda, Killip and Fawcett, (2014) highlighted similar concerns, emphasizing that the development of a skilled and stable workforce is crucial to ensure consistent quality across retrofit projects.

Moreover, the involvement of the workforce in customer engagement activities was brought up during the interviews. Another respondent noted the importance of face-to-face interactions, especially in the initial stages of projects. This assertion aligns with Killip's (2013) observations, stating that a well-trained and communicative workforce can play a crucial role in improving customer engagement and satisfaction levels. Overall, workforce and training are critical aspects of retrofit projects, with implications for project costs, quality, evaluation, and customer engagement. Consequently, policymakers and project managers should focus on fostering a skilled and stable workforce to ensure the success of retrofit projects.

5.3.1.4 Cost of evaluations/Assessments:

The analysis of the interview data identified costs and challenges as a significant theme influencing the successful implementation and progress of retrofit projects. This multifaceted theme spans issues such as the cost of implementation, the challenges of project evaluations, the complexity of integrating and managing various tools and systems, and the difficulties of customer engagement. The interviews illustrated that the costs associated with retrofit projects are a paramount concern for the stakeholders involved. Retrofitting, by its very nature, requires significant financial investment. The high costs stem from various factors, including the purchase of energy-efficient equipment and materials, labour, ongoing maintenance, and the cost of potential disruption during the retrofit process.

Moreover, the introduction of specific standards, such as the PAS 2035, which is a specification for the energy retrofit of domestic buildings in the UK, adds another layer of cost. For very basic level kind of fabric first interventions, conducting full PAS 2035 assessments is deemed too expensive and not a good value-for-money proposition. Unless paired with other technologies or installations/measures resulting in issues arising around ventilation, air quality and heating, then full PAS 2035 becomes useful in understanding all that. But windows, doors, cavity wall insulation, loft insulation, and even internal/external wall insulations are straightforward, and a full PAS 2035 is overdoing it. There could be simpler ways of doing it without a full PAS 2035 which does not pay off for the customer ultimately.

The PAS 2035 standard has increased the demand for qualified retrofit coordinators, leading to wage inflation in the sector. This wage inflation contributes to the overall project cost as organizations must decide between investing in in-house skills (which often results in higher salaries for existing staff) or hiring external consultants whose rates have significantly increased. One respondent remarked that the extra money on unnecessary assessments (using the PAS 2035 process) could go into retrofitting more homes/properties [1931, 00:15:09].

In addition, there are hidden costs that are not as easily quantifiable but add to the financial burden. For example, the time and resources invested in customer engagement, project evaluation, and managing complex tools and systems contribute to the overall cost of retrofit projects. These costs may not be immediately apparent but need to be considered when planning and implementing retrofit projects.

The challenges associated with retrofit projects are as multifaceted and complex as the costs. The interviews highlighted the lack of a consistent methodology for project evaluations, making it difficult to compare different projects' success. The use of disparate tools and systems, each with its benefits and drawbacks, further complicates the implementation and evaluation process.

Findings from the interviews are echoed in the wider literature on retrofit projects. Scholars such as (Janda, Killip and Fawcett, 2014) and Sunikka-Blank and Galvin, (2012) have emphasized the significant costs and challenges involved in retrofit projects, highlighting the need for effective strategies to mitigate these issues. Effective strategies to address these challenges could involve investing in training and development to upskill in-house staff, adopting a flexible approach to customer engagement that balances face-to-face interaction with digital methods, and choosing tools and systems that best suit the specific needs of the project.

Furthermore, the literature suggests that policies and funding mechanisms can play a crucial role in alleviating the financial burden of retrofit projects. For example, Rosenow and Eyre (2016) suggest that governmental policies can stimulate energy-efficient retrofitting by reducing the financial risk associated with such projects.

5.3.1.5 Policy and regulation challenges

The role of regulations and policies in retrofit projects emerged as a significant theme in the interviews. These policies and standards set the framework within which retrofit projects operate, influencing their design, implementation, and evaluation. In the UK, standards such as the PAS 2035 have been introduced to ensure the quality and effectiveness of retrofit projects. As noted earlier in section 5.4.3, the introduction of PAS 2035 has created a demand for qualified professionals who can ensure the standard's adherence, subsequently influencing the cost and resource allocation of retrofit projects. This aligns with the wider literature on retrofit policies; for instance, Rosenow and Eyre (2013) noted that the introduction of regulations and standards often has implications for the cost, skills, and resources involved in energy retrofitting.

The regulatory environment also influences the methodologies used for project evaluation. A systematic review of passive retrofit performance evaluation methods by (Carratt, Kokogiannakis and Daly, 2020) showed that often, the performance metrics used in evaluations were defined by the funding body. In the UK, the government remains the biggest funder of retrofit investments and thus steers guidance and information on evaluations. One interviewee highlighted the inconsistency in project evaluation methodologies used in their projects due to the lack of a uniform regulatory framework. Another noted that the Department for Energy Security does not provide relevant and up-to-date information on what kind of indicators and measures of value retrofit project evaluations should be or cover, especially around social and economic benefits [1934, 00:17:24]. These resonate with the findings of Janda, Killip and Fawcett, (no date), who stressed the need for standardized methodologies for project evaluation, as the lack thereof hampers the effective comparison and assessment of different retrofit projects.

In addition to direct regulatory influences, the interviews also touched upon the indirect effects of policies on customer engagement. For instance, one expert alluded to the regulatory balance between allowing tenants to remain in their homes during retrofit work and addressing health and safety issues. This delicate balance can be influenced by housing and health and safety regulations and can impact the level of tenants' engagement and satisfaction with retrofit projects, which in turn affects their participation in evaluations.

The importance of policy support in overcoming challenges associated with retrofit project evaluation is highlighted in the literature. Rosenow and Eyre (2016) argued that government policies can stimulate energy-efficient retrofitting by reducing the financial risk and increasing the affordability of such projects. They suggested that policy measures such as grants, subsidies, and low-interest loans can alleviate the financial burden of retrofit projects, thereby encouraging more widespread uptake.

5.4 Discussion of thematic analysis findings and recommendations

5.4.1 Key insights and summary of findings.

The thematic analysis discussed earlier gave rise of to some key insights which will inform the development of the toolkits in the next chapters. The analysis has shed light on the multi-faceted landscape of home energy retrofitting, reflecting both the enthusiasm and the challenges intrinsic to any sector undergoing innovation.

First, the analysis establishes and affirms in the first theme on retrofit evaluation processes, that retrofit project evaluation is fundamental. Stakeholders, including social housing landlords seek precise, quantifiable metrics to assess and evaluate the performance and impacts of their retrofit investments. However, the heterogenous nature of the retrofit industry and of the evaluations currently, coupled with the lack of methodological consistency, hinders the ability to make clear comparisons across projects to draw lessons. This theme ties in closely with the theme on tools and systems for retrofit evaluation, where the drive for digital innovation meets with the practical challenges of data integration. Numerous tools, software, and applications from Switchee to bespoke systems and software, are tried and tested, but the search for an optimal, holistic solution continues.

That notwithstanding, even the most sophisticated tools are only as useful or effective as its users. Customer or occupant engagements therefore emerges as a critical theme, and which echoes the challenges of balancing occupant autonomy with project needs. Retrofitting is not just a technical venture – it is deeply personal, impacting people's homes and lives. This personal dimension is further intensified by the costs associated with retrofitting. The ‘costs and challenges' theme underscores the financial strains, from wage inflation due to the rising demand for specialised skills to the escalating consultancy rates.

However, these financial pressures do not exist in a vacuum; they are intricately intertwined with regulation and policy. Initiatives such as PAS 2035 establish guidelines but also introduce market dynamics that can result in unintended cost increases. With such regulations mandating specific standards and approaches, organisations find themselves caught between policy aspirations and on-the-ground realities. In addition to all these, the human element in retrofit is highlighted by the ‘workforce and training' theme. As retrofitting projects evolve, the demand for specialised skills and knowledge increases. Upskilling becomes a double-edged sword, offering potential for enhanced in-house expertise but also creating a risk of skilled workers seeking greener pastures elsewhere.

We can therefore conclude from the thematic analysis that the home retrofitting landscape is marked by a delicate tango between ambition and reality, innovations, and challenges. As the sector advances, a harmonised approach that integrates all these issues together is deemed pivotal to the ensuring a long success of projects and their evaluations, which ultimately is good for the environment and the homes we live in today.

5.4.2 Implications of findings and linkage with research objectives.

5.4.2.1 Linking implications to research objectives.

It is important to link these key findings or insights back to the relevant research objectives to examine what the implications are and the recommendations to take forward into the next stages of the research where the toolkits are developed and implemented. Table 5-6 below concisely juxtaposes the research objective, thematic analysis implications and provides recommendations. The thematic analysis, derived from stakeholders' experiences and insights, addresses a key component of the research: understanding the challenges surrounding retrofit evaluation and evaluating existing tools and methodologies. This foundational step ensures that the subsequent research objectives are grounded in the practicalities of the field.

- *Challenges of Retrofit Evaluation*: The thematic analysis shed light on the perceived inadequacies of existing tools and methodologies. From these insights, it's evident that there's a pressing need for more user-centric, holistic, and cost-effective solutions in the sector.
- *Developing a Benefits Measurement Framework*: With an emphasis on essential indicators and criteria highlighted by stakeholders, the analysis paves the way for the creation of a framework that truly caters to the needs and concerns of those directly involved in retrofit projects.
- *Weighting and Prioritization*: Different stakeholders may have varying priorities. The analysis suggests a need for a dynamic weighting system that can cater to diverse needs without compromising on the integrity and consistency of the evaluation.
- *Retrofit Benefits Scoring Tool*: Consistency, transparency, and user-friendliness are three paramount aspects emphasized in the analysis. Any tool developed must ensure that it balances these aspects while still being adaptable enough to cater to different project nuances.

Table 5-7 Alignment of Thematic Analysis Implications with Research Objectives.

Research Objective	Implications from thematic analysis	Recommendations
Identify and evaluate the challenges of retrofit evaluation and the strengths/ weaknesses of existing methods (Objective 2)	Existing tools are perceived as inadequate; challenges in customer engagement and costs.	Develop or enhance more comprehensive, user-friendly, and cost-effective tools encompassing diverse customer engagement strategies.
Develop a benefits measurement framework (Objective 3)	Key indicators and criteria that stakeholders deem essential were highlighted.	Incorporate insights on costs, customer engagement, and regulatory challenges into the framework.
Develop a weighting/prioritization methodology (Objective 4)	Different stakeholders may prioritize differently based on their unique concerns.	Engage a broad range of stakeholders to ensure the weighting resonates with diverse needs.
Develop a retrofit benefits scoring tool (Objective 5)	Emphasis on the need for transparency, consistency, and comprehensiveness in tools.	Develop a user-friendly tool with a focus on consistent data collection, adaptable based on user feedback.

Therefore, the thematic analysis not only highlights the gaps and challenges in retrofit evaluation but also provides a roadmap for developing tools and frameworks that are both theoretically sound and practically effective. This balance ensures that the research outputs are not just academically rigorous but also of tangible value to practitioners in the field.

5.5 Summary of Chapter

This chapter commenced with an essential step in the research process: an expert review of the multi-stakeholder benefits framework formulated in Chapter 3. This phase was crucial to validate the robustness and applicability of the framework. Out of an initial set of 26 indicators, 23 were finalized post-review. Notably, some of these indicators underwent modifications based on the insights and expertise of the reviewers, ensuring the framework's enhanced accuracy and relevance.

After this, the chapter embarked on an in-depth exploration of the challenges of retrofit evaluation and the strengths and weaknesses of existing tools, methods, and frameworks used for measuring the benefits of retrofits. This exploration was driven by a thematic analysis of collected interview data from 11 industry practitioners made up of social housing representatives, academics, supply chain partners, a private occupant/tenant, and an Energy Assessor. The analysis revealed key themes including project evaluation, tools and systems, customer engagement, costs and challenges, regulation and policy, and workforce and training.

From the thematic analysis, some implications and recommendations were deduced to inform the next stages of the research. These include the following.

- the need for a more unified, standardized approach to project evaluation, reducing subjectivity and increasing the reliability of assessments.
- the development and adoption of more integrative tools that account for a wider array of indicators.
- the importance of occupant/human-centric approaches was emphasized, highlighting the necessity of tools and frameworks that cater to the needs and preferences of the end-users.

The analysis in this Chapter has primarily addressed the second objective of the research, while also setting the groundwork for the development of the methodology for the weighting or prioritization and retrofit benefits scoring tools, which are discussed in the next chapters.

Chapter 6 : DEVELOPMENT OF THE RETROBIT BENEFITS MEASUREMENT TOOLKITS: AHP-DELPHI PRIORITISATION AND BENEFIT SCORING TOOLS

6.1 Introduction

Following the literature reviews on retrofit benefits and their evaluations as well as the empirical interview results in the preceding chapter, the task in the chapter is to set out the proposed methodology (framework and tools) for assessing the benefits of social housing retrofits. The chapter details the underlying conceptual overview of the frameworks for the toolkits (discussed in the next chapter). It also presents an overview of the final retrofit benefits criteria and score thresholds used for establishing the benefits scoring tool.

6.2 The retrofit benefits weighting and prioritisation framework.

As discussed earlier in the benefits framework, each investment in a retrofit project produces several impacts or benefits to different stakeholders. A stakeholder, in this case, a housing provider, who is considering an investment in retrofit will therefore need to consider which set of benefits are more relevant or important so that the investment can be targeted and the evaluation at the end of the project focused on only the relevant impacts that are of interest to the stakeholder. To assist housing providers (social landlords) in this important task, a methodology and accompanying toolkits have been developed for prioritising and ranking the potential benefits of a retrofit investment (as outlined in the framework) and establishing appropriate weight for each benefit in the overall benefit measurement.

The methodology is built on the Analytical Hierarchy Process (AHP) technique developed and promoted by Saaty (1987). The AHP is simply a multicriteria decision-making approach (MCDM) which helps a decision maker to establish the relative priorities of any given number of alternative options or pathways based on the judgements of the decision maker. The alternative options in this case are the benefits of retrofitting. The AHP method involves about seven steps as developed (Saaty, 1987, 1991, 2002, 2008 as cited in Kutlu et al., no date, p, 114).

1. Defining the problem and determining its goal.
2. Structuring the problem hierarchy from the top through the intermediate levels to the lowest level, which will contain the list of alternatives.

3. Construct a set of pairwise comparison matrices (size n x n) for each of the lower levels…using a relative scale measurement.
4. There are n*(n-1) judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
5. Hierarchical synthesis is used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of hierarchy.
6. Having made all the pair-wise comparisons, the consistency is determined by the eigenvalue.
7. Steps 3-6 are performed for all levels in the hierarchy.

Following this process, the benefits of retrofitting can be organised in a systematic and structured way such that the benefits are compared individually with each other in what is called a 'pairwise comparison matrix' and assign a value to the importance of one benefit over the other. In doing so, the decision maker is simply asking and answering the question, 'Which of these two benefits is important to my goal of retrofitting this home or property or group of properties and by how much is it more important than the other?

This decision can be made by the retrofit project team acting as one entity, which is the simplest form. Alternatively, each project team member can perform the comparison and ranking, and then the results are merged into a group ranking. This is achieved using the Delphi technique (see section 6.2.4 below) In the case of the latter, an additional task of resolving any differences in opinions or judgements of team members is needed to achieve **consensus** on what benefits matters most to the team. In addition, there is the need to check the **consistency** of the ranking performed by individual team members. The next sections detail these methods, and processes to be followed or used to establish the weights and rank for the retrofit benefits.

6.2.1 Structuring the AHP model hierarchy

A key requirement in using the AHP approach is to present the decision problem in a hierarchical structure using a top-bottom approach. The deriving structure impacts the final weights computed for the variables or factors involved. There is no limit (theoretically) on the number of hierarchy levels to be included, however, the final weights should be computed for the lowest levels in the structure. The AHP structure for this study is shown in Figure 6-1 below.

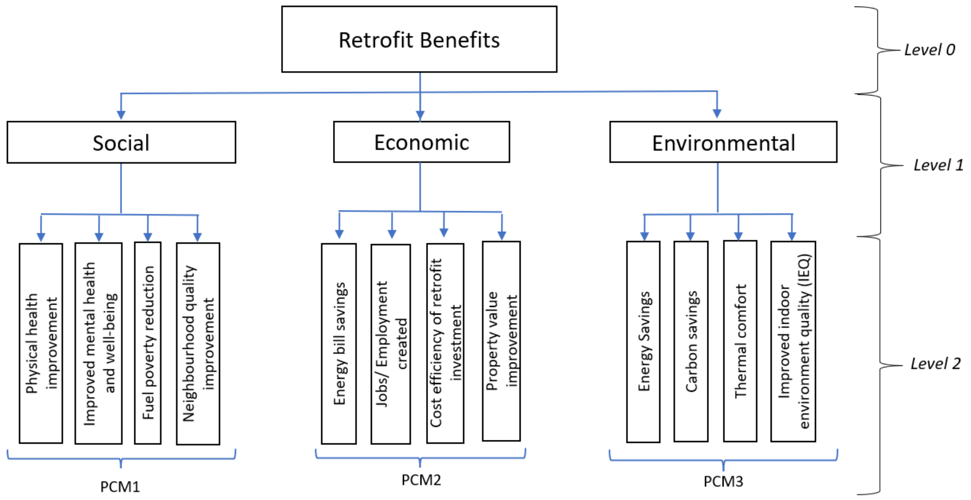

Figure 6-1 AHP hierarchy structure showing two levels

In Figure 6-1 above, level 0 represents the goal or focus of the AHP exercise, which is described as retrofit benefits. The first level (Level 1) corresponds to the criteria (benefit categories – social, economic, and environmental) and the second level (level 2) shows the sub-criteria or actual alternatives which corresponds to 4 social benefits, 4 economic benefits and 4 environmental benefits. Based on this AHP structure, a total of 3 pairwise comparison matrices are constructed, labelled PCM1, PCM2 and PCM3 (more on later in the next section).

6.2.2 Pairwise comparison matrices and judgement scales

Following the structuring of the AHP hierarchy, the next step to complete is the questionnaire to collect the judgement of individual experts (project team members) or any other stakeholders for whom ranking and prioritizing of retrofit benefits is required. The questionnaire needs two key items: pairwise comparison matrices (PCM) and a judgement scale. A PCM allows decision makers to compare two retrofit benefits at a time and judge which is more important using the judgement scale (numerical scale). The value assigned to each benefit by a decision maker is based on their level of experience and expertise and such assigned values help transform the qualitative judgements of experts into numerical measures.

6.2.2.1 Numerical or Judgement scale

Saaty (1987) recommended a fundamental scale between 1-9 to compare two elements in a criterion. The number of comparisons required to complete any comparison matrix is also given as ***n(n-1)/2***, where ***n*** is the number of criteria in a matrix (see PCM matrices below for more details). The fundamental scale is reproduced in Table 6-1 below. This is a strong advantage of the AHP – its ability to evaluate both quantitative and qualitative criteria using the same preference scale.

In the AHP questionnaire, each team member or respondent is asked to compare each pair of retrofit benefits with the rest and assign it a value between 1 and 9 using the scale in Table 6-1. A value of 1 indicates that two benefits are of equal importance and the highest value of 9 indicates that one benefit is extremely important than the other (Paneru, 2019). Note that negative values are not allowed in the comparison matrix. In other words, no criteria (benefit) i, should be less than or equal to zero ($i \geq 0$). For computation purposes, the a_{ij} is taken to denote the pair-wise judgement value of an expert between retrofit benefits i and j.

Reciprocals are however allowed. As explained in Table 6-1, a reciprocal value is given to a benefits comparison to indicate the negative importance of one benefit over another. For example, if the retrofit benefit i has "very strong importance" than retrofit benefit j, then i is assigned the value '7' which is entered into the judgement matrix. If j is now being compared with i, then a reciprocal value of '1/7' is to be entered in the matrix. These benefit comparison values will be used to compute the weights and rankings for the various benefits.

Table 6-1 Judgement scale for AHP pairwise comparison

Numerical scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Equal to moderate importance	When compromise is needed
3	Moderate importance	Experience and judgement strongly favour one activity over another
4	Moderate to strong importance	When compromise is needed
5	Essential or strong importance	Experience and judgement strongly favour activity over another
6	Strong to very strong importance	When compromise is needed
7	Very strong importance	Activity is strongly favoured, and its dominance demonstrated in practice
8	Very strong to extreme importance	When compromise is needed
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
Reciprocals	If activity ***i*** has one of the above numbers assigned to it when compared with activity ***j***, then ***j*** has the reciprocal value when compared with ***i***	

Source: Adapted from Saaty (1987) and Al-Harbi (2001)

6.2.2.2 Pairwise comparison (PCM) matrices

The PCM matrices (based on the AHP hierarchy in Figure 6-1 above, enable the pair-wise comparison judgement of decision makers to be collected. Given that level 1 of the hierarchy contains the three benefits categories, no pair-wise comparison will be done at that level. Category weights will instead be computed later by aggregating the weights for the individual benefits under each category. Only 3 matrices are thus constructed for this study and presented below (Tables 6-2, 6-3 and 6-4). Comparing and expressing one's opinion on two alternatives at a time rather than simultaneously over all the alternatives are argued by psychologists to be simpler and more accurate (Ishizaka and Labib, 2011) and pair-wise judgements can be cross-checked for consistency. The order in which alternatives are presented in a comparison matrix is believed to impact successive pairwise judgements (Webber et al.,1997). The retrofit benefits are thus presented in alphabetical order to eliminate or lessen the presentation biases. As depicted in the matrices, all the three PCMs have 3 benefits each.

These PCMs are to be completed by each person designated by the retrofit project lead or coordinator. In completing them, each participant needs to base their opinions on their cumulative knowledge and experience in retrofits generally and on the specific retrofit for which the ranking and weighting of benefits is being undertaken. Each respondent is expected to complete and turn in a set of three (3) PCMs at the end of the process to the retrofit project lead for analysis.

Table 6-2 PCM1 - Pairwise comparison matrix for social benefits

	A	B	C	D
Fuel poverty reduction (A)				
Improved Mental health/ well-being (B)				
Neighbourhood quality improvement (C)				
Physical health improvement (D)				

Table 6-3 PCM2 - Pairwise comparison matrix for environmental benefits

	A	B	C	D
Carbon savings (A)				
Energy Savings (B)				
Indoor Environment Quality Improvement- IEQ (C)				
Thermal comfort (Winter/ Summer) (D)				

Table 6-4 PCM3 Pairwise comparison matrix for economic benefits

	A	B	C	D
Additional Jobs/ Employment Created (A)				
Cost efficiency of retrofit investment (B)				
Energy Bill savings (C)				
Property value improvement (D)				

A sample of a completed PCM for the social benefit category is presented in Table 6-5. From this table, in Row 1, column 2 (B), the respondent compared "fuel poverty reduction" with "improved mental health/well-being". The value of 3 indicates that "fuel poverty reduction" has moderate importance over "improved mental health/well-being". In row 3 column 2 (B), "neighbourhood quality improvement" is compared with "improved mental health/well-being". However, this comparison has already been completed in row 2, column C, so a reciprocal (1/7) of this value (7) is inserted into row 3, column B. Also, wherever a benefit is compared against itself, the value 1 is entered indicating that there is equal importance.

Table 6-5 sample of completed pairwise comparison matrix for social benefit category.

		A	B	C	D
1	Fuel poverty reduction (A)	1	3	5	9
2	Improved Mental health/ well-being (B)	1/3	1	7	1/4
3	Neighbourhood quality improvement (C)	1/5	1/7	1	2
4	Physical health improvement (D)	1/9	4	1/2	1

As mentioned earlier, the number of comparisons to be completed per PCM is estimated as $Nc = n(n-1)/2$,

where n is the number of the criteria/benefits in the matrix.

It is recommended that the maximum number of criteria in a matrix range should fall within the number seven plus or minus two (Saaty et al., 2003, cited in Goepel, 2013). The criteria (benefits) and the number of comparisons to be completed for the three PCMs are estimated below and fall within this range/limit. Each expert respondent will therefore complete approximately 18 comparisons across the three matrices.

PCM1 = 4 benefits = 4(4-1)/2 = 6 comparisons

PCM2 = 4 benefits = 4(4-1)/2 = 6 comparisons

PCM3 = 4 benefits = 4(4-1)/2 = 6 comparisons

6.2.3 Consistency checking

After completing the individual comparison judgements, the next logical step is to combine the individual judgements from each expert/respondent into a group comparison matrix. This is the consensus-checking stage and is aimed at identifying any inconsistencies and conflicting judgements between respondents so that appropriate corrective measures can be suggested. Before proceeding to do this, however, the individual judgements first need to be checked for consistency.

6.2.3.1 Consistency checks – AHP

The consistency checking method of the AHP is founded mathematically on the resolution of an Eigenvalue problem. A matrix is used to organise the outcomes of the pair-wise comparisons. The consistency ratio is determined by the Eigenvalue, which depends on the matrix's first (dominant) normalised right Eigenvector, which provides the ratio scale (weighting). Consistency checking is completed once for all respondents in the first round of pairwise comparison judgements because once each respondent's judgments meet the consistency threshold, it is expected that the subsequent rounds of pairwise comparisons will also achieve the desired thresholds.

The consistency-checking method employed in this methodology follows the work of Goepel (2013) which is based on the ordinal consistency approach. This method implements an automatic consistency checking process for each decision maker's pairwise judgements ensuring a quick and accurate computation of results. Before detailing this automatic consistency checking process, a fundamental overview of the general approach and assumptions for consistency checking adopted in this method is outlined.

6.2.3.2 Priorities derivation

Priorities derivation is aimed at obtaining a set of priorities that are consistent with the comparisons in a matrix. That is, for a set of priorities $p_1 \dots p_n$, p_i/p_j matches with the comparisons m_{ij} in a consistent matrix. Also, the introduction of slight inconsistencies should result in only slight variations in priorities (Ishizaka and Labib, 2011). To derive the priorities of a decision maker from the pairwise comparisons, several methods have been proposed, which either use the eigenvalue method or the logarithmic least squares (geometric mean) method. Ishizaka & Lusti, (2006) conclude that they do not think that one method of priority derivation is superior to another after conducting a comparative Monte Carlo simulation on the methods.

The geometric mean method is adopted for use in this study and in the spreadsheet tool due to its psychological and mathematical properties (Barzilai and Lootsma, 1997 as cited in Alonso and Lamata, 2006). The geometric mean method addresses a rank reversal problem with Saaty's (1977, 1980) eigenvalue approach.

The eigenvalue approach proposed uses the principal Eigenvector **P** as the desired priorities vector.

$$A \times P = \lambda \times P \quad (1)$$

where **A** is the comparison matrix; **P** is the priorities vector; $\boldsymbol{\lambda}$ is the largest or maximal eigenvalue.

(Johnson, Beine and Wang, no date) found that the right eigenvector is not always equal to the left eigenvector using this eigenvalue to elicit priorities. In other words, when alternatives are eliminated or withdrawn or when the ranking is based on how the problem is phrased, a change in the ranking or ordering of the alternatives is noted.

6.2.3.3 Consistency index

As discussed earlier, a PCM, *m,* presents the relationship between *n* alternatives in a decision matrix and *m* is considered consistent if it satisfies the transitivity property $m_{ij} = m_{ik} \times m_{kj}$ for all $i, j, k = 1, \dots n$. Also, *m* is reciprocal if $m_{ij} = 1/m_{ji}$, for all $i, j = 1, \dots n$.

However, consistency is not always achieved in practice and where the inconsistency is observed, it is necessary to measure the degree of inconsistency. Saaty (1977) proposed a measure for inconsistency (CI):

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

where λ_{max} is the largest eigenvalue of *m* and *n* is the dimension of the matrix.

6.2.3.4 Consistency ratio

Using the CI, a consistency ratio (CR) representing inconsistency can be estimated as

$$CR = \frac{CI}{RI} \quad (3)$$

where RI (random index) represents an average value of randomly generated CI (an average of 500 randomly filled matrices) (Alonso & Lamata, 2006) which is reliant on the *n* and on the process of generating random numbers.

If the pairwise comparisons of a decision maker are perfectly consistent, then $\lambda_{max} = n$.

A pairwise judgement is acceptable as consistent if it meets the threshold of $CR \leq 0.1$ proposed by Saaty (1977). Failure to satisfy this threshold requires the decision maker to revise their judgement to improve consistency.

The CR has received huge criticisms in two major areas. Firstly, the CR is sensitive to the scale used to elicit judgements and secondly, there are problems with the $CR \leq 0.1$ accept/reject threshold. Using a 9-point scale, Lane and Verdini (1989 cited in (Bana, Costa and Vansnick, 2008)) demonstrated that Saaty's CR threshold is overly strict because the standard deviation of CI for randomly generated matrices is quite low resulting in the acceptance of contradictory judgements in matrices. On the other hand, Kuenz Murphy (1993) has demonstrated that when *n* rises, the 9-point scale given by Saaty produces results that are outside the bounds of consistency, leading to the rejection of reasonable matrices (Alonso and Lamata, 2006, p, 448).

These problems have led to several alternative approaches being developed. For example, Crawford and Williams, (no date) proposed the Geometric Consistency Index (GCI) which sums up the difference between the ratio of the prioritised calculations and the provided comparisons (Dong *et al.*, 2015). GCI is also fraught with similar issues as the CR, and though it is not an adopted approach for consistency checking, it is nonetheless computed as part of the spreadsheet tool for illustration purposes.

$$\mathrm{GCI} = \frac{2\sum_{i<j}\left(\log a_{ij} - \log\frac{p_i}{p_j}\right)^2}{(n-1)(n-2)} \qquad (4)$$

Salo and Hamalainen (1997) also proposed another method using the transitivity rule, which was later improved by Ji and Jiang (2003).

$$\sqrt{\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}(a_{ij} - \log\frac{p_i}{p_j})}{n(n-1)/2}} \qquad (5)$$

However, these and many other consistency indexes proposed do not provide their corresponding consistency thresholds and therefore lack any meaningful interpretation (Alonso and Lamata, 2006). Consequently, Alonso and Lamata (2006) computed a regression of the random indices and proposed a modified criterion of matrix acceptance. Known as the Alonso/Lamata linear fit, their approach introduces two novelties. First, it simplifies the consistency index estimation from Saaty, by using the maximum right eigenvalue λ_{max} the matrix as the consistency index.

Secondly, the decision maker can specify a level of consistency desired to meet the needs of his situation or case, rather than being limited to a fixed consistency threshold. Thus, the consistency of a matrix is dependent on the scope of the decision-maker.

Essentially, therefore, two factors determine whether a matrix is considered sufficiently consistent.

a) A consistency index (λ_{max})

b) The consistency level needed (α), such that $0 < \alpha \leq 1$, with α specified as a percentage and providing adaptability to different scopes.

The Alonso/Lamata consistency criterion will only find a matrix to be sufficiently consistent if and only if,

$$\lambda_{max} \leq n + \alpha(1.7699n - 4.3513) \quad (6)$$

Relating their new consistency criterion with the original consistency criterion in equation (3) above, Saaty's consistency using eigenvalue can be expressed as

$$\lambda_{max} \leq n + 0.1(1.7699n - 4.3513) \quad (7)$$

Following Goepel (2013) the Alonso/Lamata linear fit consistency criterion is used to test for consistency of a matrix in this methodology and implemented in the spreadsheet tool as,

$$CR = \frac{\lambda_{max} - N}{2.7699N - 4.3513 - N} \quad (8)$$

6.2.3.5 Automatic consistency checks

Reaching a consistency threshold or consensus in AHP and Delphi methods requires many iterative rounds of pairwise comparison judgements, a situation that can wear out decision-makers and lead to high attrition rates, which threatens the reliability and validity of final computed weightings and rankings. To overcome this scenario, software or algorithms can be implemented to automate the process and suggest amendments to individual decision-makers pairwise comparisons to achieve the required thresholds of consistency (Herrera-Viedma *et al.*, 2005).

The automation is implemented within the spreadsheet-based AHP-Delphi tool. The tool suggests values that need to be changed when a decision maker submits their pairwise comparison judgments, bringing their consistency closer to the desired consistency threshold. The inconsistent judgements are coded from 1-3 to indicate the level of inconsistency where 1 is the most inconsistent, followed by 2 and 3. Decision makers are not obliged to accept the automatic recommended judgement value changes but can modify their inconsistent judgements as they see fit, given the overall objective of the process (see Appendix A2.1 for the tool guidance on how this implemented).

To identify the inconsistent comparisons, the algorithm looks for the pair of alternatives *i,j* with

$$max\left(\varepsilon_{ij} = a_{ij}\frac{p_j}{p_i}\right) \qquad (9)$$

6.2.3.6 Aggregating priorities/Final weights for retrofit benefits.

After establishing the consistency (and consensus – see section 6.2.4) of each decision maker's comparison matrix, the final step is to combine the local priorities across all criteria to arrive at the overall priority. The traditional AHP approach uses an additive aggregation and normalises the sum of the local priorities (Ishizaka and Labib, 2009).

$$p_i = \sum_j w_j \times l_{ij} \qquad (10)$$

where p_i is the overall priority of the alternative i; l_{ij} is the local priority; w_j is the weight of criterion *j*.

As mentioned earlier when discussing the consistency index and ratio, the approach (also termed distributive mode) suffers from a rank reversal problem. Scholars have debated and are split into two on weight aggregation; i) the eigenvalue vector (EV) approaches which rely on additive aggregation on the one side and ii) the geometric mean vector approaches which rely on multiplicative aggregation, on the other hand. In contrast to additive aggregation, which is linear, multiplicative aggregation allows for the selection of a better compromise. Within the decision-makers comparison matrix, the row geometric mean method (RGMM) is adopted for computing row priorities. However, the final group or consensus priorities utilise the eigenvector method (EVM), because additive aggregation is the only way to retrieve exact weights (Vargas, 1997). Integrating both approaches in the current method and spreadsheet tool draws on the strengths of each approach while minimising their potential weaknesses.

For a set of preference relations between benefit i and j in a $n \, x \, n$ judgement matrix, where $i \neq j$, the global weight is given as

$$w_i = \prod_{j=1}^{n} P_{ij}^{1/n} \qquad (11)$$

6.2.3.7 Participant or expert weighting

It is possible and reasonable to reflect the level of experience and expertise of the various decision-makers in the final aggregation of priorities. In other words, assigning different weights to the judgements of different experts. This is consistent with traditional group decision-making approaches to capture the level of knowledge and social and personal experiences of experts or decision-makers. Achieving this however is not straightforward, especially when considering the correctness and rationality of the weights assigned to each expert.

Principally, this is approached in two ways, using either a subjective system or an objective one. Subjective methods have included requiring each respondent/expert to subjectively rank the other experts/decision-makers involved in the pairwise comparisons. Besides the obvious weakness of strong subjectivity in expert judgements, using this approach also breaks the cardinal requirement of anonymity in Delphi studies. Objective expert weighting methods establish the weights for each expert based on the responses and information provided, which can be challenging and complex (Yue, 2012).

While acknowledging that there will be very senior colleagues with superior knowledge and experience, the purpose of this ranking and weighing exercise is to obtain a representative view across the board of what benefits are relevant and need highlighting. Therefore, using expert weighting will defeat this objective by allowing some experts to have a higher influence on the final weights generated because their responses or judgements carry a higher weighting. For this proposed methodology therefore, expert weighting is not deemed necessary or relevant, hence all judgements are weighted equally. That said, provision is made for expert weighting in the methodology, for instances where a project team deems it necessary. The project lead is given the responsibility to determine intuitively the weightings for each respective team member. The implementation of this is detailed in the weighting tool's guidance notes in Appendix A2.2, while Figure 6-2 below provides an overview of the AHP implementation process adopted and implemented in the AHP spreadsheet tool.

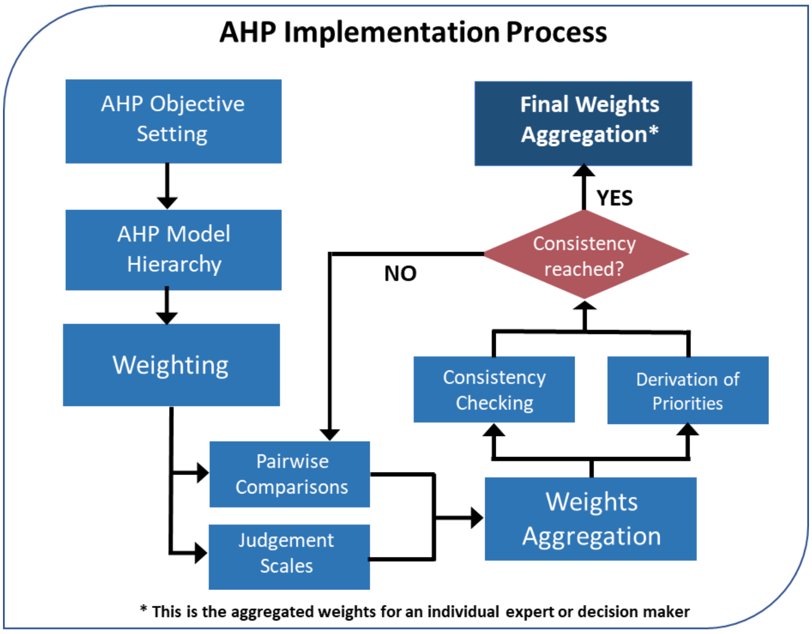

Figure 6-2 Overview of the AHP process.

6.2.4 Consensus checking (Group consensus)

Achieving consensus in a Delphi can be done in several ways (with or without mathematical aggregation). Ishizaka and Labib (2011) suggest the use of consensus votes on judgements or consensus votes on priorities where no mathematical aggregation is used in reaching consensus. This approach is useful and relevant for expert panels or groups that are more "synergistic". The group can reach a consensus on the value to be entered for each pairwise comparison matrix. Alternatively, each decision-maker completes their pairwise comparisons and then a consensus on the priorities is reached through a consensus vote.

This approach is recommended for use in retrofit projects where the project lead or retrofit coordinator assembles the rest of the team to conduct the consensus vote on either the pairwise comparison judgements or on the priorities after individual pairwise judgements and priorities calculated are completed (O'Leary, 1993). On the other hand, where a consensus vote is too complex or where a panel is not synergistic and spatially diverse, a mathematical aggregation can be adopted to reach a consensus. If each decision maker's pairwise comparisons achieve a perfect consistency (as outlined in the AHP sections earlier), two methods exist for consensus checking; 1) the geometric mean method (GMM) and 2) the weighted arithmetic mean method (WAMM).

The WAMM computes the arithmetic mean of all experts for the pairwise comparisons. For example, if person A gives a value of 7 and person B gives a value of 1/7 for a particular alternative, then the consensus between person A and B using WAMM is (7+1/7)/2 = 3.57. In the GMM, priorities are computed from the geometric mean of individual pairwise evaluations used as elements in pairwise matrices. This method is recommended as it preserves the reciprocal property of matrices (Ishizaka and Labib, 2011b). It represents a compromise of all the opinions or evaluations of the decision-makers in the group and does reflect the opinion of any group member. Using the GMM method, the group consensus of persons A and B in the scenario above will be $\sqrt{7 \times \frac{1}{7}} = 1$. The GMM method is chosen and implemented in the benefits weighting spreadsheet tool where a weighted geometric mean is used to consolidate the pairwise comparisons of all participants into an aggregated group decision matrix. The computation uses the decision matrix elements of each decision-maker $a_{ij(k)}$ and the weight of each decision-maker w_k (where expert weighting is implemented)

$$c_{ij} = \exp \frac{\sum_{k=1}^{N} w_k \ln a_{ij(k)}}{\sum_{k=1}^{N} w_k} \tag{12}$$

However, before aggregating weights and priorities as outlined above, the judgment relations of all experts $k(a_{ij})$ needs to be checked for consensus. To do this, a consensus indicator is established (in Table 6-6).

Each expert's judgement is automatically checked for consensus in the spreadsheet tool, using the defined consensus indicators. For each expert, a consensus value is estimated, and advice values are provided (recommended changes to their initial judgement) to achieve the required level of consensus with the group opinion. This feedback is sent to each expert and constitutes the second round of the Delphi survey. The next section provides detailed implementation guidance notes for using the associated spreadsheet tool (ReBAT Benefits Prioritization and Ranking Tool).

Table 6-6 Interpretation of defined consensus indicator (S)*

S*	≤ 50%	50% - 65%	65% - 75%	75% - 85%	≥85%
Consensus	No consensus	Low	Moderate	High	Very High

6.3 Establishing a numerical scoring scale for the retrofit benefit indicators

6.3.1 Defining the Scoring criteria and thresholds

This section sets out the proposed scoring criteria and thresholds for each of the retrofit benefit indicators in the retrofit benefits measurement framework established earlier in Chapter 5, Section 5.2.4. Out of the 23 indicators in the final framework, only 12 are included in the scoring tool. The purpose of the criteria is to enable a retrofit project to be scored in terms of its contribution towards the achievement of efficiency improvements in the existing domestic housing stock in the UK (especially the worst-performing domestic properties within the social housing sector).

It is important to note in advance that the central element of the approach to this scoring methodology and indeed the entire study is a whole-house approach to retrofit. Consequently, the scores are targeted at multi-measures projects although they may be applied to single-measures projects. Following the workflow process outlined in Chapter 7, Section 7.5, the scoring criteria & thresholds are divided into three levels, basic, intermediate, and advanced levels (Table 6-7 below) to give users a range of choices with different levels of effort, detail, and rigour. However, this study only focuses on the basic level evaluation and so is the discussion on scoring thresholds.

Table 6-7 Evaluation level/ stage for retrofit benefits following PAS 2035

Social benefits	Environment benefits	Economic benefits
Basic Evaluation (Essential Version)		
Improved Physical Health	Energy Savings	Energy Bill Savings
Improved Mental health	Carbon savings	Jobs/ Employment created.
Fuel poverty reduction	Indoor environment quality (IEQ)	The cost efficiency of retrofit investment
Neighbourhood quality improvement	Thermal comfort (survey)	Property value improvement
Intermediate Evaluation (Physical Monitoring and brief occupant survey)		
Improved spatial quality and aesthetics of home	Ventilation improvements (air tightness) Thermal comfort (physical monitoring/measurements)	Energy bill savings (metered or utility readings)
Advanced Evaluation (Extension/Detailed survey, submetering, thermographic surveys)		
Reputation & Goodwill	Local energy supply improvement	Maintenance & repairs savings
Strengthened local supply chain partnerships	Regulatory Compliance	Property value improvement

6.3.2 Environment Benefits Indicator criteria thresholds

6.3.2.1 Energy savings

Method 1: Use the SAP/EPC scores from both the pre- and post-retrofit scenarios to estimate the savings achieved. Where post-retrofit SAP/EPC assessment has not yet been completed or cannot be done, the potential savings from the pre-retrofit EPC assessment can be used after adjusting for the comfort take or rebound effect.

Method 2: Capture and record utility/ household energy consumption data before and after the retrofit (ideally covering a 12-month duration - which includes a winter and summer season). Where possible both total and net energy use should be reported. Given the duration required, this indicator is best suited for the intermediate or advanced stage/level of monitoring to allow time to compile the utility data.

Data sources, collection, and analysis: Basic building characteristics and energy systems information catalogued from building plans and specifications combined with a walkthrough energy audit of homes before and/or after the retrofit project. Alternatively, occupants' surveys can be used as the data source to estimate reductions/savings in energy consumption. Calculation of total energy consumption (per unit i.e., floor area) or by property (aggregated into project level) or by energy source. The results can be compared with past consumption (before retrofit) and expressed as a percentage reduction or savings in energy use. Where baseline or past consumption data does not exist, the estimated energy consumption of the retrofitted home can be benchmarked with a similar property with similar characteristics in the neighbourhood which did not undergo any retrofitting.

Criteria thresholds

Deep retrofit is essentially any building retrofit that reduces the final energy consumption by a *significant percentage* compared with pre-retrofit levels and leads to a very high energy performance (EU, 2019). The "significant percentage" reduction in energy consumption is given as typically more than 60% by the EU (2019). Following the scoring scales defined in section 5.3, and the EU recommendation above, the thresholds for 'Energy savings are defined below.

a) **A high score of 5** for retrofit projects that result in more than 60% energy savings or reduction in energy consumption (these correspond to deep retrofits).
b) **Two medium scores of 4 and 3** for projects that produce more than 20% but less than 60% energy savings or reduction in energy consumption (medium retrofits)
c) **Two low scores of 2 and 1** for projects that result in less than 20% of energy savings or achieve no reduction in energy consumption.

As might be obvious, the above scoring thresholds are relevant when energy savings are estimated from metering or physical measurements where savings are verified objectively and factually. That notwithstanding, the same score thresholds can be used where energy savings are estimated from SAP/EPC data.

Also, similar scoring thresholds and rationale are applied to the rest of the environmental benefit indicators.

6.3.2.2 Carbon savings

Theoretically, carbon savings and energy savings may or may not be correlated. Where there is a correlation, carbon savings can be estimated using conversion factors applied to the total energy savings. There are instances where the energy mix of a property or project remains significantly unchanged before and after the retrofit project. However, energy savings and carbon can be uncorrelated. When a property switches energy use or changes its energy mix significantly, carbon emissions may be reduced while actual energy consumption remains constant or in some instances increases. This is typical in the case of introducing renewable energy in a retrofit project. The amount of actual energy consumed (in kWh) may not change much or remain the same, but because renewable energy (solar or wind) is significantly less polluting than natural gas or oil, carbon emissions will be reduced significantly. This needs to be considered in the estimation of carbon savings for retrofit projects (at all scales).

Method 1: Like energy savings, CO2 emissions data can be obtained from the pre- and post-works EPCs (specifically the environmental impact rating scores). The difference in emissions between post and pre-retrofit scores represents the savings in carbon and can be expressed in percentage savings. For SAP/EPC calculations, data must be obtained on the EPC ratings of buildings pre-, and post-retrofit, to identify the upgrade in ratings achieved. This will allow each property to be scored individually.

Method 2: Where SAP emissions data is not available, it can be calculated by using direct monitoring of final energy consumption over 12 months (pre- and post-retrofit) multiplied by the appropriate carbon conversion factors (kgCO_2eq/kWh or kgCO_2eq/MWh) for the energy types used in the building. Carbon emissions factors for the UK are available from Conversion Factors 2021. The UK government provides further guidance on how to measure and report carbon and other greenhouse gases here.

Collection and Analysis: The total carbon emissions saved can be expressed as a percentage (%) reduction in carbon emissions at the property or project level. The total % reduction in CO_2 should be used to score the retrofit project using the scoring thresholds outlined below.

Criteria thresholds and rationale: The thresholds defined for energy savings also apply to carbon savings.

6.3.2.3 Indoor environment quality (IEQ)

Ascertaining the ideal indoor conditions conducive to building occupants' comfort, satisfaction and health has been a major area of research in the built environment. Various techniques and approaches (subjective and objective) for measuring IEQ have also been proposed and used over the period.

This scoring methodology adopts occupant surveys for the assessment of IEQ. This is consistent with the recommendations of PAS 2019:2035, that basic monitoring and evaluation of retrofit projects are done through occupant surveys (see section 14.4 of BSI & BEIS, (2019)). The retrofit scoring tool aggregates three key IEQ indicators, namely, indoor air quality (IAQ), acoustic comfort (noise), and lighting (illuminance). The following sections detail the definitions, methods and data required to measure and assess these in the scoring tool. Occupants respond to one question on these indicators. A score of 4 or 5 on each question represents an improvement in the indicator. The responses are aggregated into a single indicator of the improvement in indoor environment quality and scored on the spreadsheet tool.

Indoor air quality (Air comfort): Respondents answer a question on their opinion of the air quality in their home in general after the retrofit (compared with before the retrofit situation). Their responses are rated from 5 very satisfied to 1 very dissatisfied.

Acoustic comfort (Reduced noise): Occupants are asked to describe the overall noise level in their homes. They can choose from 5, very satisfied (or no noise) to 1, very dissatisfied (a lot of noise). Noise here includes internal noise, that from neighbours and outside the house.

Lighting (illuminance): Occupants are asked to rate the overall lighting levels in their home (considering both natural daylight and electric lighting), using the same response scale as indoor air quality (Allan *et al.*, 2019).

6.3.2.4 Thermal comfort

This indicator measures improvements in the thermal comfort of a home or dwelling due to better control of room temperatures, lower temperature differences, air drafts and air humidity (Warm in winter/cool in summer). Given the subjective-based approach to its evaluation in the essential (basic) evaluation level/stage, the ASHRAE 55[3] definition of thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment and is assessed mainly by subjective evaluation" is adopted. Thermal comfort is a seasonal-dependent indicator, and some studies have separate indicators for winter and summer thermal comfort.

For residential retrofits, involving a subjective survey measurement of thermal comfort, the percentage of households expressing an improvement in thermal comfort or satisfaction with the thermal comfort in their homes post-retrofit is recommended and adopted in this framework and tool (following Ncube & Riffat, 2012).

Method 1: three questions in the occupant survey questionnaire address thermal comfort. There is a general question asking occupants to rate the overall thermal comfort in their homes using the very satisfied (5), and very dissatisfied (1) scale. Season-specific questions for winter and summer are also included for projects that prefer to measure winter and summer thermal comfort separately.

Method 2: This is for intermediate/advanced evaluation levels where physical monitoring of indoor temperature parameters is carried out for pre- and post-retrofit scenarios and analysed. Alternatively, simulation and modelling approaches can be used such as in Energy Plus or Passivhaus et cetera.

Criteria threshold and rationale: Following Ncube and Riffat, (2012), a scoring criterion for thermal comfort is defined as the percentage of people accepting the thermal environment in their retrofit home (5 for more than 80% acceptance or expressed satisfaction, 4 for 61-80%, 3 for 41-60%, 2 for 20-40% and 1 for less than 20%).

6.3.3 Social benefits indicator criteria thresholds

As discussed in Chapter 2, section 2.3.3.1, the correlation between retrofit interventions and the improvement of occupants' physical health is well-documented. Modelling work conducted by Santamouris, (2016) on European nations to estimate the required investments to eradicate fuel poverty in Europe between 2015 and 2050 estimated that such an endeavour can result in an estimated reduction in health problems ranging between

[3] *ANSI/ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy, also parallel with ISO 7730:2005*

50% and 90% post-retrofit. Pedersen, Gao and Wierzbicka, (2021) found that about 69% of respondents reported their general health as good/very good following retrofit improvements to their homes. Other studies have produced similar results. The incidence of colds and flu was reported to have decreased by as much as 50% when indoor quality was improved in homes (Carnegie Mellong, 2005 as cited in Santamouris, 2016). Similar reductions of 50% in the incidence of anxiety and depression are reported by Gilbertson and Green (2008) in their study involving the rehabilitation of low-income homes.

Lastly, occupant surveys have been a staple for measuring the health impacts of home energy efficiency intervention works or retrofits. Other methods such as data linkage longitudinal analysis (Curl, Kearns and Mason, 2015), community-based field studies (Gupta, Barnfield and Hipwood, 2014), household monitoring studies as well and economic evaluation and modelling (Washan, Stenning and Goodman, 2014) have also been used. The REBAT scoring tool with an emphasis on a human-centred approach, simplicity, and cost-effectiveness, has adopted occupant surveys to establish the health benefits of retrofit projects, following Poortinga et al., (2018a) who also implemented some of the other methods in their study.

6.3.3.1 Improved Physical health.

The thresholds for this indicator are anchored in research linking housing conditions to physical well-being (see Chapter 2, section 2.3.3.1). As mentioned, numerous studies have highlighted the tangible health benefits of retrofitting, ranging from reduced respiratory problems due to improved indoor air quality to diminished risk of injuries from enhanced safety measures (Curl, Kearns and Mason, 2015; Hamilton *et al.*, 2015; B *et al.*, 2018). A study by (Sharpe *et al.*, 2019) found a direct correlation between housing improvements and reduced hospital admissions, showcasing the pivotal role retrofitting plays in physical health. The thresholds chosen for this indicator, therefore, reflect the varying degrees to which a retrofit project can improve overall physical health outcomes and are informed by these empirical studies.

6.3.3.2 Improved Mental health.

Thresholds for improved mental health are rooted in evidence that ties housing quality with psychological well-being (Liddell and Guiney, 2015; Pevalin *et al.*, 2017). Liddel and Guiney (2015)[4] especially summarise several important publications showcasing evidence for the association between mental well-being and improving home energy efficiency. However, it is a daunting task to specify how retrofitting can generate improved mental health and well-being, especially given the diverse range of mental health outcomes that are associated with housing quality. These include prolonged thermal discomfort (Gilbertson, Grimsley and Green, 2012), the worry about energy bills (Anderson, White and Finney, 2012), the worry and fear of falling into fuel poverty or debt (Tod *et al.*, 2012), loss of space (spatial shrink) from only being able to adequately heat and use one or two rooms (Liddell and Morris, 2010), just to mention a few.

While a considerable number of the reviewed studies do not explicitly provide statistics on the number of households or the percentage of improvements in mental health, they nonetheless consistently indicate a significant likelihood of enhanced mental well-being linked to retrofitting. However, Gilbertson & Green's (2008) research has shown that retrofitting can lead to considerable reductions in anxiety, depression, and distress. A notable study revealed a 48% decline in anxiety and depression after housing improvements. The scoring thresholds, therefore, provide an indicative guide to the potential psychological benefits a retrofit project may confer.

6.3.3.3 Fuel poverty (reduction - improved social welfare)

Similarly to 'Improved health and mental health', this benefit indicator is addressed in section 2.3.3.2. It is an intricate challenge, deeply rooted in the interplay between high fuel prices, household income, and inadequate energy efficiency in homes. When households face difficulty in properly heating their homes due to these factors, they are deemed to be in a state of fuel poverty. Given the extensive research and policy discourse surrounding this issue (Liddell and Morris, 2010; Walker *et al.*, 2014; Vilches, Barrios Padura and Molina Huelva, 2016; Monteiro *et al.*, 2017), it is evident that addressing fuel poverty, especially within the social housing sector, is of paramount importance.

[4] This study had a focus on people living in cold and damp homes.

6.3.3.4 Neighbourhood quality improvement

The criteria for Neighbourhood Quality Improvement have been formulated based on the broader impact of retrofit projects on community well-being. As housing conditions improve, there's often a cascading positive effect on the surrounding community. This can manifest in reduced crime rates, increased social cohesion, and elevated neighbourhood pride. In a groundbreaking study, (Chapman *et al.*, 2009) found that children in retrofitted homes had fewer school absences, hinting at the broader societal benefits of such interventions. The thresholds established for this category reflect the multiplicity of outcomes a retrofit project can have on neighbourhood quality, in this instance, five of them.

6.3.4 Economic benefits indicator thresholds

6.3.4.1 Energy Bill Savings

The essence of this indicator lies in the tangible fiscal benefits that homeowners and tenants experience post-retrofit. The thresholds for energy bill savings are drawn from a confluence of data sources, notably from (Colclough, 2021), which underscores savings of between €400-€2000 annually, primarily due to heating efficiencies:

1: less than 20% savings — This reflects projects that, for whatever reason, did not result in any tangible energy bill reductions.

2-5: Ranging from less than 20% to above 80% savings — The gradient of these scores mirrors the percentage reduction in energy costs, drawing a direct line between the efficiency of the retrofit and the fiscal benefits realized.

6.3.4.2 Jobs/ Employment created.

The broader economic ripple effects of retrofit projects encompass job creation in various sectors. Drawing from data by Buildings Performance Institute Europe (BPIE)., (2020) and others, the ability of such projects to stimulate employment becomes evident:

1: Less than 10 FTE jobs per £1m — At this tier, the job creation impact is minimal.

2-5: Spanning 12 to above 22 FTE jobs per £1m — These thresholds capture the spectrum of employment opportunities, shedding light on the project's broader socio-economic contribution.

6.3.4.3 Cost efficiency of retrofit investment

The true hallmark of a successful retrofit is its cost efficiency. The more energy saved per pound invested, the more value derived from the retrofit. Santamouris (2016) and Fingleton et al. (2021) provide some insights:

1 for below 200 kWh — Reflects limited efficiency.

2-5: From 201 - 500 kWh, escalating to above 1,000 kWh — These thresholds serve as a testament to how adeptly resources have been utilized in the retrofit project, directly correlating investment with energy savings.

6.3.4.4 Property value improvement

An enhanced property value post-retrofit serves as both a fiscal and symbolic win for homeowners. Research, including insights from Colclough (2021), illustrates the tangible upswing in property values:

1: Less than 2% — Minimal appreciative value.

2-5: Ranging from 2-3% to over 5% — These delineations map the incremental value growth of properties, reflecting both the tangible and intangible benefits accrued from the retrofit. By anchoring these thresholds in robust research and empirical data, we seek to offer a nuanced, comprehensive lens through which the economic benefits of retrofit projects can be discerned and appreciated.

6.4 Expert review of scoring scales and thresholds

6.4.1 Expert Selection

The expert selection again followed the guidelines explained in Chapter 4 (section 4.6.1.2). Following Bryman (2012), experts who participated in the review of the retrofit benefits framework were excluded from this review, as participants should not be part of the previous stages of the study.

6.4.2 Design of the review questionnaire

For the expert review and feedback on the final list of benefit indicators, criteria and scoring thresholds/scales extracted from the literature reviews, an interview guide and a 'Yes/No' spreadsheet questionnaire like the one used for the review of the benefits framework in chapter 5 (section 5.1.2) was developed to facilitate discussions with expert practitioners. The interview guide was structured to systematically cover a variety of topics crucial to the evaluation of the retrofit scoring tool. Each section was designed to prompt specific responses that would inform the reliability, accuracy, and effectiveness of the tool. It was divided into 4 sections. The first addressed the benefit indicators chosen, their completeness, clarity in description and the data sources recommended for evaluating the benefit indicators. The second section addressed the scoring criteria, scale, and thresholds, while the third and fourth sections covered practical aspects such as the features and results presentation as well overall methodology of the scoring tool (first draft).

The Yes/No spreadsheet was a first draft of the tool but with only the list of indicators, criteria and scoring thresholds (pictured in Table 6-8 below). All the benefits indicators were presented on the same sheet but categorised into social, environmental, and economic to allow for ease of review. The questionnaire was distributed to experts who were allowed to either review and submit their feedback directly on the questionnaire or participate in a structured interview or both. The feedback included two questions for each indicator. A YES/NO answer indicating agreement or otherwise with the defined criteria and thresholds for an indicator and a comment section to provide further details on the reason for the (dis)agreement. All documents related to the interview process, including the interview guide, and consent forms, are provided in Appendix A3 for reference.

6.4.3 Sampling and Interview arrangements

A purposive sampling strategy was employed, consistent with the KRNW approaches discussed earlier in the methods section. Participants were chosen based on their experience, knowledge, and relevance to the field of building retrofits. Interview arrangements were made to accommodate the experts' availability, and all the sessions were conducted adhering to ethical guidelines. Over 20 invitations were sent to industry practitioners with knowledge of housing retrofitting, including housing providers and academics. Out of these, 5 experts responded and participated in the review which is not uncommon in specialized fields where experts often have tight schedules. Some experts could not be interviewed due to scheduling challenges. Multiple follow-ups were carried out to confirm participation; some invitees were followed up 3–4 times to gauge their interest and availability. The interviews were conducted using Microsoft Teams to accommodate the busy schedules and different locations of the participants.

Expert Review Spreadsheet Questionnaire for Retrofit benefits scoring criteria and scale

Please point out your review and agreement on the measures by **clicking only on one** of two options: **Yes or No** (in the review column). Please **submit your suggestions in the comment box (whether you answered Yes or No)**
You can test the tool, by entering your benefit scores in the "Score" column - the **defined score are 1, 3 or 5 however 2 and 4 are between values.** The results are presented in "Results" sheet.

Category	Benefit Indicator	Description	Criteria	Data Collection and calculation method	Score Threshold	Rationale	Sources	Score	Review question Do you agree with the defined measure?	Kindly Comment on why you agree or disagree
SOCIAL BENEFITS	**Physical health improvement** *(Self-reported improvement in physical health & well-being)*	Reported personal health and well-being improvements of residents from retrofit measures installed. Improved indoor quality of homes contributes to improved respiratory health, satisfaction with thermal conditions and reduced social isolation.	% of occupants reporting improved physical health or well-being post-retrofit.	Occupant survey responses – Q14 in questionnaire. Average of answers from all respondents	1: Less than 30% 3: 30 – 60% 5: above 60%	Reduction of health problems between 50% and 90% - estimate (Santamouris, 2016) 69% reported general health as good/very good (Pedersen et al., 2021)	Pedersen et al., (2021) Hamilton et al (2015) Thema et al., 2017 Santomouris, (2016) Gilbertson & Green, (2008) Poortinga et al., (2018)		☐ Yes ☐ No	
	Improved Mental health/ well-being	Reduction in anxiety and distress or depression in response to improve building characteristics. Improved indoor environment also affects general mood and confidence of occupants eliminating the underlying conditions of anxiety and depression. Affordable heating (reduced spending on heating bills) resulting from retrofits leads to improved well-being by relieving financial stress. Social isolation (which affects mental health) is also reduced as people can spend more time together or invite people into their homes.	% improvement in the mood and confidence of occupants or reduction in reported mental health risk factors (anxiety/distress) among tenants or % post retrofit.	Occupant survey responses – Q15-16 in questionnaire. Average of answers from all respondents	1: less than 20% 3: 20 – 40% 5: above 40%	Depression & anxiety fell by 48% following home improvements (Gilbertson & Green, 2008).	Gilbertson & Green, (2008) Thema & Wuppertal, (2018) Poortinga et al., (2018)		☐ Yes ☐ No	
	Fuel poverty reduction *(reduction - improved social welfare)*	Reduction in the number of households in fuel poverty. Retrofitting improves the thermal performance of homes and thus reduces the cost of heating. This relieves the financial burden on households.	% of households in retrofitted homes removed from the risk of fuel poverty (based on self-reported subjective fuel poverty question)	Occupant survey responses – Q17 in questionnaire. Average of answers from all respondents Occupant survey.	1: Less than 30% 3: 30 – 60% 5: above 60%		Santamouris, (2019) Thema & Wuppertal, (2018) Hong et al., (2009) Fingleton et al., (2021) Poortinga et al., (2018) Grey et al., (2017)		☐ Yes ☐ No	
	Neighbourhood Quality Improvement *(Identity and attractiveness)*	General improvements in social relations and sense of safety and crime rates in a neighbourhood following renovation or retrofits	Does the retrofit project lead to any of these outcomes, measured from occupant survey? a. Not worried about crime b. Good neighbourhood c. Social and community participation c. No problems with anti-social behaviour d. No problem with vandalism/graffiti	Occupancy survey responses – Q19 – Q23 in Occupant questionnaire Average of answers from all respondents.	1 = only one outcome achieved 3 = 2 or 3 outcomes achieved 5 = all 4 outcomes achieved	Chapman et al., (2009) reports that Children in the intervention group compared to control group had 1.80 fewer days off school.	Chapman et al., (2009)		☐ Yes ☐ No	

Table 6-8 Expert review questionnaire for retrofit benefits scoring thresholds and scales.

6.4.4 Results from the review and final scoring thresholds and scales

6.4.4.1 Benefit Indicators

1. *Neighbourhood Quality Improvement Indicator*: One of the reviewers raised a concern about the link between neighbourhood quality improvement and a retrofit project, suggesting they may not be very direct, especially for smaller projects that retrofit just one house or a few buildings. In response to the feedback, the definition of the neighbourhood quality improvement indicator has been adjusted. It has been clarified that the neighbourhood quality improvement indicator applies mainly to larger retrofit programmes where there's a potential to impact the entire neighbourhood's quality, rather than individual properties.

2. *Cost Efficiency and Energy Bill Saving Indicators*: Another expert observed an overlap between energy bill saving and cost efficiency, especially when cost efficiency is measured in terms of kilowatt per hour and asked for this to be revisited. To address the concerns, a refined definition to differentiate between the two has been adopted. Energy bill saving focuses on the direct financial benefits for occupants, while cost efficiency concerns the broader economic advantage of the retrofit intervention in energy terms.

3. *Capturing the impacts of retrofit projects on the well-being of occupants during retrofit projects*: an issue was also raised around how to capture the impacts on well-being during construction or installation phases. Tenant displacement or decanting during retrofit projects is undeniably a critical factor that can significantly impact the well-being and satisfaction of building occupants. The very nature of some retrofit projects may necessitate the temporary relocation of tenants, and this can introduce a myriad of logistical, financial, and psychological stressors. However, the suggestion has not been implemented for a couple of reasons; 1) The time required for retrofit projects can vary significantly based on the complexity of interventions, unforeseen complications, or external factors like weather conditions. Moreover, not all retrofit projects necessitate decanting. Including this metric might introduce bias against those projects that require more intensive interventions and capturing a consistent "impact duration" might be elusive. Instead, a recommendation is provided to retrofit teams to consider this as part of their occupancy surveys.

4. *Energy consumption during the retrofit and its impact on energy savings*: The energy consumed in implementing the retrofit itself was also raised as a potential point of consideration for the scoring tool. Indeed, any holistic understanding of a retrofit's net energy benefits must consider both the energy savings and the energy expended in achieving those savings. Energy used during the retrofit may comprise direct energy usage from construction machinery and equipment which is the most apparent. Furthermore, the production of materials can also involve indirect energy expenditure, captured in the concept of *embodied energy*. There may also be instances of temporary energy consumption, such as when occupants require alternative accommodations during the retrofit.

   However, a methodological decision was made not to include this as an indicator to be measured or as part of the estimation of energy savings for the following reasons.

   a) the primary aim of the present study is to evaluate post-retrofit benefits, given their enduring impact on occupants, stakeholders, and the environment and while energy consumption during the retrofit is undeniably essential, its magnitude may be minimal when juxtaposed against the potential long-term energy savings once the retrofit is complete.

   b) there appears to be an absence of established metrics in the literature to capture this. Developing a new metric is an option to explore, however, given the scope of the current scoring tool, this was avoided. Future iterations of the scoring tool can explore this further. Potential approaches to capture this indicator in future works could include.

      1. *Energy Consumption per Square Foot*: the energy consumed per square foot of retrofitted space. This basic metric can act as a foundational step, refined by subsequent research.
      2. *Engage with Industry Professionals*: Surveys or interviews can be conducted to understand how professionals in the field perceive this energy consumption and its importance.

   Given the recognized gap in literature and practice concerning energy consumption during retrofit, it is recommended that future research specifically delve into this area.

6.4.4.2 Scoring criteria and thresholds

1. *Consistency of thresholds and a three-point scale (physical health, mental health, fuel poverty):* These final indicators had only three levels of scoring (1, 3, and 5). One reviewer indicated that the three-point option lacked precision, especially considering the range endpoints some as little as 2% making it difficult to accurately score a benefit indicator.

Table 6-9 Amended scoring thresholds for three indicators (Energy savings, Carbon savings & Energy bill savings)

Scale	Original Threshold	*New threshold*
1 =	No reduction/savings	Less than 20% savings
2 =	Less than 20% savings	20 – 40% savings
3 =	20 – 40% savings	41 – 60% savings
4 =	41 – 60% savings	61 – 80%savings
5 =	Above 60% savings	Above 80% savings

2. *Points for No Savings (energy, carbon, and bills):* The thresholds for Energy savings, carbon savings and energy bill savings had the lowest score threshold being "1 = No reduction/savings". The original thinking for this score threshold was conceived with some considerations in mind.
   a) *recognition of variabilities*: Some projects, due to the rebound effect or comfort take-back, might not manifest clear-cut energy savings. This can often mask the true benefits of a retrofit.
   b) *change in energy composition*: Even if there's no reduction in energy consumption, the energy mix might shift towards more sustainable sources, leading to carbon savings. Such nuanced benefits were deemed worthy of acknowledgement.
   c) *capturing all data*: Not all retrofits guarantee anticipated savings due to factors like improper installation, suboptimal material choices, or inadequate maintenance. A threshold for "no savings" ensures such outcomes are accurately recorded rather than overlooked.

However, the expert reviews suggested revisiting these thresholds. Their feedback highlighted a counter-intuitiveness of this approach in awarding scores for no tangible savings or reductions in the context of evaluating the effectiveness of a retrofit project. If the goal is to emphasize the importance of achieving tangible benefits, then it logically follows that projects that do not achieve any savings should not earn any points. Additionally, a critique was raised on the broad spectrum of the upper end of the threshold awarding 5 points for savings between 60% and 100%. Considering this feedback, establishing a more balanced scoring scale, and eliminating the 'no savings problem', the thresholds for these three indicators were re-evaluated and adjusted. The revised scoring scale is detailed in Table 6-10 above.

3. *Property value improvement:* Further reviews led to the thresholds for property value improvement being adjusted. The update was to the upper limits of each score threshold to provide a clearer delineation of the per cent increase ranges. The updated thresholds ensure that each scoring range is explicitly defined, preventing any potential overlap or ambiguity. Specifically:
   a) The old thresholds had a potential overlap between ranges. For instance, "3 = 3 – <4%" could be interpreted to include values right at 4%, which could also fall under "4= 4 - 5%".
   b) The new thresholds rectify this by clearly defining non-overlapping intervals, such as "3 = 3 – 3.9% increase", which removes the ambiguity and brings about precision and avoids generalizations.

   These changes, while seemingly minor, play a crucial role in ensuring clarity, precision, and objectivity when evaluating the property value improvement resulting from retrofit projects.

4. *Jobs created or additional jobs indicator:* A query was raised on the jobs created per £1 million investment criteria/metric for this indicator. One expert suggested that this may imply that retrofit projects need to invest at least that amount, which is not always the case. However, no adjustment was made to this criterion for two reasons. 1) this is the standard metric used in industry and especially in estimating the economy-wide job impacts of various investments, including retrofit projects. 2) the £1 million figure is a proportionate metric, meaning that even if a project doesn't spend/invest up to £1 million, the additional jobs created can be proportionally calculated against the standard Full Time Equivalent (FTE) jobs per £1 million multiplier being used.

Table 6-10 Final scoring criteria and thresholds for the social benefit indicators.

Benefit Indicator	Criteria	Score Threshold	Sources
Physical health improvement *(Self-reported improvement in physical health & well-being)*	% of occupants reporting improved physical health or well-being post-retrofit.	1 = Less than 20% HH 2 = 20 – 40% HH 3 = 41 – 60% HH 4 = 61 – 80% HH 5 = Above 80% HH HH - Households	(Pedersen et al., 2021) ; Hamilton et al 2015 ; Thema et al., 2017 ; Santamouris, 2016 ; Gilbertson & Green, 2008 ; Poortinga et al., 2018)
Improved Mental health/ well-being	% improvement in the mood and confidence of occupants or reduction in reported mental health risk factors (anxiety/distress) among occupants, post-retrofit.	1 = less than 20% 2 = 20 – 30% 3 = 31 – 40% 4 = 41 – 50% 5 = above 50%	(Gilbertson & Green, 2008; Thema & Wuppertal, 2018; Poortinga et al., 2018)
Fuel poverty reduction *(reduction - improved social welfare)*	% of households in retrofitted homes removed from the risk of fuel poverty (based on a self-reported subjective fuel poverty question)	1 = Less than 20% HH 2 = 20 – 40% HH 3 = 41 – 60% HH 4 = 61 – 80% HH 5 = Above 80% HH HH - Households	(Santamouris, 2019; Thema & Wuppertal, 2018; Hong et al., 2009; Fingleton et al., 2021; Poortinga et al., 2018; Grey et al., 2017)
Neighbourhood Quality Improvement *(Identity and attractiveness)*	Does the retrofit project lead to any of these outcomes, measured from the occupant survey? a. Not worried about crime b. Good neighbourhood c. Social and community participation d. No problems with anti-social behaviour e. No problem with vandalism/graffiti	1 = Only one outcome achieved 2 = 2 outcomes achieved 3 = 3 outcomes achieved 4 = 4 outcomes achieved 5 = all 5 outcomes achieved	Chapman et al., (2009)

Table 6-11 Final scoring criteria and thresholds for the environmental benefit indicators.

Benefit Indicator	Criteria	Score thresholds	Sources
Energy Savings *(Total energy saved)*	Percentage (%) reduction or savings in annual energy consumption post-retrofit based on EPC/SAP estimates (potential savings) or actual monitoring of utility consumption from meters or bills.	1 = Less than 20% savings 2 = 20 – 40% savings 3 = 41 – 60% savings 4 = 61 – 80% savings 5 = Above 80% savings	(Fingleton et al., 2021; European Commission, 2020; Colclough, 2021; Ahrentzen et al., 2016; Hamilton et al., 2015; European Parliament & European Union, 2018; EU, 2019)
Carbon savings *(Emissions saved from energy savings)*	Percentage annual reduction in CO2eq/year after retrofits (from EPC estimates or monitored or simulated data).	1 = Less than 20% savings 2 = 20 – 40% savings 3 = 41 – 60% savings 4 = 61 – 80% savings 5 = Above 80% savings	(Colclough 2021; UK Climate Change Act, 2008; Fingleton et al., 2021; Santamouris, 2016)
Indoor Environment Quality - IEQ *(improved indoor air, acoustics, and lighting)*	Percentage (%) of households reporting improvement or satisfaction with indoor air quality, and acoustic and lighting comfort. Or percentage reduction in air contaminants in homes or % Improvement in lighting quality from photometric measurements	1 = Less than 20% HH 2 = 20 – 40% HH 3 = 41 – 60% HH 4 = 61 – 80% HH 5 = Above 80% HH HH - Households	(Frey et al., 2015; Broderick et al., 2017; Pedersen et al., 2021; Heinzerling et al., 2013; Hunn et al., 2012; Mui and Chan, 2011; Chiang et al., 2002; Ncube and Riffat, 2012; Dubois et al., 2016)
Thermal comfort (Winter/ Summer)	% of households reporting an improvement in the temperature of their home (winter and summer temperatures) or percentage increase in winter temperature or reduction in summer temperature in homes (from spot measurements).	1 = Less than 20% HH 2 = 20 – 40% HH 3 = 41 – 60% HH 4 = 61 – 80% HH 5 = Above 80% HH HH - Households	Pedersen et al. 2021; Heinzerling et al., 2013; Hong et al., 2009; Fingleton et al., 2021; Mui and Chan, 2011 ; Chiang et al., 2002 ; Ncube and Riffat, 2012 ; Hunn et al., 2012)

Table 6-12 Final scoring criteria and thresholds for the economic benefit indicators.

Benefit Indicator	Criteria	Score Threshold	Sources
Energy Bill Savings *(Bill savings or extra warmth from retrofitting)*	Percentage annual reduction in energy costs/bills after retrofit (onsite renewable could also generate financial benefits and may be included where possible)	1 = Less than 20% savings 2 = 20 – 40% savings 3 = 41 – 60% savings 4 = 61 – 80% savings 5 = Above 80% savings	(EU, 2019; Fingleton et al., 2021)
Jobs/ Employment created *(Additional jobs created per £m invested)*	Number of additional full-time equivalent (FTE) jobs generated from the project (direct, indirect & induced) per 1 million pounds invested in a retrofit project Data from a survey of Main contractor and/or sub-contractors – (See Contractor Questionnaire in Appendix A2.2)	1 = < 10 FTE jobs per £1m 2 = 10 – 14 FTE jobs per £1m 3 = 14 – 18 FTE jobs per £1m 4 = 18 – 22 FTE jobs per £1m 5 = > 22 FTE jobs per £1m	(Santamouris 2016; Oliveira et al. 2014; Buildings Performance Institute Europe (BPIE), 2020; Thema & Wuppertal, 2018; Bell, 2012; Fingleton et al., 2021)
Cost efficiency of retrofit investment *(Cost efficiency of retrofit investment)*	kWh/yr./£1000 invested or kWh/yr./ £1m invested (for large projects/investments) Both are expressed as a percentage of energy saved per amount invested.	1 = < 200 kWh 2 = 201 – 500 kWh 3 = 501 – 800 kWh 4 = 801 – 1,000 kWh 5 = > 1,000 kWh	(Santamouris, 2016; Fingleton et al., 2021)
Property value improvement *(Increase in the market value of the retrofitted property)*	£ invested in the retrofit project OR £/residential unit or £/m2 of renovated floor area	1 = < 2% increase 2 = 2 – 2.9% increase 3 = 3 – 3.9% increase 4 = 4 – 4.9% increase 5 = >5% increase	(Fuerst et al., 2015; Stanley et al., 2016; Colclough 2021)

6.5 Chapter Summary

The essence of this chapter revolved around the formulation and delineation of the retrofit benefit measurement toolkit and addressed the 4th and 5th objectives of the study. At its core, the toolkit's design aimed to ensure a holistic assessment of retrofit projects, capturing both quantitative and qualitative benefits but with a more human and multi-stakeholder focus, and paving the way for informed decision-making.

The tasks were to lay the conceptual underpinning for the benefits measurement toolkit. Central to the development of the toolkit was the integration of the Analytic Hierarchy Process and Delphi methodologies. These established techniques provided a structured and systematic approach to prioritising the multiple wider benefits of retrofit projects. The Delphi method, with its iterative consensus-building process, will help to leverage expert opinions to establish weights or rankings for the selected retrofit benefits, ensuring the resultant toolkit is rooted in both theory and practice. Simultaneously, AHP offers a mathematically rigorous means of determining the relative importance of each identified benefit, adding a layer of precision to the toolkit.

The chapter also outlined a scoring tool for retrofit benefits, a key component of the study that is to assist in measuring the performance of a retrofit project. The scoring scales, criteria and thresholds have been established on the back of empirical evidence (through expert review and input). It provides an at-a-glance overview of the multifaceted benefits of retrofitting homes. These conceptual ideas have been taken forward into the next chapter which discusses the more practical tasks of implementing the toolkit, considering, user-friendliness, simplicity, reliability, and cost-effectiveness. In essence, while chapter 6 provided the “why” and “what”, chapter 7 will showcase the “how” of the toolkit.

Chapter 7 : THE RETROFIT BENEFITS MEASUREMENT TOOLKITS (REBAT)

7.1 Introduction

This chapter presents the spreadsheet-based tools developed for this study. The chapter opens with a conceptual design of the integrated AHP-Delphi benefits prioritisation tool (including an overview of using computer-based solutions for implementing Delphi-AHP) and this is followed by justifications for the choice of Microsoft Excel as the platform to implement the tools. The details of the benefits prioritisation tool based on AHP and Delphi techniques (henceforth prioritisation tool) and the methodology for the retrofit benefit scoring tool (based on the multi-stakeholder framework) are then presented. The scoring tool is henceforth referred to as the REBAT.

7.2 Overview of computer or software-based Delphi and AHP

As part of the toolkit being developed, the authors opted for a digitized implementation of the methodology rather than the traditional manual or paper-based approach. Hsu and Sandford, (2012) refer to this approach as "real-time" or "e-Delphi". Further, as highlighted in the previous chapter, the toolkit uses the normative Delphi type which seeks to establish or obtain consensus on the topic of interest. This type of Delphi Hsu and Sandford (2012) argue is more suitable for generating evaluation frameworks, developing criteria for benchmarking as well as developing and/or evaluating indicators essential to a particular field or area of interest or concern. For more details on the other two Delphi categories, forecasting Delphi and policy Delphi, see Hsu and Sandford (2012).

Real-time Delphi (RTD) has grown in popularity since the early 1970s in line with the surge in internet technologies and led to the implementation of computer-based applications for the Delphi process (Hsu and Sandford, 2012). More recently, RTD has been implemented in multiple fields of research including education (Gary and Gracht, 2015), nursing (Varndell, Fry and Elliott, 2021); ICT (Keller and von der Gracht, 2014); logistics and construction project management (Kian Manesh Rad, Sun and Bosché, 2017b).

Given the challenges with classic Delphi studies including long durations to complete survey rounds and high attrition among expert panels, Linstone & Turoff, (1975) first discussed the use of technology to facilitate the process. The concept of real-time Delphi, however, was conceived by Gordon & Pease, (2006) who "developed a new approach to performing a Delphi study that does not involve the use of sequential rounds and as a result, greatly improves the efficiency of the process and shortens the time to perform such studies" (p. 321). Following this several other computer-based or Delphi software have been developed by various researchers mostly to meet the needs of their bespoke studies (Gary and Gracht, no date; Markmann, Darkow and Gracht, no date; Gheorghiu et al., 2017); andKian Manesh Rad et al., 2017b). The first of these bespoke RT Delphi tools was developed around the late 1990s, called Professional Delphi Scan (Varndell, Fry and Elliott, 2021). Most of these studies lacked detailed discussions of the software tools without regard to replicability. That said some studies adopted open-access software tools (see Aengenheyster et al., (2017) for a comparative analysis of four of these tools). Table 7-1 below presents an adapted summary of Aengenheyster et al., (2017)'s analysis updated to include some more recent software tools and further limitations of the original four.

Table 7-1 Comparative overview of some RT Delphi software systems.

RT Delphi software system	Summary of key limitations
Risk Assessment and Horizon Scanning (RAHS)	• No ability to alter the survey layout. • No pre-test features are available. • The structure of the survey limits understanding of real-time responses • No user manual / technical resources were provided. • Partial respondent anonymity
eDelfoi	• Limited ability to alter survey layout. • No pre-test features are available. • The real-time factor is not represented to participants in an untestable way. • The software system is unstable, technical issues limit the use of the software system
Global Features Intelligence System (GFIS)	• Limited ability to alter survey layout. • The real-time factor is not represented to participants in an untestable way. • Limited data output compatibility • The software system is unstable, technical issues limit the use of the software system. • The software system is complex and is not intuitive. • Respondent anonymity is not guaranteed
Survey	• The software system is comprehensible, but some features require more explanation. • Account setup is quite cumbersome, taking up to a week
Real-Time Delphi by Millennium Project	• Specific to real-time Delphi and may not be suited for other research methodologies. • May require some technical familiarity to fully exploit. • Limited customization of the interface

RT Delphi software system	Summary of key limitations
DelphiManager	• Limited to specific Delphi study structures • May have features that are unnecessary for simpler Delphi studies. • Licensing and access restrictions
Custom Systems (i.e., MySQL/PHP/MATLAB/ Django front-end)	• Requires technical expertise for setup and maintenance. • Potentially high setup costs • Not always user-friendly for non-technical researchers or participants

Source: Compiled from (Aengenheyster *et al.*, 2017 and other sources)

The AHP multicriteria decision support tool which is integrated with Delphi for the prioritisation tool has also seen the deployment of technology tools in its implementation. A brief overview of some of these AHP-based software products is presented in Table 7-2 below. Ossadnik and Lange, (1999) first compared three such AHP software, namely AutoMan, ECPro, and HIPRE 3+, concluding that ECPro held the stronger analytical potential of the three. Within a decade several other tools have since been developed and launched to facilitate the AHP in decision-making. Ossadnik & Kaspar, (2013) identified 12 of such software tools that supported the AHP application (some of which are summarised in Table 7-2 below).

These platforms, which are designed to enhance and expedite the AHP procedure, have their distinct advantages, making them particularly useful in situations or for specific user groups. SuperDecisions for example provides an integrated approach for both AHP and ANP methodologies (Rui, 2003; Ismael *et al.*, 2020). By incorporating graphical user interfaces, sensitivity analyses, and real-world application templates, these tools have expanded the capabilities of AHP analysis (Ishizaka and Siraj, 2018). As with any specialized software, however, these tools frequently come with limitations such as steep learning curves, prospective software costs, and compatibility issues. In addition, the relative novelty of tools necessitates that their full capabilities, stability, and user reception be thoroughly documented and evaluated (this falls outside the scope of the current study). Considering these factors and the desire for a universally accessible, cost-effective, and adaptable platform for the integrated AHP-Delphi methodology, Microsoft Excel appears to be a viable option for the development of the prioritisation toolkit.

Table 7-2 Comparative overview of AHP software tools.

AHP Tool/Software	Features	Strengths and Limitations	Source(s)
Expert Choice (formerly ECPro)	One of the earliest and most popular AHP software tools. Offers collaborative decision-making features, sensitivity analysis, and more.	Strengths: Robust, user-friendly interface, and extensive documentation. Limitations: Cost, may be overly complex for simple decisions.	(Ishizaka and Labib, 2009; Erdogan, Šaparauskas and Turskis, 2017); Saaty, 1990
SuperDecisions	Designed for the Analytic Network Process (ANP) but supports AHP. Facilitates handling complex decisions involving interdependent relationships.	Strengths: Effective for complex decisions involving interdependencies. Limitations: Learning curve due to complexity; designed more for ANP than AHP.	(Rui, 2003; Adams, 2011; Mu and Pereyra-Rojas, 2018); Saaty and Vargas, 2006
AHP-OS	Online tool for AHP. Facilitates collaboration among multiple users.	Strengths: Web-based, accessible from any location, and promotes collaborative decision-making. Limitations: Requires stable internet connection, less comprehensive than standalone software.	(Goepel, 2018)Pelaez and Lamata, 2003
Decision Lens	Designed for strategic prioritization and resource allocation using AHP. Incorporates AHP within a broader decision framework.	Strengths: Broad framework allowing for integration with other techniques. Limitations: Cost, best suited for strategic and business decisions.	(Cicone Jr *et al.*, 2008; Saito *et al.*, 2015)
PriEsT	Open-source tool for AHP and other priority estimation techniques.	Strengths: No-cost option, flexibility in choosing methods. Limitations: Might lack the polished UI and support of commercial software.	(Siraj, Mikhailov and Keane, 2015) (Brunelli, 2015)
MACBETH (Measuring Attractiveness by a Categorical-Based Evaluation Technique)	Uses qualitative judgments about differences to help decision-makers when quantities are hard to obtain.	Strengths: Simplifies the decision-making process when quantitative measures are difficult to ascertain. Helps in facilitating judgments. Limitations: It doesn't use the eigenvalue method like traditional AHP but can be complementary to AHP. It might be less familiar to those accustomed to standard AHP methods.	(Costa, De Corte and Vansnick, 2003; Bana e Costa, De Corte and Vansnick, 2005; Ertay, Kahraman and Kaya, 2013; Kundakcı, 2019)

RightChoice	This is a multi-criteria decision-making software tool based on the Simple Multi-Attribute Rating Technique (SMART) method. SMART is a method where attributes or criteria are weighted by allocating points among them.	Strengths: Very simple and easy to use, with flexibility in handling different scenarios and settings. Limitations: May be too simple for very complex decision problems and numerous interacting criteria.	(Ossadnik and Kaspar, 2013; Ishizaka and Siraj, 2018; Tavana *et al.*, 2023)
Make It Rational (MIR)	MIR facilitates decision-making by allowing users to structure complex decisions into a hierarchy or network of criteria and alternatives (using AHP and ANP methodologies)	Strengths: MIR offer an easy-to-navigate user interface, and supports both AHP and ANP methodologies, allows robustness checks with multi-user capabilities and cloud-based functionality. Limitations: Steep learning curve; maybe too complex for relatively simple decisions and proprietary.	(Ossadnik and Kaspar, 2013; Ishizaka and Siraj, 2018; Tavana *et al.*, 2023)
REBAT Prioritisation Tool	This is the proposed spreadsheet-based tool to allow projects to prioritise and rank alternatives using the AHP methodology. It allows weights to be allocated to different criteria and the ranking of these to support decision-making.	Strengths: REBAT is easy to use, implemented in a familiar spreadsheet environment. It provides flexibility in criteria and levels of consistencies. It can be completed electronically or manually. Limitations: The hierarchy of the decision problem is not included in the template. Where there are multiple categories, it does not provide final aggregation across these categories (this is to be introduced in later iterations).	Goepel, 2013

Source: Compiled from various literature sources (indicated in table).[5]

[5] For an extensive list of Decision Support Resource, visit the following site: https://kt.ijs.si/MarkoBohanec/dss.html

7.2.1 The Choice of Microsoft Excel in the Prioritisation Tool Implementation.[6]

Implementing an integrated RT Delphi-AHP study requires the development of specialised software, which can often be sophisticated and necessitate further configurations, guidance, and training to operate, and this can constitute a drawback to the original purpose of conducting an RT Delphi-AHP study. Further, designing bespoke software in the first place is no mean feat, and requires specialised knowledge in computer programming, coding, and software development as well as a significant budget (Li, 2021).

Given these constraints, alternative approaches of utilising existing proprietary software tools have emerged which tend to merge the positives of the classic and RT Delphi in a sequential process. This blended approach still follows the classic Delphi stages but utilises tools to automate the input and analysis of survey results such as computing consensus and consistency. All forms of Delphi implementation still require the initial phases involving study and survey designs, expert selection etc. to be completed before integrating into software, computer, or web-based tools.

As mentioned earlier, however, for practical reasons and the intended audience of the prioritisation tool, adopting an existing software solution is not considered a viable option. Proprietary software comes at a cost and given that retrofit projects and indeed social housing providers in the UK often operate within constrained budgets, there may not be the financial flexibility to invest in new, specialised software (Pawson and Mullins, 2010). This is especially true for smaller providers, as evidenced by the interview results in Chapter 5. Moreover, training staff to use new software presents further costs and can also be both time-consuming and challenging to accomplish when considering the tight timelines for delivering retrofit projects. Lastly, the often-bureaucratic nature of some social housing providers might mean that developing or adopting new software systems or tools will require lengthy approval processes.

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[6] The discussions and justification provided here equally apply to the other tools developed for this study – The benefits scoring tool. A separate justification will not be provided for this to avoid repetition.

7.2.1.1 Organisational level justification for using Excel.

At the organisational level, the decision to implement the prioritisation tool in Microsoft Excel is justified. Given the blend of flexibility, familiarity, and function, Excel is considered a logical choice for the AHP-Delphi prioritisation tool. Many social housing teams already have access to Microsoft Office Suite and, by extension, Excel, therefore implementing a toolkit within this familiar environment can lead to quicker adoption and less resistance among staff (Laumer and Eckhardt, 2010). Furthermore, social housing providers utilise Excel, daily often using it for budgeting, forecasting, and record-keeping. A toolkit that integrates seamlessly into their existing digital ecosystem can therefore foster improved workflow integration. In addition, situating the tool within Excel can facilitate its merger with other existing datasets that providers maintain in Excel such as stock portfolios, maintenance records or resident feedback. Besides it is easy to export such datasets into Excel formats (where they exist in different systems). This interoperability can lead to easier and richer analyses and more informed decision-making. Lastly, leveraging Excel, which is already widely available to these organisations, circumvents the need for bureaucratic approvals and avoids delays (Manzi and Morrison, 2018), ensuring that the benefits of retrofit prioritisation can be realised sooner.

7.2.1.2 Technical and performance justification for using Excel.

Besides the organisation, monetary and time savings potential of using Microsoft Excel, there is the need to justify its technical capabilities for implementing the integrated Delphi-AHP in a practical and user-friendly manner. While the specific application of an AHP-Delphi integrated method within Excel is relatively novel, Excel has been employed in various research contexts, from data management to advanced analytical modelling. Its suitability for managing iterative processes, combined with its computational and representation tools, positions it as a viable platform for the prioritisation toolkit.

The versatility of spreadsheets (Microsoft Excel) as tools for data analysis is well-documented (Birch, 2017). Its widespread use in academia and the professional realm means many potential users and collaborators are already familiar with its interface. This factor reduces the learning curve associated with specialised software (Beniger and Robyn, 1978). Also, modern iterations of Excel, particularly those integrated with cloud platforms like OneDrive, allow for real-time collaboration[7] (Attaran, 2007), which is a boon when synchronising feedback from multiple Delphi participants. Moreover, while there's an investment cost associated with procuring the Microsoft Office suite, it often proves to be more cost-effective than specialised software and its scalability also means it can handle a range of dataset sizes without significant performance degradation (Power, 2004).

Excel's capabilities are also able to effectively handle the fundamental operations of AHP and Delphi. It is effective for structuring the pairwise comparison matrices essential for AHP (Saaty, 1980) and in the Delphi context, its table-based format can allow for iterative rounds of expert feedback to be neatly catalogued. Moreover, Excel's "Data Validation" feature can be employed to ensure that users provide appropriate input values, especially for their ranking of alternatives in AHP (Saaty, 2008).

As far as analysis goes, Excel's computational capabilities both in terms of built-in functions and the potential for scripting with VBA, allow for robust data analysis (Walkenbach, 2010), while the visualisation tools can be effectively leveraged to provide feedback, a key aspect of the Delphi methodology (Lindstone and Turoff, 1975). To ensure that the pairwise comparisons are consistent, the consistency ratio (CR) is typically computed in AHP. Excel, with its vast array of mathematical functions, facilitates the calculation of the consistency index (CI) and the subsequent consistency ratio (CR) without necessitating additional software (Ishizaka & Labib, 2009). Lastly, Excel's "MMULT" and "TRANSPOSE" functions, among others, can be harnessed to compute the necessary principal eigenvector and eigenvalue of the comparison matrix, making the derivation of weights for criteria alternatives straightforward (Forman and Gass, 2001).

7.3 The AHP-Delphi prioritisation tool

7.3.1 Overview of the tool

The full methodology discussed in Chapter 6; section 6.2 is implemented in the Excel-based tool. However, the tool was not built completely from scratch but builds on an existing template developed by Goepel, (2013). The decision to settle on Goepel's template was after an exhaustive search. A couple of options were found but most of these were very basic and lacked the rigour and theoretical underpinnings needed for the study's

[7] While very useful, the current version of the tool has not been setup or tested for its functionality on cloud-based collaborative environment. This can be explored in future studies.

purpose. Goepel's work is supported by a peer-reviewed conference paper, and he also implements the ordinal consistency approach which is what this study proposes (in chapter 6, section 6.2.3).

The ReBAT benefits weighting, and prioritisation toolkit is designed to allow retrofit project stakeholders to easily rank and assign weights to the wider benefits of retrofit projects. The tool is a spreadsheet template implemented in Microsoft Excel (at least MS Excel 2013 and upwards). Each major retrofit benefits category has a separate workbook. The original template from Geopel is designed for the classic AHP scenario where decision-making involves only one alternative with multiple criteria. The ReBAT toolkit and methodology however has three benefit categories (alternatives) and stakeholders will rank different benefits (criteria/indicators) in each. For this reason, it became practically difficult to combine all three retrofit categories (alternatives) in one spreadsheet document (workbook), especially when considering the need for multiple inputs from different experts (in the Delphi process). Hence, there is a workbook for each of the three retrofit benefits categories namely.

- Environment benefits – AHPcalc – 2022
- Social benefits – AHPcalc – 2022
- Economic benefits – AHPcalc – 2022

Each of these workbooks consists of pair-wise comparison matrices (PCM) for the retrofit benefits in that category/workbook. A maximum of 20 experts or participants can input their PCM decisions (see next section for justification). There is also a sheet for the consolidation of all judgments, a summary sheet to display the results, a sheet with reference tables (random index, limits for geometric consistency index GCI, judgment scales) and a sheet for solving the eigenvalue problem when using the eigenvector method (EVM). Figure 7-1 below shows a snapshot of the summary sheet from the Economic benefits workbook. Detailed guidance on using the tool is provided in Appendix A 2.2.

Table 7-3 Similarities and differences between Goepel's (2013) original template and the proposed REBAT tool.

Goepel (2013)	REBAT Tool
Similarities	
Decision makers can specify their level of consistency needed (α)	
Final weights aggregation (for a category) uses a combination of the row geometric mean method (RGMM) and the eigen value method (EVM) – see section 6.2.3.6.	
Both tools implement participant or expert weighting options (however, in the REBAT, only the moderator can set this value and it is not visible to participants).	
Differences	
Consistency is calculated using the Consistency ration (CR) and Geometric consistency index (GCI)	Implements only the consistency ratio (CR) for calculating the consistency of a decision maker's pairwise comparison.

7.3.2 Expert Panel Sample size

As mentioned in the previous section, in determining the optimal panel size for the REBAT prioritisation tool considering the target audience, a maximum of 20 panellists was deemed the most suitable. This decision aligns with the recommendations of many Delphi researchers who suggest panel sizes between 10 and 50 to balance the diversity of perspectives with the manageability of the process (Okoli and Pawlowski, 2004). Given the unique characteristics and challenges faced by social housing landlords, it's imperative to ensure that the tool is not just theoretically rigorous but also practically implementable. A smaller, more focused panel facilitates a more concise and targeted consensus-building process, enhancing the relevance and utility of the results (Hsu and Sandford, 2007). Additionally, the choice of Microsoft Excel as the implementation platform further supports the decision for a more compact panel size. Excel, while widely accessible and familiar to many professionals, is best suited for handling smaller datasets to ensure ease of data management, analysis, and interpretation. Moreover, considering the potential challenges related to participant attrition across Delphi rounds, a panel size of 20 strikes a balance, providing a cushion against dropouts while ensuring a manageable and meaningful participatory experience for all involved (Linstone and Turoff, 1975, 2002).

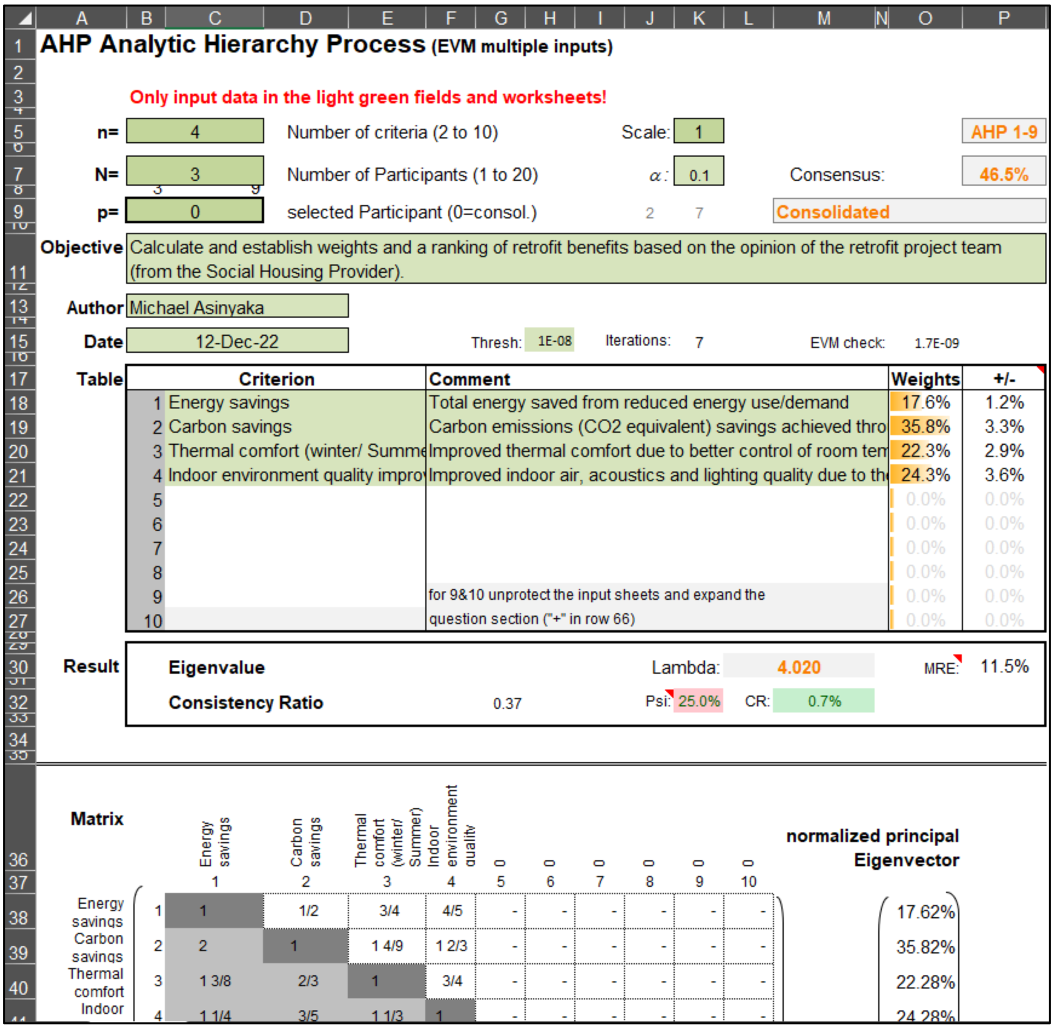


Figure 7-1 A snapshot of the Summary Sheet of the REBAT prioritisation tool (for the environment benefits category). Source: Adapted and adopted from (Goepel, 2013).

7.3.3 Implementing the benefits weighting and prioritisation tool

The prioritisation tool can be used in the classic Delphi process or a 'modified' process. Both are briefly explained in this section. In both approaches, a moderator is needed to coordinate and guide the experts towards consensus. The moderator role can be performed by the retrofit coordinator in the first instance or by any other appointed entity by the retrofit project team/owner. Whichever approach is followed, a retrofit project team can use the prioritisation spreadsheet tool to achieve the following manually or automatically (Özdemir, R. G., and Ayağ, Z. 2011, p, 200; Kamal and Al-Harbi, 2001).

1. synthesizing the pair-wise comparison matrix of individual experts
2. calculating the priority vector for a criterion
3. calculating the consistency ratio.

4. calculating λ_{max} (largest eigenvalue)
5. calculating the consistency index, CI.
6. checking the consistency of the pairwise comparison matrix to check whether the decision-makers comparisons were consistent or not.
7. generating advice values for each expert towards achieving group consensus.
8. computing the aggregated group weights and/or priorities.

7.3.3.1 Using the classic Delphi process to implement the prioritisation tool.

The prioritisation tool can be used in the classic Delphi process where experts are sent only the pairwise comparisons to complete individually and return these to the moderator (retrofit coordinator or project coordinator can take on this role). The coordinator inputs the individual responses into a master copy of the tool to generate individual consistencies for each expert as well as the group consensus to conclude the first round of Delphi surveys. Any experts who need to make amendments to their PM decisions will then be contacted with the suggested amendment automatically generated by the ReBAT prioritisation tool algorithm. That will constitute the second round of Delphi and this process can be repeated as many times as necessary to achieve the acceptable group consensus and individual consistency indices.

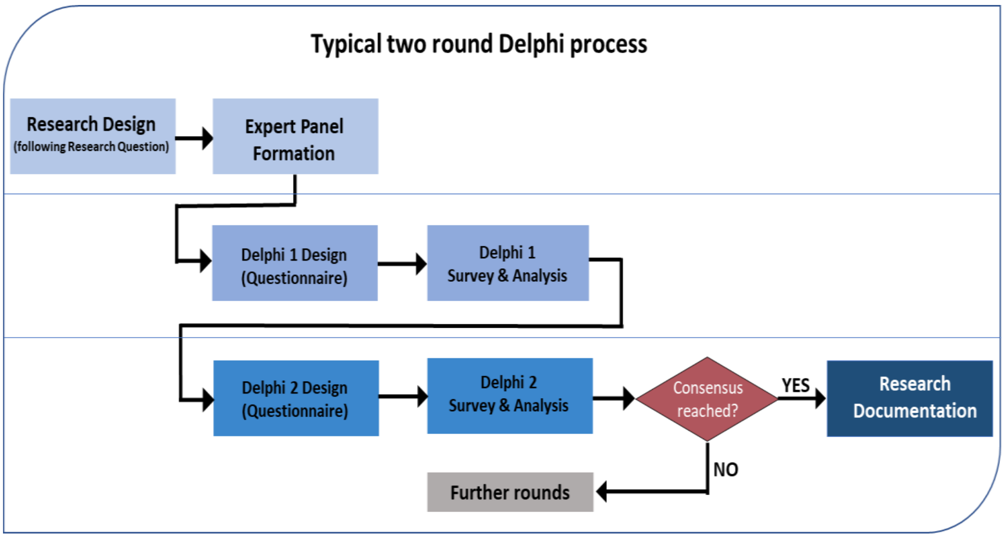


Figure 7-2 An overview of the classic or typical two-round Delphi process

7.3.3.2 Using a 'modified' Delphi process to implement the prioritisation tool.

An alternative to the classic Delphi process is a 'modified' Delphi process. Several 'modified' Delphi processes have been implemented in previous studies, one of which is using the Delphi in a group or team-based setting, in what is called a 'Decision Delphi' or 'Delphi Conference' (Linstone and Turoff, 2002; Murry and Hammons, 1995; Day and Bobeva; 2005 and Powell, 2003). Considering a retrofit project as an example, the key stakeholders on the retrofit project can be assembled to complete the PCMs as a team and adjust the PCMs until group consensus is reached. This approach deviates from the classic or traditional Delphi approach, renowned for its iterative rounds and emphasis on individual expert inputs, which has long been lauded for its ability to guard against potential biases by ensuring participant anonymity (Rowe and Wright, 1999; Linstone and Turoff, 1975). This layer of anonymity, intrinsic to the Delphi method, provides a safeguard against the undue influence of dominant voices, ensuring a more equitable consensus-building process.

However, the integration of the Delphi method with group-based settings provides an enriched lens for understanding the dynamics of consensus-building. This modified version stems from the potential benefits of direct face-to-face discussions, immediate feedback, and the fostering of group synergies (Linstone and Turoff, 2002). For instance, Murry and Hammons (1995) expound on the value of such group-based deliberations, noting the potential for richer interactions and direct negotiation of differing views. Similarly, Day and Bobeva (2005) highlight scenarios where the fusion of remote rounds with face-to-face sessions can harness the merits of both individual and group contributions. This happens when participants collaboratively engage in pairwise comparisons, ensuring the process benefits from real-time clarifications and rich discussions.

Therefore, a methodological blend fusing the reflective solitude of the individual Delphi rounds with the dynamism of group sessions can indeed be an effective procedure for consensus-building. Besides, the structured nature of the AHP process, underpinned by meticulous criteria definitions and pairwise comparisons, seems more amenable to group deliberations. For these reasons, this study recommends that where a project team decides to use a group-based consensus approach, there should be an initial round of pairwise comparisons executed traditionally with individual inputs, then followed by group sessions once divergent opinions are narrowed, harnessing both individual insights and group synergies as discussed above (Murray and Hammons, 1995; Day and Bobeva, 2005). Such a balanced approach ensures methodological rigour while optimizing the benefits of group interactions.

While this approach offers the advantages of efficiency, immediate feedback, and dynamic interaction, it simultaneously introduces challenges to group dynamics. Dominant personalities might exert undue influence, risking conformity biases (Rowe and Wright, 1999). Furthermore, the logistical challenges of assembling experts and the potential loss of the valued Delphi anonymity can't be dismissed. It's worth noting also that the retrofit coordinator or moderator needs to carefully plan the study bearing in mind the potential pitfalls to avoid the risk of "groupthink", where decisions are made based on the desire for harmony or group conformity rather than critical evaluation (Janis, 1972).

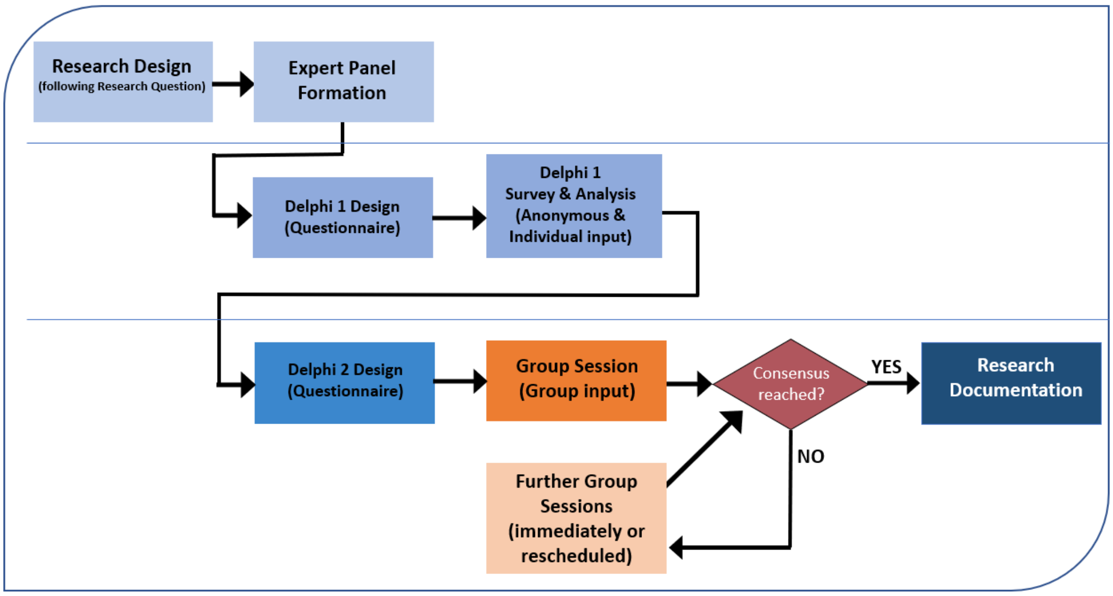


Figure 7-3 A recommended 'modified' 'Delphi conference' process recommended for retrofit the ReBAT prioritisation tool.

7.4 The retrofit benefits scoring tool (REBAT).

7.4.1 Overview of the REBAT retrofit benefits scoring tool.

As discussed in section 7.2.1 above, Microsoft Excel is the platform used to develop the toolkits for this study. The REBAT Scoring tool provides a nuanced and systematic approach to assessing the multifaceted benefits of retrofit projects in the UK's housing sector. Targeted primarily at housing associations/registered landlords, it attempts to go beyond merely quantifying or assessing benefits, to offering a platform for a comprehensive evaluation and enabling a standardized benchmarking across retrofit projects. The overall design is built with user-friendliness in mind, employing a structured layout with rows and columns to capture, analyse and visualise data related to the various benefits derived from a retrofit project (Figure 7-4 provides a snapshot of the interface of the REBAT tool).

7.4.2 Scoring criteria and thresholds for scoring.

The second sheet of the tool contains the retrofit benefit indicators and criteria as well as the thresholds for scoring each one. As discussed in Chapter 6, section 6.3, there are twelve (12) indicators split evenly between the three benefit categories, social, environmental, and economic indicators. Each benefit is followed by a description of the indicator, the criteria for scoring or measuring it and an indication of what data to collect to assess and quantify them as part of the retrofit project.

In adherence to the human-centred approach to retrofit evaluation advocated for by this study and in considering the aim to have a simple and flexible toolkit, approximately 8 of the indicators are assessed via occupant surveys. As mentioned, this tool implements only the basic version of the retrofit benefits measurement framework discussed in section 6.3.

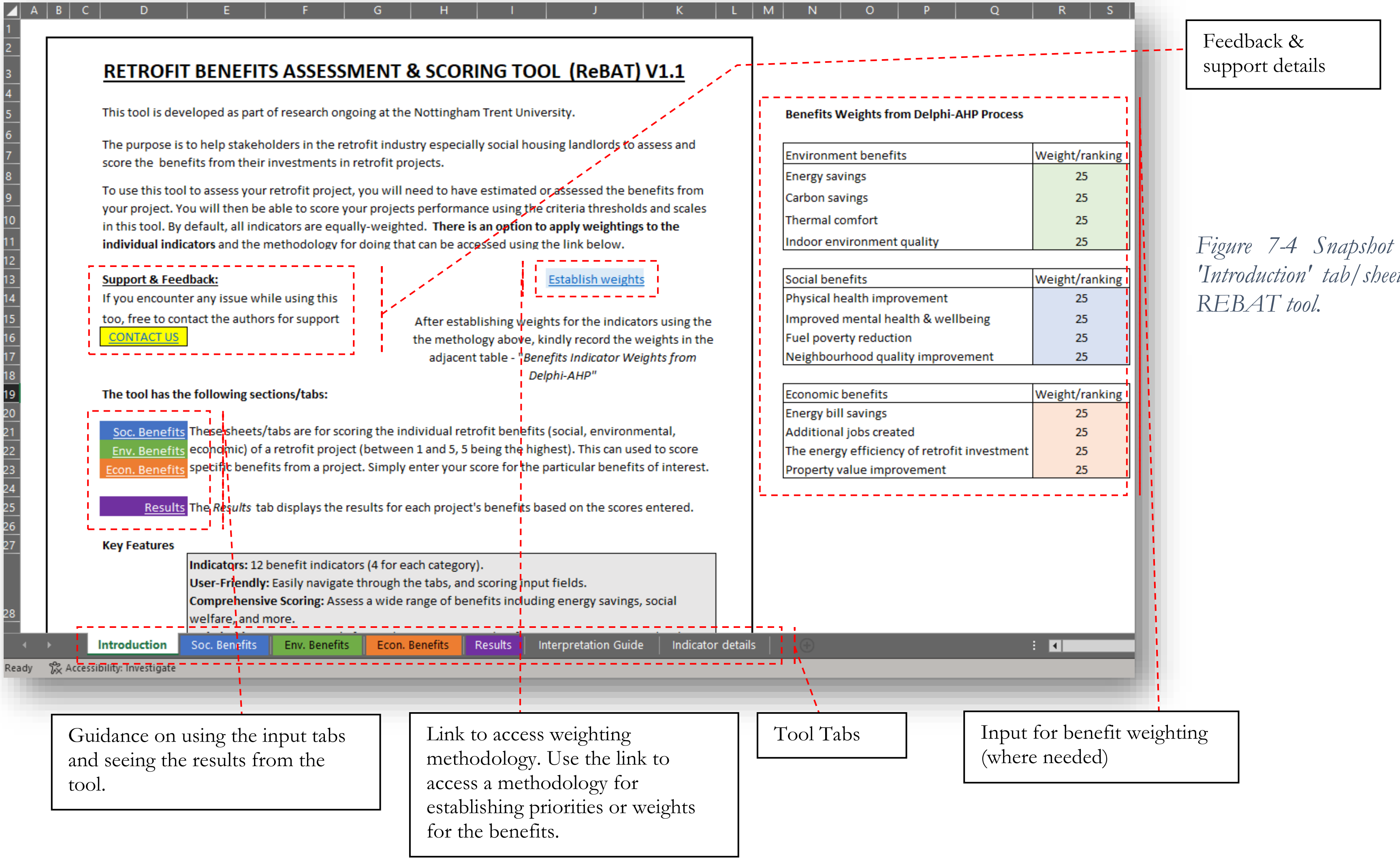
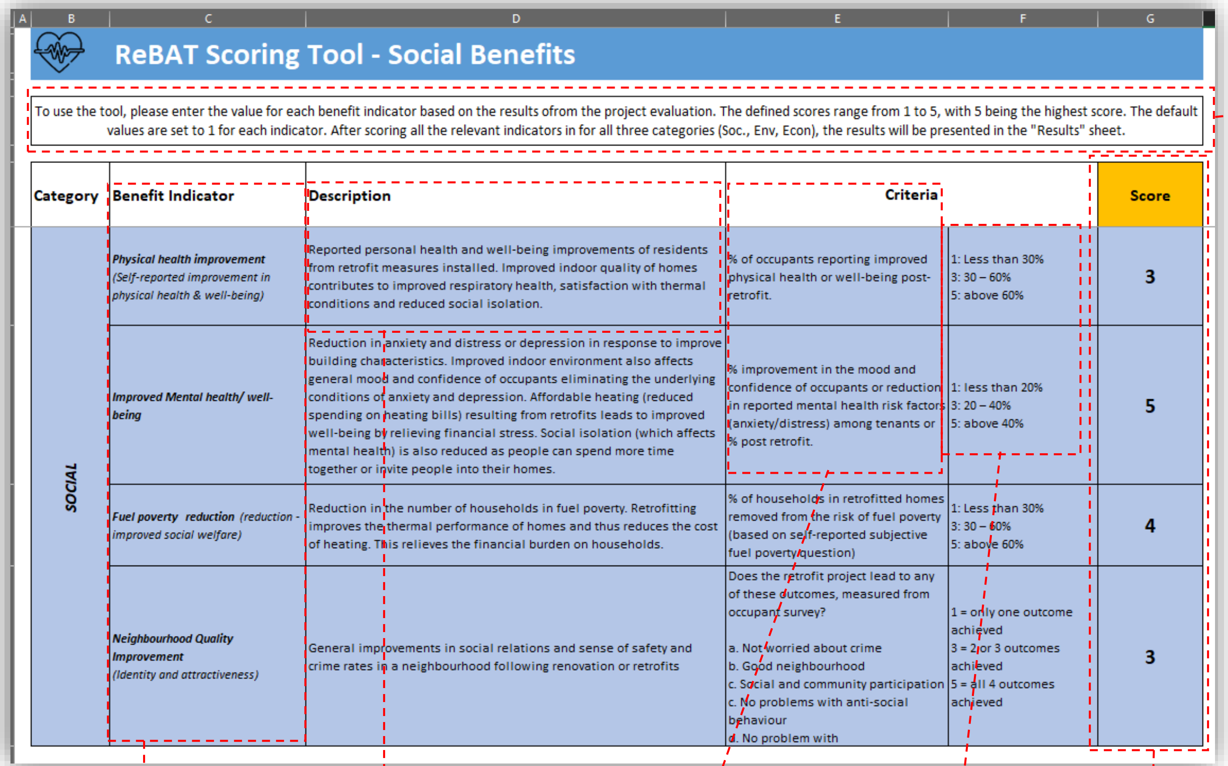


Figure 7-4 Snapshot of the 'Introduction' tab/sheet of the REBAT tool.



ReBAT Scoring Tool - Social Benefits

To use the tool, please enter the value for each benefit indicator based on the results ofrom the project evaluation. The defined scores range from 1 to 5, with 5 being the highest score. The default values are set to 1 for each indicator. After scoring all the relevant indicators in for all three categories (Soc., Env, Econ), the results will be presented in the "Results" sheet.

Category	Benefit Indicator	Description	Criteria		Score
SOCIAL	***Physical health improvement*** *(Self-reported improvement in physical health & well-being)*	Reported personal health and well-being improvements of residents from retrofit measures installed. Improved indoor quality of homes contributes to improved respiratory health, satisfaction with thermal conditions and reduced social isolation.	% of occupants reporting improved physical health or well-being post-retrofit.	1: Less than 30% 3: 30 – 60% 5: above 60%	3
	Improved Mental health/ well-being	Reduction in anxiety and distress or depression in response to improve building characteristics. Improved indoor environment also affects general mood and confidence of occupants eliminating the underlying conditions of anxiety and depression. Affordable heating (reduced spending on heating bills) resulting from retrofits leads to improved well-being by relieving financial stress. Social isolation (which affects mental health) is also reduced as people can spend more time together or invite people into their homes.	% improvement in the mood and confidence of occupants or reduction in reported mental health risk factors (anxiety/distress) among tenants or % post retrofit.	1: less than 20% 3: 20 – 40% 5: above 40%	5
	Fuel poverty reduction *(reduction - improved social welfare)*	Reduction in the number of households in fuel poverty. Retrofitting improves the thermal performance of homes and thus reduces the cost of heating. This relieves the financial burden on households.	% of households in retrofitted homes removed from the risk of fuel poverty (based on self-reported subjective fuel poverty question)	1: Less than 30% 3: 30 – 60% 5: above 60%	4
	Neighbourhood Quality Improvement *(Identity and attractiveness)*	General improvements in social relations and sense of safety and crime rates in a neighbourhood following renovation or retrofits	Does the retrofit project lead to any of these outcomes, measured from occupant survey? a. Not worried about crime b. Good neighbourhood c. Social and community participation c. No problems with anti-social behaviour d. No problem with	1 = only one outcome achieved 3 = 2 or 3 outcomes achieved 5 = all 4 outcomes achieved	3

Instructions for scoring benefits.

Benefit indicators (4 for each benefit category (12 in total).

Description of benefit indicator

Criteria for measuring or assessing benefit indicator.

Thresholds for scoring benefits using a 5-point scale.

Score input. Inputs allowed is 1, 2, 3, 4 or 5, and are based on the Score Threshold (where 5 = highest score & 1= lowest score.

Figure 7-5 Snapshot of the scoring sheet for social benefits in the REBAT tool

7.4.3 Computing the score for an indicator.

On the scoring sheet (shown in Figure 7-5 above), users can input a score for each retrofit benefit indicator between 1 and 5, where 5 is the highest score and 1 is the lowest score (following the scoring scales defined in section 6.3.2, Table 6-7). Each score between 1 and 5 corresponds to the scoring thresholds of that indicator. For example, in the environment benefits category, a user can score the Indoor Air Quality indicator as follows.

1. = Less than 20%
2. = 20 – 40%
3. = 41 – 60%
4. = 61 – 80%
5. = Above 80%

Read in conjunction with the scoring criteria, the thresholds can be interpreted as score a project as 1 if less than 20% of the households in a retrofit project reported that there has been an improvement in the indoor air quality of their homes or are satisfied with the acoustic and lighting conditions. Where more than 80% report improvements in air, sound, and lighting qualities, that project receives a score of 5.

7.4.3.1 Step 1: Calculate the weighted score for each benefit indicator.

When a user inputs a score, this is automatically stored in a backend sheet (protected and hidden). Table 7-4 shows a snapshot of how this is represented. In that sheet are three table arrays each for the benefit categories. If the project team undertook a benefit prioritisation and obtained weights for the indicators, these will be input on the **Introduction sheet** and stored in the Backend sheet. To compute the weighted score for an indicator, the following expression is used.

$$S_i = \frac{I_i x W_i}{N} \qquad (9)$$

Where:

Si is the weighted score for the i^{th} indicator.

Ii is the user input score for the i^{th} indicator.

Wi is the weight or rank of the i^{th} indicator.

N is a normalization factor (constant value represented by the sum of the weights for that benefit category).

In other words, Si represents the final weighted score for the benefit indicator say, Thermal Comfort, while ***Ii*** is the score or input that a user inputs into the score column on the Criteria Scoring sheet. ***Wi*** is the individual weight or ranking assigned to each benefit indicator by default or through using the REBAT Prioritisation tool or some other technique of choice. Lastly, ***N*** represents the sum of the weighted scores for all the benefits indicators in a particular benefit category. For instance, in Table 7-4 below, 100 represents the sum of the weights for the four environmental benefit indicators while ***Si*** for Thermal comfort is **0.5.**

Table 7-4 Backend view of the REBAT Scoring tool for the Environmental benefits category.

Benefit Indicators	Score	Weight	Weighted Score
Energy savings	5	25	1.25
Indoor environment quality	4	25	1
Thermal comfort	5	25	1.25
Carbon savings	2	25	0.5
		100	**4.0**

7.4.3.2 Step 2: Compute the average weighted score for each benefit category.

After obtaining the weighted scores for each benefit indicator, the tool automatically computes the Weighted score for each of the three benefit categories using the expression.

$$A_S = \frac{1}{n}\sum_{i=1}^{n} S_i \tag{10}$$

where:

A_S represents the average weighted score for each benefit category.
n is the number of benefit indicators under a category.
The summation runs from *i*=1 (the first indicator) to *i*=*n* (the nth indicator) for the weighted scores *Si*.

From Table 7-3 above, the average weighted score for the Environmental benefit category (A_{SEnv}) is 3.25. The figures are based on a scoring of a hypothetical retrofit project. Tables 7-4 and 7-5 show the results for the Social and Economic benefit categories.

Table 7-5 Backend view of the REBAT Scoring tool backend view for the Social benefits category.

Benefit Indicators	Score	Weight	Weighted Score
Physical Health Improvement	3	25	0.75
Improved Mental Health	5	25	1.25
Fuel Poverty Reduction	4	25	1
Neighbourhood Quality	3	25	0.75
		100	**3.75**

Table 7-6 Backend view of REBAT Scoring tool backend view for the Economic benefits category.

Benefit Indicators	Score	Weight	Weighted Score
Energy Bill Savings	5	25	1.25
New Jobs/Employment creation	5	25	1.25
Cost efficiency of retrofitting	4	25	1
Property Value Improvement	4	25	1
		100	**4.5**

7.4.3.3 Step 3: Overall weighted Score for the retrofit project (Project Score)

The final calculation performed by the ReBAT Scoring tool is the overall weighted score for the retrofit project (Project Score). The tool uses the following expression for this purpose.

$$A_{Total} = \frac{1}{n}\sum_{j=1}^{m} A_j \qquad (11)$$

Where:

A_{Total} is the overall average weighted score across all categories.

m is the total number of categories.

The summation runs from j=1 (the first category) to j=m (the *mth* category), summing up the average weighted scores j for each category.

7.4.4 The Results and Visualisation.

The results of the computations discussed in the above section (7.4.3) are visualised on the results sheet (which acts as the dashboard). Figure 7-6 below shows the results sheet for the hypothetical project scored in 7.4.3 above. The scoring results are further displayed in a spider or radial chart (shown in Figure 7-7 below).

SOCIAL

Benefit	Score
Physical health improvement	0.75
Improved Mental health	1.25
Fuel poverty reduction	1
Neighbourhood Quality improve	0.75

Si weighted indicator score

SOC score	3.75

Ai weighted category score

ENVIRONMENTAL

Benefit	Score
Energy savings	1.25
Carbon savings	1
Indoor environment quality	1.25
Thermal comfort	0.5

Si weighted indicator score

ENV Score	4

Ai weighted category score

ECONOMIC

Benefit	Score
Energy Bill savings	1.25
New Jobs/employment created	1.25
Cost efficiency of retrofit	1.00
Property value improvement	1.00

Si weighted indicator score

ECON Score	4.50

Ai weighted category score

Figure 7-6 Weighted score results for benefit indicators and categories.

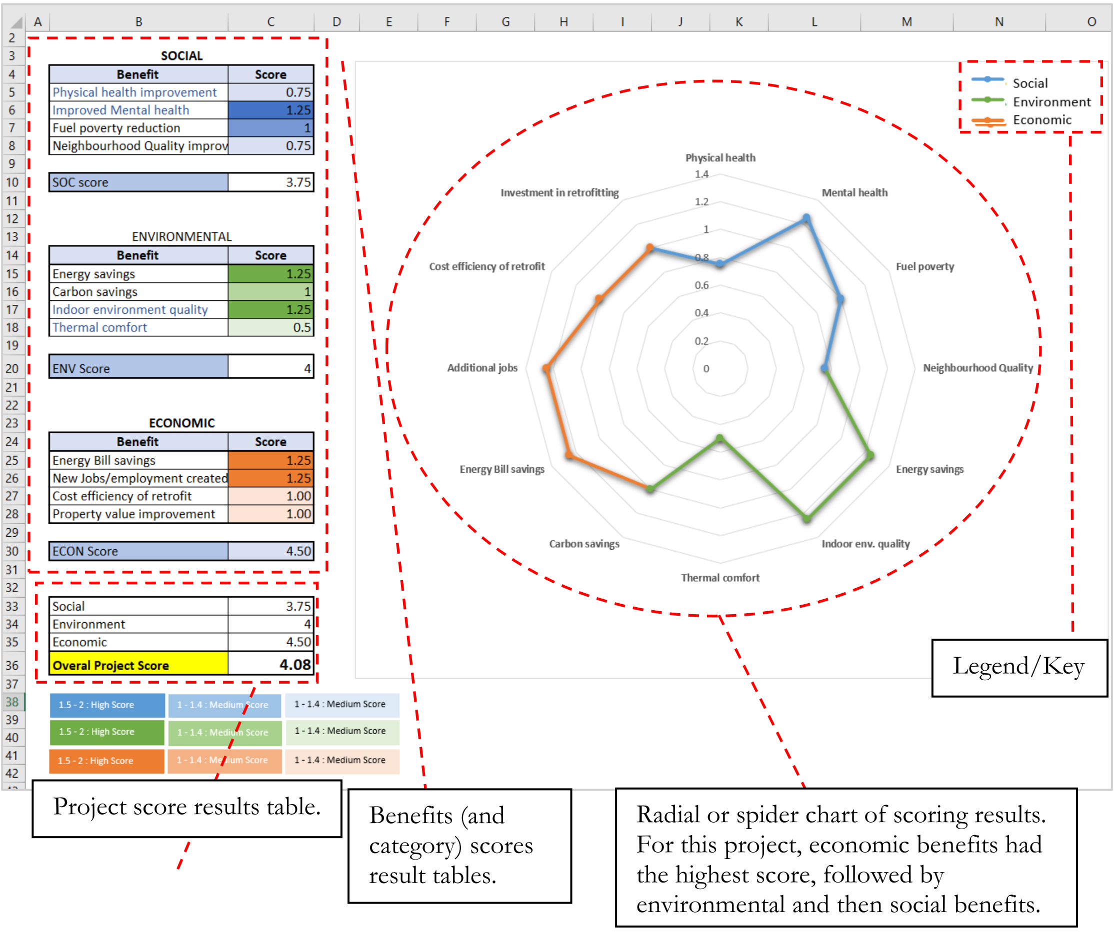


Figure 7-7 Snapshot of the REBAT tool's results dashboard (below)

7.4.4.1 Interpreting the results

The results from the REBAT Scoring tool provide a lot of insights for each project assessed and can be interpreted in multiple ways depending on the needs and requirements of the project team. The ultimate interpretation is the overall score of the project which both indicates how well the project has performed in and of itself but also can serve as a benchmark for comparison with other similar projects or simply to allow for a general comparison of the similarities and diversities across a portfolio of retrofit projects and programmes. Further, the REBAT Scoring tool can be used at various stages of a retrofit project. However, it is best suited for use at the pre-retrofit and post-retrofit evaluation stages. At the pre-retrofit or early stages of the project, the results from the tool can serve as an early business-case level assessment which can work across many projects and serve as a benchmarking and or benefits prioritization tool for the project team.

The interpretation of results is intentionally left open to the project team to consider and decide. However, for this study, an interpretation guide is summarised in Figure 7-8 below. The interpretation could start with a holistic view of the project by comparing the average scores of the three categories: Social, Environmental and Economic; then proceed to identify which category scores highest and lowest, setting the stage for further engagements.

From Figure 7-8 below, each benefit indicator's score is interpreted with a colour code, where a deeper colour represents a higher score and vice versa. A brief overview of this guide is presented in the next section.

A. Social Benefits:

Improved Physical and Mental Health: A score close to the maximum suggests a significantly positive impact on the residents' health. A lower score may indicate areas to optimize in future projects.

Fuel Poverty Reduction: A crucial indicator for social equality. A high score indicates fewer residents struggling with energy bills, while a lower score demands further investigation.

Neighbourhood Quality Improvement: Gauge the broader community impact. Are common areas enhanced? Is there improved accessibility?

Figure 7-8 Interpretation Guide for the REBAT Tool

B. Environmental Benefits:

Energy and Carbon Savings: Key indicators of the project's sustainability. High scores show a project's alignment with environmental targets, while lower scores may indicate missed opportunities.

Indoor Environment Quality and Thermal Comfort: Directly linked to residents' daily life quality. Higher scores suggest comfortable, healthy living conditions.

C. Economic Benefits:

Energy Bill Savings: A tangible benefit for residents. High scores mean more savings, a direct metric for assessing the retrofit's immediate economic impact.

New/Additional jobs created: A higher score signifies a boost to the local economy, a broader benefit beyond the immediate project.

Cost Efficiency and Property Value Improvement: Indicators of the project's long-term viability and its potential appeal in the housing market.

7.5 The Workflow Process for Implementing the Toolkit.

7.5.1 The Retrofit Process.

As a construction activity, retrofitting requires planning and adherence to a work schedule and code of practice that is compatible with industry standards. This is required to guarantee the achievement and maintenance of quality in retrofit projects. The government-sponsored review of the industry to address quality concerns and unintended consequences of retrofit projects advocated the creation of a quality standard for retrofit works called TrustMark. Together with the installer standard PAS 2030:2019 and the code of conduct PAS 2035:2019, it is used to implement retrofit measures in dwellings. The retrofit project workflow suggested for this study therefore incorporates the PAS 2035 retrofit process's guidelines. This is because beginning in 2021–2022, PAS 2035 applied to all household retrofit projects completed in the UK. Projects funded by the UK government and the government's Local Authority Delivery Schemes are included in this.

The two standards (PAS 2035 and PAS 2030) are essentially founded on the following principles.

- Retrofit is a whole-house activity and should be viewed as such.
- Retrofit should prioritise fabric.
- Retrofit projects should incorporate expert design input.
- In retrofit projects, consumers and homeowners should be protected.
- Retrofit projects must be overseen by capable and certified individuals.

A higher-level overview of the workflow process for implementing the retrofit benefits assessment toolkit is provided in Figure 7-9 below.

7.5.1 Overview of the toolkit (Retrofit Benefits Assessment Toolkit – REBAT)

The main purpose of the REBAT toolkit is to assist homeowners (social landlords especially) in measuring the benefits from their investments in retrofitting their homes beyond cost and carbon savings simply and systematically to allow for robust and informed retrofit investment decision-making for social landlords and their residents/tenants.

It is meant to be a supporting tool for housing landlords in their measuring and assessing the wider benefits of retrofit activities. It may also be useful in setting priorities and identifying impacts to measure when defining retrofit goals and strategies.

The toolkit consists of the following elements.

A **framework of 23 key retrofit benefits** with indicators categorised into social, environmental, and economic.

A **benefit weighting and prioritisation methodology** with guidance for establishing priorities and ranking of retrofit impacts.

A **methodology and framework (including an Excel spreadsheet tool)** with criteria and scoring scales and thresholds) for scoring and assessing a retrofit project consisting of **12 essential retrofit indicators**.

An **occupant and contractor questionnaire** to assist data collection where needed to measure and score the retrofit benefits indicators.

7.5.2 Key features of the toolkits.

1. The toolkit and methodology can be applied at a **building level or project level** and is only designed for residential dwellings of all types. However, not all benefit indicators can be assessed and scored at both levels. The framework specifies which indicators apply at the building level and project level.
2. The framework is flexible and allows users to select which benefit indicators are relevant and meet their priorities. That, users do not need to measure and score all 11 essential indicators. They can start with only one or two and build on over time.
3. The **measuring period and baseline year are flexible** and not strictly defined so users can set their reporting period for the various indicators. However, the methodology (as shown in the workflow process below) recommends some minimum periods (based on PAS 2035) needed to fully assess or measure some indicators. For example, nearly all 11 essential indicators can be assessed in the first 3 to 6 months post-retrofit. However, some indicators may require longer periods up to 12 months and beyond if a more detailed and comprehensive assessment is to be undertaken.

7.5.3 The toolkit implementation workflow or timeline

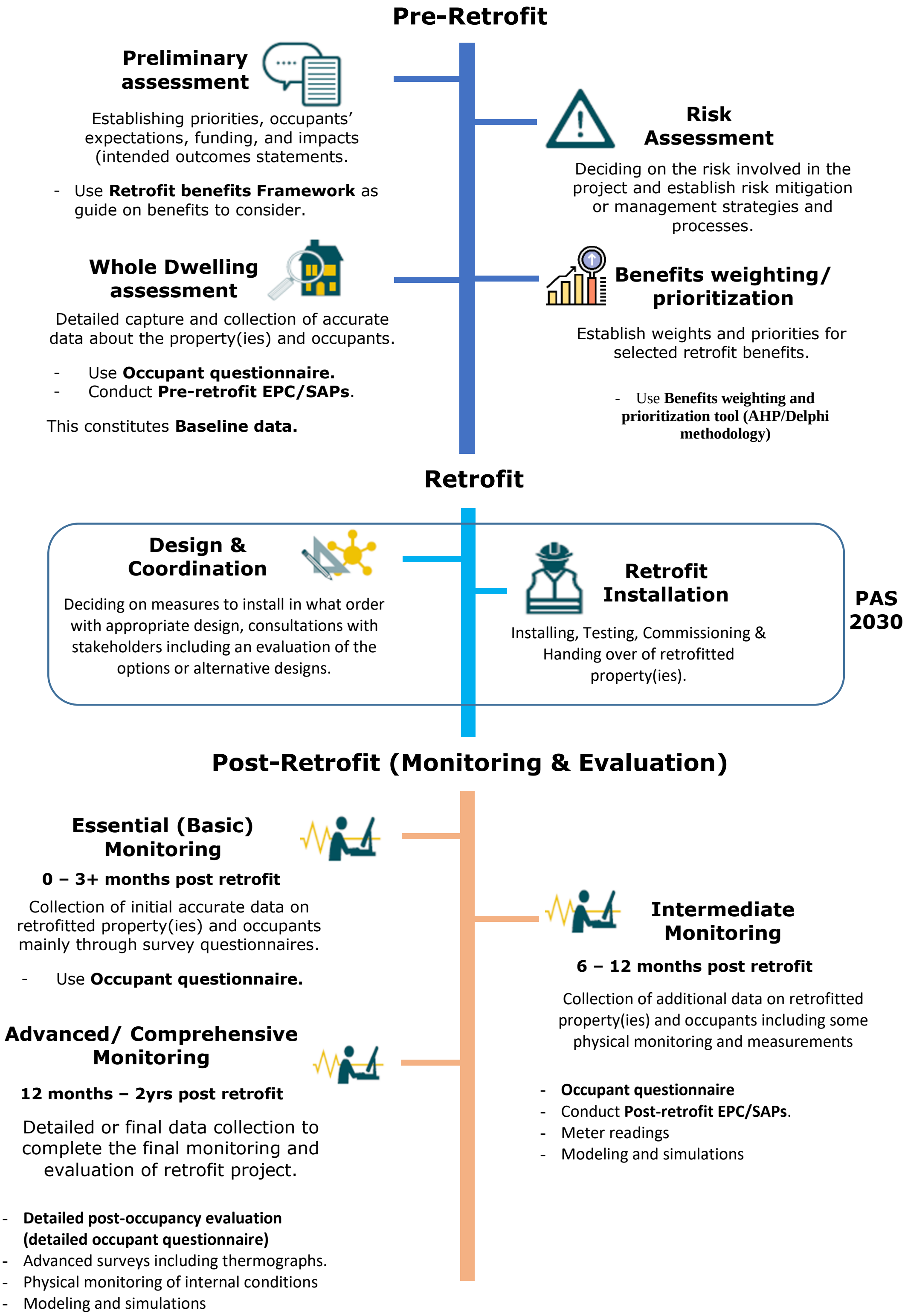


Figure 7-9 A workflow timeline for the REBAT Tool

4. The key roles and responsibilities necessary for implementing the toolkit closely follow the PAS 2035 process, to avoid duplicity of efforts and/or confusion. Besides, as mentioned earlier, the retrofit coordinator or project manager for the retrofit project is responsible for coordinating and implementing the toolkit. In addition, the following points/conditions need to be considered before using the methodology.
    a. Define and allocate staff to the retrofit monitoring process and implement the methodology.
    b. Establish the availability and access to data sources.
    c. A general monitoring process for the retrofit project (into which this methodology will fit) or contribute to.
    d. Establish reporting procedures, data organisation, storage, retrieval, and protection.
    e. Develop a strategy for communicating and involving all key stakeholders in the retrofit (monitoring) process.

7.6 Chapter Summary

This chapter set out to practically implement the benefits weighting and scoring methodologies developed in Chapter 6. It presented an overview of the various approaches to implementing the AHP and Delphi methods as well as a review of various proprietary and open-source software tools. Both tools are however implemented in a spreadsheet format utilising Microsoft Excel given the desire for user-friendliness ease of use and integration with existing systems of retrofit teams. Spreadsheets and Excel is already to many retrofit project teams and RSLs who routinely use it for other project functions including budgeting, forecasting and data management. The prioritisation tool is built upon an existing template by Goepel (2013) while the scoring tool is developed from scratch to include scoring sheets and a results dashboard which also includes guides to interpreting the results. Finally, workflow process is developed to provide guidance on the when and how to implement the toolkits developed and this includes an occupant and contractor questionnaires to assist with data collection.

Chapter 8 : Evaluation of the REBAT Tool

8.1 Introduction

This chapter aims to present the empirical evaluation of the REBAT Tool, a pivotal component of this research project. The objective of this empirical evaluation is to ascertain the tool's effectiveness and applicability in real-world scenarios, thereby providing an evidence-based foundation for its broader use and this responds to the final objective of this study. The chapter describes the results of the expert focus group interview to validate the REBAT tool and the evaluation of its practical usefulness. The next section provides a general overview of evaluations in research followed by section 8.3 providing details of the overall design considerations for the evaluations.

8.2 Evaluation/Validation Technique

The evaluation of the REBAT tool involved focus group interviews which provided a platform for a collective evaluation. This approach is advantageous in revealing the dynamics of how the tool would be used in a team setting and for gathering multiple viewpoints in a time-efficient manner. The choice of focus group discussions as the primary evaluation technique is underpinned by a set of research and practical considerations. Focus groups offer a different set of benefits, such as the generation of collective insights that cannot be easily obtained through one-on-one interviews (which has been the predominant technique throughout this study).

They are particularly useful for exploring group norms, uncovering multiple perspectives, and understanding complex behaviours and motivations (Krueger and Casey, 2015). Given that retrofit projects often involve multiple stakeholders with varied interests, focus groups can replicate this dynamic and offer insights into how the scoring tool will be received and used in a team setting (Morgan, 1997). Further, it is highly compatible with qualitative research paradigms and can facilitate the type of rich, context-dependent knowledge that this study aims to generate (Creswell and Creswell, 2018). Therefore, focus group discussions were deemed to offer the most effective and comprehensive way to evaluate the retrofit scoring tool.

8.3 The benefits measurement toolkit evaluation

Following the expert reviews and subsequent refinements, the next critical step is the evaluation of the toolkit via focus group discussions. This allows for a real-time exchange of thoughts among multiple stakeholders, thereby providing multifaceted insights into the tool's usability, relevance, and accuracy. Focus group discussions are advantageous because they facilitate interactive discussions, elicit diverse views, and can uncover facets of the problem that may not be immediately obvious (Morgan, 1997).

8.3.1 Preparations for Focus Group including participant recruitment.

To prepare for the focus group, a script was developed outlining the key discussion points, objectives, and time allocations for each section of the conversation. In addition, a visual aid with prompt (PowerPoint presentation) questions was created to guide the discussion and to ensure that all relevant topics would be covered. All participants were briefed beforehand on the objectives of the focus group and were provided with an overview of the toolkit to familiarize themselves before the discussion. Each participant was provided with a copy of the retrofit scoring tool and an accompanying how-to guide. This allowed the participants to familiarize themselves with the tool independently before the focus group discussion. To gauge their initial impressions and collect preliminary feedback, a pre-evaluation questionnaire was distributed. This strategy aimed to capture any shifts in the participants' opinions and understandings before and after the group discussion, thus providing an additional layer of insight into the tool's usability and effectiveness. However, it's worth noting that only one participant completed this pre-evaluation questionnaire, limiting its utility as a comprehensive evaluation metric.

The research initially aimed for at least three separate focus groups to ensure a broad perspective. Existing retrofit project teams, either currently working on or having recently completed a project, were specifically targeted for recruitment. This strategy was chosen over creating ad-hoc groups, as the former was believed to offer more cohesive and meaningful dialogues (Smithson, 2000). Four organizations, including registered social landlords and construction project management consultants, agreed to participate. However, logistical difficulties presented themselves when it came to scheduling the focus groups. Many organizations were deeply involved in putting together bids for government funding through the Social Housing Decarbonisation Fund (SHDF) or were concluding demonstration projects for the same scheme, making scheduling particularly challenging. Despite best efforts, including employing a snowballing approach for participant recruitment and extensive outreach both via email and at industry events, it proved difficult to synchronize schedules among all participating team members from the various organizations.

As a result, only one focus group could be successfully organized. This group consisted of six participants, including the researcher, who acted as the moderator. While the reduced number of focus groups limited the breadth of the study, the depth of the discussion benefited from the participants' high level of expertise and their shared experience working in closely-knit project teams. The challenges faced in recruitment and scheduling reiterate the practical difficulties often encountered in fieldwork, particularly in specialized sectors with time-sensitive workstreams.

8.3.2 Execution of Focus Group

8.3.2.1 Setting, duration and participants

The focus group was held online using Microsoft Teams, given the geographically dispersed nature of the participants and the convenience offered by the platform. The session lasted approximately 1.5 hours. The researcher served as the moderator and used a PowerPoint presentation to give an overview of the research, the retrofit scoring tool, and the purpose of the focus group. An agenda had been shared in advance as part of the invitation to participants. Four industry practitioners participated in the focus group, including.

8.3.2.2 Data Capture

The focus group was transcribed in real time using Microsoft Teams' automatic transcription feature. The generated transcript was downloaded after the meeting for subsequent analysis. All data were anonymized to maintain participant confidentiality.

8.3.2.3 Discussion Focus

Participants were generally positive about the retrofit scoring tool, showing particular interest in its potential applicability beyond the social housing and residential sectors. Discussions notably focused on the alignment of benefit indicators with the funding priorities of different stakeholders, such as government bodies and social landlords. Surprisingly, the Marketing Director was not previously aware of the broader benefits of retrofitting beyond energy efficiency, highlighting a potential awareness gap in the industry. Discussions also touched on the existing challenges and barriers to retrofitting, including negative public perception and the need to improve the reputation of retrofit measures among occupants.

Table 8-1 Focus Group Participants.

Focus Group Participants[8]		
Participant ID[9]	Professional Role	Experience (years)
FGA-1	Project Manager with a background as a Passivhaus consultant and Retrofit Coordinator	15+ years
FGA-2	Project Manager and Sustainability and ESG Lead	5 years
FGA-3	Marketing Director	30+ years
FGA-4	Senior Project Manager and Technical Lead Services for Carbon Life Cycle Assessments	5+ years

8.3.2.4 Challenges and Ethics

The primary challenge encountered was scheduling, as initially, six organizations were approached, but only one focus group could be organized, and two participants could not join due to timing conflicts among the participants. All ethical protocols were followed, including sending out consent forms, ensuring anonymity, and maintaining data confidentiality.

8.3.3 Analysis Strategy.

The analysis strategy for the focus group data followed the methods outlined in Chapter 4 (research methods and design). As highlighted earlier, the focus group discussion was recorded using Microsoft Teams and subsequently transcribed automatically. To ensure the accuracy of the transcription, the document was downloaded in MS Word format and meticulously reviewed for errors. Edits were made to correct grammatical errors and mis-transcriptions resulting from dialectical variations. All participants were anonymized using alphanumeric IDs (e.g., FGA-1, FGA-2, etc.) to maintain confidentiality.

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[8] Two additional professionals provided feedback via a post-evaluation survey, as they missed the focus group due to scheduling classes. However, their data was not included in the analysis to maintain methodological consistency, as their submissions were not collected under identical conditions and settings and lacks the interactive dynamics of a focus group.

[9] FGA – Focus Group A (the number indicate participant 1, 2 etc.). Were there other focus group interviews, they would have IDs FGB-1 (focus group B, participant 1); FGC-1 (focus group C, participant 1) etc…

Unlike the main empirical analysis detailed in Chapter 5, which utilized qualitative software (NVivo & MaxQDA), to assist with data coding and theme identification, the thematic analysis for this focus group was conducted manually. Following an inductive approach, themes were allowed to naturally emerge from the data. Although the overall questions and discussions during the interview provided some preconceived ideas for potential codes, the final coding structure was developed through a detailed review of the transcript. Themes were identified, categorized, and subsequently analysed to provide a comprehensive view of the focus group's perspectives.

Group Dynamics

No special methods were employed to analyse group dynamics specifically, however, the interactions among participants were noted. All participants worked within the same organization, leading to a general rapport and comfort level in the discussion. However, disparities in knowledge about wider retrofit benefits among participants were evident. The marketing participant appeared to have limited awareness compared to the project managers, who demonstrated a deeper understanding of the subject. This difference in levels of awareness and expertise informed the interpretation of the data and has been factored into the discussion of results.

8.4 Results of Focus Interviews and Final Retrofit Benefits Scoring Tool.

8.4.1 Analysis overview

Following the thematic analysis strategy outlined in Chapter 4 (section 4.6.4.1) and Section 8.5.3 above, the cleaned transcript was read multiple times and coded. An initial list of 31 codes emerged. This was further reviewed, some codes were merged, clustered, or nested together to create a more condensed overview of the data and help establish potential themes. Appendix A1.1 provides the list of 31 initial codes accompanied by a brief description of each. Following this iterative process, a condensed list of seven (7) potential themes emerged (which are detailed in Table 8-2 below).

8.4.2 Initial coding and theme development and refinement.

During the initial coding phase, raw data from the focus group interviews were meticulously examined to identify specific points of interest, insights, or recurring patterns. These were labelled with succinct descriptors to encapsulate the essence of the passage or point in question. Through this inductive process, 31 unique codes emerged, serving as preliminary anchors for subsequent theme development. The theme development phase involved clustering related codes and examining their interconnections. This process sought to identify overarching narratives or commonalities within the data. The clustering of the initial codes yielded seven distinct themes that collectively provided a comprehensive representation of the feedback and perspectives shared by the focus group participants regarding the retrofit benefits scoring tool.

Table 8-2 Summary of the final 7 themes from the thematic analysis of the focus group interview.

No	*Theme*	*Theme definition/description.*
1	Usability and Interface concerns	Captures feedback related to the user-friendliness, layout, and interaction aspects of the tool. Also highlights any technical glitches, user pain points, or aspects of the tool that were particularly liked or disliked by the participants.
2	Metrics accuracy & relevance	Discusses the metrics used by the tool to evaluate and score retrofit projects and explores whether these metrics are perceived as accurate, relevant, and in alignment with industry standards and expectations.
3	Comparative value	Encompasses discussions comparing the retrofit benefits scoring tool to other existing tools or methodologies and aims to understand how this tool stands out or falls short compared to other tools in the market.
4	Operational integration	Examines how the tool can be or has been integrated into existing workflows and project processes, and considers potential challenges, barriers, or facilitators in adopting and implementing the tool in real-world scenarios.
5	Training and onboarding	Delves into the perceived learning curve associated with the tool and highlights suggestions or concerns regarding training needs, resources, or materials that might aid users in effectively adopting the tool.
6	Contextual use and value proposition	Focuses on understanding the perceived role and value of the tool within the broader retrofitting ecosystem. Discusses how professionals see the tool benefiting them in their specific roles, the value it offers in real-world projects, and its broader contribution to the retrofitting industry.
7	Future enhancements and scalability	Gathers feedback on how the tool can be improved, adapted, or scaled for broader or different applications, including any suggestions for added features, integrations, or adjustments that would increase the tool's utility.

The initial themes derived from the coding and clustering processes were subjected to a thorough evaluation to ensure they were coherent and distinct and captured the richness of the data. Upon examination, the seven themes were deemed to be well-defined, capturing the essence of the participants' feedback without significant overlaps or ambiguities. While the usual refinement process involves collapsing, expanding, or merging themes based on their relevance and distinctiveness, the themes in this analysis stood strong without the need for such adjustments. Their inherent clarity and distinctiveness made further refinement unnecessary, allowing the research to confidently proceed with these themes for in-depth analysis and discussion. This decision aligns with the research's commitment to represent the perspectives and insights of the focus group participants authentically and comprehensively.

8.4.3 Thematic exploration and analysis of focus group interview

8.4.3.1 Usability and Interface Concerns

The theme "Usability & Interface Concerns" emphasizes feedback related to the user's experience, focusing on the user-friendliness, layout, and interactional aspects of the tool. This theme is pertinent as it determines how easily adaptable and scalable the tool is in a professional setting. It also underscores the necessity for user-friendly and interactive tools, particularly when introducing new methodologies or technologies to an established field like retrofitting. The feedback provided by *FGA-1* sheds significant light on the potential versatility of the tool when they allude to its applicability beyond just retrofit projects. The rhetorical query, *"[want to ask] whether you have considered... the tool to be used for projects that are not retrofit?"* highlights the tool's inherent capabilities, prompting thoughts about its potential expansion to other related sectors. This potential serves as a testament to its robustness and adaptability, traits essential for wide-ranging industry adoption.

However, while discussing the broader aspects of retrofitting, a shadow of concern is cast. *FGA-1* points to the daunting task of reversing the tarnished reputation of retrofitting, noting that the mere mention often leads to reluctance: *"…as soon as you say Retrofit, a lot of people will say no."* This sentiment, rooted in historical challenges like the lack of adequate governmental frameworks, underscores the importance of ensuring user-friendliness. It is not merely about ease of use, but more crucially about building trust. If a tool can be perceived as user-friendly and reliable, it might play a role in reshaping perceptions, serving as a stepping stone towards more positive industry-wide acceptance. In essence, while the tool seems to fare well in terms of usability and inclusivity, there's an undercurrent emphasizing the need for it to also embody trustworthiness in a sector, where perceptions, often based on past mishaps, play a pivotal role in adoption and acceptance. This can be achieved with live case studies and validations of the tool to further emphasize its robustness and adaptability.

8.4.3.2 Metrics Accuracy & Relevance

The significance of metrics within the context of retrofit projects cannot be understated. Metrics serve as tangible markers that guide, inform, and validate the processes and outcomes of retrofitting efforts. Their accuracy and relevance, therefore, become the bedrock on which stakeholders place their trust and make informed decisions. This theme therefore explored respondents' feedback on the metrics and scoring thresholds presented in the tool.

FGA-1's remarks on the *"multi-stakeholder matrix measurements,"* suggest appreciation for a holistic approach to metric representation. This sentiment underscores the importance of comprehensive metrics that cater to various stakeholders in the retrofitting landscape, thereby ensuring that diverse perspectives and concerns are captured and addressed. Further, *FGA-2* delves into the distinction between various metric categories - social, stakeholder engagement, user feedback, financial, and environmental, to name a few. Mentioning that the tool references and incorporates *"EPC and SAP reviews post-retrofit, pre-retrofit"* highlights the tool's broad spectrum of metric categories. It's pertinent that the tool doesn't narrowly focus on just one dimension but seeks to present a well-rounded view of the retrofit project's impact.

FGA-3 introduces another dimension by bringing attention to the alignment of metrics with industry standards and expectations, referencing entities like UKGBC. Their inquiry about whether the metrics resonate with investors' expectations underscores the broader industry implications. It's not just about having metrics; it's about having the right metrics that align with industry norms and stakeholder expectations, which is what the retrofit benefits scoring seeks to achieve, especially with future iterations that will incorporate intermediate and advanced evaluation indicators and metrics.

This theme of alignment is echoed further by *FGA-4*, who points out the inclusion of metrics like *"social value" and "air quality."* The mentioning of these indicators hints at an appreciation for the tool's expansive view, capturing both tangible (like air quality) and intangible (like social value) project outcomes. Lastly, *FGA-1's* emphasis on the *"educational piece on the retrofit work"* serves as a reminder that while metrics are indispensable, so too is the understanding and interpretation of these metrics. The best tools not only present metrics but facilitate a deeper understanding of their significance. Thus, the accuracy and relevance of metrics in the retrofit tool are crucial not just for validation, but also for fostering trust, aligning with industry standards, and ensuring that all retrofit project facets are holistically represented and understood.

8.4.3.3 Comparative Value

The theme of comparative value delves into how the retrofit benefits scoring tool positions itself among other existing tools or methodologies in the market. From an academic perspective, the crux of this theme rests on understanding the unique selling points and potential shortcomings of the tool relative to other similar tools or frameworks.

As mentioned earlier, the multi-stakeholder approach of the tool has been commended. A continuation of this thought emerges in another segment of the interview when FGA-1 remarks; *"And I like the fact that it doesn't restrict the indicators to just benefits to the occupier, but it covers much more strategic elements such as reputation or crime rate and so it gives you a very wide perspective"*. This is significant. While the primary concern of many retrofitting tools might be occupier benefits (given that these benefits are direct and most tangible), this tool broadens the scope to encompass societal or community-level benefits, such as reputation or crime rate. Such a perspective adds layers of depth to the analysis, allowing for a more expansive understanding of retrofit benefits.

In extending the examination of comparative value, another insightful perspective is presented by *FGA-1*: *"…and that makes me, you know, instantly think that that matrix will be fantastic, not just for retrofit projects, but for any development project. It could be used to measure the wider benefits of any project"*. This sentiment, beyond just commending the tool, places it in a broader context, suggesting its versatility and applicability beyond its primary purpose. It subtly underscores the universality of the metrics used in the tool, which, by extrapolation, can be viewed as a commendation of its design and conceptualization. A tool that transcends its immediate scope to be deemed applicable in broader contexts speaks about its comparative value.

In addition, the mention of a client looking to demonstrate the wider benefits for the community in a project funded by "levelling up" is particularly telling. It echoes the modern-day emphasis on community engagement, social value, and the need to measure impacts beyond mere monetary gains or direct tangible benefits. The suggestion that the tool might be apt for such a purpose again elevates its comparative value. The retrofit benefits scoring tool, in this case, isn't just a tool for evaluating retrofit projects but becomes a potential tool for gauging community-centric, wider benefits.

The end of the quote further emphasizes its adaptability: *"…even if it's just not a pure retrofit, even if it's just … a redevelopment of brownfield"*. This hints at the tool's potential scalability and adaptability, underscoring its potential as an asset not just within the confines of retrofitting but also in the wider domain of urban development and planning. In other words, the comparative value of the retrofit benefits scoring tool isn't merely rooted in how it measures up against other retrofit-specific tools but also in its adaptability, scalability, and potential for wider application, making it a versatile toolkit in other similarly built environment domains such as urban development and planning.

8.4.3.4 Operational Integration

Operational integration refers to the seamless integration of a tool or framework into existing systems and processes. In the context of the retrofit benefits scoring tool, stakeholders touched on multiple facets of its operational viability. Earlier in the expert interviews discussed in Chapter 5, a similar theme emerged, where one of the social housing respondents alluded to the need for any tool or framework to easily integrate with the existing systems and procedures of RSLs. It was, therefore, necessary to explore this theme further in the focus interview evaluating the final benefits scoring tool.

A core observation from respondent FGA-1 draws attention to how adaptable the tool is across different retrofit frameworks. Their mention of *"PAS 2035 projects"* alludes to the fact that the tool may be primed for specific retrofit standards. However, there's a clear curiosity and perhaps a latent need in the market for such a tool to be adaptable across other recognized frameworks like "Passivhaus" and "Enerphit." This not only emphasizes the tool's potential versatility but also a market demand to widen its applicability across different retrofit frameworks (which can also be considered a limitation of the current tool).

Yet, while recognizing the potential, there's a technological challenge pinpointed. The tool, being Excel-based, may not be as dynamic or user-friendly as stakeholders might hope, especially when interfacing with clients. The respondent's suggestion to transition to a platform like *"Power BI"* accentuates a desire for enhanced user interaction and wider accessibility. The advantage of such platforms is twofold: they heighten user experience and offer a dynamic, web-based tool that can be readily shared and accessed by various stakeholders.

Interestingly, there's another caution as well. The mention of *"not very professional contractors"* and the subsequent negative outcomes serve as a stark reminder that while tools can be technologically sound and metrically accurate, the human element and the integrity of the execution process remain pivotal. For the tool to achieve its intended outcomes, there's a paramount need for professionalism, knowledge, and transparency in its application, lest it falls prey to *"unintended consequences"* that can hinder its adoption.

8.4.3.5 Training and Onboarding

Understanding a tool's intricacies and its broader implications in an industry can often be a gateway to its widespread adoption. The theme of training and onboarding underscores this very sentiment concerning the retrofit benefits scoring tool. From the focus group interview, respondent *FGA-4* offers a unique perspective, shedding light on the disconnect that exists between technical jargon and the layman's understanding of retrofit. Expressing an initial perception that retrofit is largely about *"efficiency and cutting down energy bills",* there's a marked revelation when exposed to the wider ambit of benefits, including the *"social value"* and aspects such as air quality. Such a narrative brings forth a crucial question: Is the vast expanse of benefits associated with retrofit universally understood or is there a layer of opacity that needs to be addressed; a question they pose to the interviewer/researcher?

The recurrent query on the known nature of these benefits hints at the presence of a potential knowledge gap, further echoed by FGA-1's remarks on the challenges of defining "what retrofit is". This ambiguity has tangible consequences, as witnessed in the early government retrofit schemes. The unpreparedness, lack of clarity, and oversight resulted in the exploitation by unprofessional contractors. Such incidents are not just setbacks in project execution, but they also risk warping the public's perception of retrofit and its benefits.

It is within this complex backdrop that the current research positions itself, aspiring to remedy the gaps. The challenges which prompted this research are substantial. The difficulties in decision-making, compounded by inconsistent and, at times, irrelevant measures of retrofit benefits, create a chaotic landscape for industry professionals and stakeholders. As noted in the research background, the exclusion of these wider benefits is problematic but equally concerning is the flawed measurement of such benefits when they are considered. It's a dual challenge: there's a need for inclusion and accurate measurement.

By developing a comprehensive toolkit, this research hopes to achieve a two-fold objective. Firstly, it aims to provide a standardized metric system, bringing clarity and consistency to evaluations. Secondly, it is a tool for education and advocacy. By showcasing a comprehensive list of benefits and providing a method to measure them, the tool not only aids in project evaluation but also acts as a repository of knowledge. It educates users on the breadth and depth of benefits associated with retrofit projects. The ultimate aspiration is for the tools to be instruments of enlightenment, bringing clarity to the ambiguities and uncertainties around retrofit and benefit measurement. Such comments from the evaluation indicate that this objective is being achieved.

8.4.3.6 Contextual Use and Value Proposition

The value of any tool is contingent on its ability to address specific needs within its intended application domain. Evaluating the feedback from the focus interview concerning the contextual use and value proposition of the retrofit benefits scoring tool reveals a coherent narrative that emphasizes the tool's applicability, relevance, and potential in the broader retrofitting landscape.

Feedback from FGA-1 highlights the tool's practicality for professionals within the retrofitting sector. *FGA-1,* a project manager and retrofit coordinator, recognizes the tool's capability to provide actionable insights that inform crucial discussions with a diverse range of stakeholders, from clients and investors to building users; *"it just looks to me, you know, as a project manager such a fantastic opportunity of a very practical hands-on tool that gives you the information that you need to inform discussions with clients and investors and you know, your building users."* This captures the essence of the tool's design: to serve as a versatile, data-driven instrument that facilitates informed decision-making across multiple project phases.

In addition, *FGA-2* underscores the value proposition of the tool beyond its immediate context. In recognizing a "massive niche" for the tool, they emphasize the tool's potential to cater to a diverse range of retrofit projects, irrespective of their scale or context; *"[we]…have another project, … and using a tool like this will definitely help them because that's the kind of thing… they are looking at implementing and so yeah, I can see a massive niche there for you to keep exploring."* The enthusiastic reception and anticipation of *"all the potential applications"* hint at an industry appetite for structured, data-driven evaluation tools that can navigate the complexities of retrofit benefits.

Also, *FGA-4's* reference to the *"people place planet"* paradigm resonates with the overarching aim of this research. The tool, in its design and functionality, captures a holistic view of retrofit projects, emphasizing the symbiotic relationship between societal well-being, environmental sustainability, and infrastructural development. It's a testament to the tool's alignment with broader industry trends and terminologies. Finally, *FGA-2's* mention of Cornwall's low-carbon partnership and the potential for collaboration with Registered Social Landlords (RSLs) introduces an exciting avenue for the tool's dissemination and application. Such collaborations can not only amplify the tool's reach and relevance but also enrich its database, making it even more comprehensive and robust as suggested later in chapter 9 for future research.

In essence, the feedback paints a promising picture of the retrofit benefits scoring tool's position and propositional value within the retrofitting industry. As a versatile, comprehensive, and relevant tool, it possesses the potential to revolutionize how professionals evaluate, plan, and implement retrofit projects. Its value proposition isn't just in its metrics or algorithms but in its ability to bridge knowledge gaps, foster collaborations, and guide stakeholders towards a more sustainable, informed, and holistic approach to retrofitting.

8.4.3.7 Future Enhancements and Scalability Discussion.

Feedback on how the tool can be improved, adapted, or scaled for broader or different applications is invaluable. This theme gathers insights on how the retrofit benefits scoring tool might be fine-tuned, expanded, or even repurposed for broader applications. The comments from the evaluators shed light on multiple avenues of exploration and adaptation.

The holistic nature of the tool, as underlined by *FGA-1*, highlights its versatility. The underlying matrix framework, which is central to evaluating the wider benefits of retrofit projects, is not just limited to retrofits. Its applicability extends to any development project, as suggested by *FGA-1* in the context of *'levelling up'* projects or brownfield redevelopments. This remark underscores the tool's potential scalability beyond its current function. While the tool was developed in the context of retrofits, its core functionality – to measure the broader societal, environmental, and economic implications of projects – has universal relevance.

The query posed by *FGA-2 "is there a financial strand in this as well that you would look to either incorporate or align with in some way to get a holistic view?"* indirectly validates one of this study's central arguments – that stakeholders often have an inherent bias towards financial and economic benefits, overshadowing the social and environmental dimensions. While economic metrics, such as energy bill savings, undeniably carry weight, the essence of this tool – and the research it emanates from—lies in its endeavour to advance the less-tangible, wider benefits to an equal footing. The query also serves as a reflection of the prevailing mindset in the industry, emphasizing the importance and relevance of this research's objective: to counterbalance this economic and techno-centric view with a comprehensive and human-centric perspective that equally values social and environmental benefits.

On the technical front, the transition from Excel to a more dynamic and interactive platform, such as Power BI, as recommended by *FGA-1*, is noteworthy. Not only does this shift offer an improved user experience, but it also caters to the evolving needs of the industry—where interactive, shareable, and web-based tools are gaining prominence. Migrating to a platform like Power BI would thus enhance the tool's accessibility, user-friendliness, and overall appeal. Finally, *FGA-2's* suggestion of adding an economic indicator related to the *"%age reduction in rent payments being missed"* resonates with the tool's ethos – to capture the wide-ranging impacts of retrofit projects. Such an indicator however is best captured in a "tenant satisfaction" indicator which the tool already captures, enhancing the tool's comprehensiveness.

8.4.4 Summary of theme interconnections and conclusion

The thematic analysis unveiled deep connections between different facets of feedback, painting a holistic picture of the retrofit benefits scoring tool's perception and potential.

The relationship between the initial understanding of the tool and its subsequent onboarding process emerged as a pivotal link. An initial grasp of the tool's purpose and capabilities directly influenced the perceived need for a structured training and onboarding process. This is evident from the expressed sentiment where the depth and breadth of retrofitting benefits weren't always immediately recognized, underscoring the need to bridge these knowledge gaps. Furthermore, the tool's utility in practice is deeply intertwined with its ease of integration into current workflows. Stakeholders' capacity to visualize the tool's inclusion in their daily operations influences their perception of its value. This feedback, in turn, provides a roadmap for future enhancements and adjustments. Suggestions, such as considering integration with platforms like Power BI, reinforce this interplay between current utility and future scalability.

The tool's value proposition within the broader retrofitting landscape also plays a significant role in the onboarding willingness. If professionals discern considerable value in the tool, they might be more amenable to dedicating time to its learning process. Conversely, if the tool's worth isn't palpable, even the most comprehensive training might not ensure its broad adoption. This sentiment was echoed in suggestions pointing toward the tool's applications beyond just retrofitting projects, underlining its perceived broader value. In concluding these interwoven themes, the feedback narrates a story of potential, hurdles, and areas ripe for enhancement. There's a consensus recognizing the tool's significance in the retrofitting domain, albeit juxtaposed against operational challenges and the necessity for a substantial onboarding process. The journey to its widespread acceptance in the industry rests on several keystones: clear communication of its capabilities, seamless operational integration, proactive enhancements based on feedback, and a robust approach to training and advocacy.

8.5 Chapter Summary

The thematic analysis of the feedback from the focus group evaluation interview reveals a cohesive narrative around the retrofit benefits scoring tool's potential, challenges, and areas of improvement. There's a clear acknowledgement of its value within the retrofitting landscape, but this is tempered by operational concerns and the need for robust onboarding. For the tool to receive adoption and be deemed indispensable, some key issues need to be addressed moving forward.

Clarity and Communication: Stakeholders need a clear understanding of the tool's capabilities and purpose.

Integration and Adaptability: The seamless integration of the tool into existing work processes is crucial and needs to be explored further.

Expansion and Improvement: Continuous enhancements based on user feedback will ensure the tool remains relevant and versatile. More research is needed in this area, as highlighted in the next chapter.

Education Potential and Advocacy: Bridging knowledge gaps and promoting the tool's broader benefits will catalyse its acceptance.

In summary, while the retrofit benefits scoring tool has garnered a positive response, its journey towards becoming an industry standard hinge on addressing the interconnected challenges highlighted by the themes. Its promise lies not just in measuring benefits but in transforming how the retrofitting industry views, values, and implements projects.

Chapter 9 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

9.1 Introduction

The chapter provides the conclusions of the study by providing a summary of the findings of the research and its contributions to knowledge. It starts with a discussion of how the objectives of the research have been achieved, followed by a summary of findings and the study's contributions of knowledge as well as implications these findings with recommendations. The final section outlines the limitations of the research possible areas for future research.

9.2 Meeting the research Objectives: Main conclusions

This study set out to present a comprehensive framework and toolkit for measuring the wider benefits of home energy retrofit projects, with 6 distinct objectives. To achieve the objectives, the research conducted two literature reviews, one on the retrofit benefits, their identification and classification in chapter two and another on the evaluation methods and tools in chapter 3. These two reviews gave a good context and background as well as identifying the relevant stakeholders and retrofit benefits needed to develop a comprehensive multi-stakeholder retrofit benefits framework at the end of chapter 3. To augment the conceptual multi-stakeholder framework and to understand and integrate industry feedback into the development of the tools, semi-structured interviews were conducted with practitioners, who also reviewed and provided input to the framework. These were covered in the fifth chapter.

In addition, a prioritisation methodology based on an integrated AHP-Delphi approach was developed to help in prioritising and ranking the benefits given the multiple interests are stakeholders in Chapter 6. This was then followed by the conceptual development of the retrofits benefit scoring tool. Chapter 7 presented the main toolkits (benefit prioritisation and weighting tool and the retrofit benefit scoring tool). These together with a sample questionnaire to assist with occupant surveys to gather necessary data to quantify and score benefits and finally, a high-level workflow to inform and guide the retrofit evaluation process, form the toolkits developed from the study. The retrofit scoring tool was subsequently evaluated through a focus group interview in Chapter 8. Table 9-1 below summarizes the key objectives addressed and how.

Table 9-1 Summary of research objectives achieved.

Objective	**Attained**	**How (Methods Used)**
To review the literature on the wider benefits of retrofitting and their categorisation.	Chapter 2 Reviewed wider benefits & how to categorise them	A detailed literature review was conducted on the wider benefits of retrofitting homes in the UK, their categorisation and policy and legal landscape driving/hindering retrofits
To identify and evaluate the strengths and weaknesses of existing methods, tools, and frameworks for identifying and measuring the benefits of retrofits.	Chapter 3 + 5 Literature and expert review and feedback on conceptual benefits framework.	A literature review into existing methods, approaches, and tools for retrofit project evaluation was conducted
To develop a benefits measurement framework based on the synthesis of existing literature, which defines criteria, indicators, and metrics.		A conceptual stakeholder matrix framework mapping benefits multiple stakeholders developed and reviewed in Chapter 5 by experts for clarity and conciseness.
To develop a weighting or prioritisation methodology for ranking the different retrofit benefit indicators and criteria at different levels and scales of measurement.	Chapter 6 + 7 Set conceptual methodologies, criteria, scoring scale and thresholds for weighting and scoring tools.	Adopted an integrated AHP-Delphi methodology to develop the weighting and prioritisation tool which is implemented in a spreadsheet format using Microsoft Excel.
To develop a retrofit benefits scoring tool with criteria thresholds, data collection and implementation guidelines to assist the use of the tools.	Chapter 6 + 7 implements the tools in a spreadsheet, with integration into the weighting tool developed under objective 5.	A spreadsheet retrofit benefits scoring tool is developed with 12 out of the 23 indicators in the benefits matrix framework, with an interpretation guide to aid results interpretation.
Evaluate and test the developed framework and tools to assess its effectiveness as well as issues for its further improvement	Chapter 8 Benefits scoring tool evaluation of the through an expert focus review interview.	The focus group interview examined the benefit scoring tool together with its indicators, criteria, metrics and importantly the usability and relevance to industry professionals and projects.

9.2.1 Objective 1: To review the literature on the wider benefits of retrofitting and their categorisation.

A literature review was carried out on home energy retrofits (Chapter 2) using academic databases such as SCOPUS, Web of Science and Google Scholar. It included peer-reviewed articles, reports, industry reports and case studies and covered issues such as what constitutes home retrofits, the benefits of retrofits, categorising them and the legal and policy landscape of retrofits in the UK. The review revealed that home energy retrofit projects generate a range of benefits beyond just energy (bills) and carbon savings. These include improved physical and mental health, higher property values, and positive environmental impacts such as improvements in local energy supply through renewable generation.

The review also demonstrated that there was a lack of standardization in measuring and categorizing these benefits as well as in communicating these as part of project outcomes. This polarity in terminologies for benefits combined with the adoption of different methodologies and metrics, makes it challenging to compare and consolidate findings from different projects. Chapter 2 also highlighted that social housing presents unique opportunities and challenges, especially for scaling retrofitting, making it a particularly important sector for retrofit research, thus supporting this study's focus on social housing. Some social housing providers (Registered Social Landlords – RSLs) are spearheading this and the government has introduced several policies and schemes to unlock this opportunity in the sector. However, the review shows that while these have achieved some varying degrees of success, there is still significant complexity and fragmentation present and the need for more simplified schemes with improved targeting of vulnerable households as well as more robust and inclusive implementation systems. In other words, clarity and consistency are needed in retrofit policymaking to overcome the difficulties in the sector.

9.2.2 Objective 2: To identify and evaluate the strengths and weaknesses of existing methods, tools, and frameworks for identifying and measuring the benefits of retrofits.

Following the review in Chapter 2, the third objective sought to identify and critically evaluate the methodologies and tools currently in use for measuring and assessing the wider benefit of retrofit projects. An extended literature review was conducted with a specific focus on methods of retrofit evaluation.

Literature Review

The review found that most methods fall into roughly four broad categories – simulation and modelling methods (more on the technical aspects of buildings); experimental and monitoring-based methods; economic and financial-based methods and framework-based methods/tools. That said, there appears to be a predominance in the use of quantitative metrics across the various groups of methods/approaches. Perhaps that is a result of the overemphasis on quantitative benefits and/or metrics such as energy and bill savings, carbon savings and maintenance and repair savings. Similar observations are seen with modelling and simulation studies which tend to focus more on the technical aspects of building performance analysis and systems optimisation to achieve the best measures that lead to the highest energy savings and carbon reductions. This presents a situation where in retrofit project evaluations, qualitative-based metrics and methods are almost either marginalised, neglected or sporadically integrated to avoid appearing lopsided.

The review also found that most existing studies focused on individual benefits or stakeholders, often in isolation. There was a lack of integrated approaches that considered multiple benefits holistically. Closely related to this is the techno-centric focus of tools and evaluations and the need to re-emphasise a human-centred approach to evaluations considering multi-stakeholder perspectives. Finally, there is a nascent but growing interest in interdisciplinary approaches that attempt to integrate social science-based methods/metrics with engineering-based ones to provide a more holistic view of retrofit benefits.

Empirical Work

To supplement the literature review findings, semi-structured interviews were conducted with 11 industry experts and practitioners to understand the on-the-ground challenges and practical aspects of retrofit project evaluation. The interviews served to map out a good understanding of industry stakeholders' perspectives on the key challenges of retrofit evaluation and to triangulate the findings from the literature review to offer a well-rounded review. Experts emphasized the difficulties of measuring qualitative benefits, such as improved mental and physical health and translating them into quantitative metrics. To address this challenge, the REBAT tool provides guidance on how to utilise survey responses to, a basic level, quantify (qualitatively), the percentage of households that have experienced an improvement in their mental or physical health well-being. Future iterations of the tool will explore quantitative assessment of qualitative benefit indicators. It also supported the literature findings on the lack of comprehensive tools that consider multi-benefits and multi-stakeholder perspectives. Specifically, respondents called for new techniques and measures that dealt with airtightness and thermal bridging for example.

In addition, the empirical data revealed that retrofit project evaluations do not necessarily follow or adopt a consistent methodology, partly due to the multiple indicators which require different methods/tools sometimes to evaluate. However, the inconsistencies go beyond methods to include the quality of evaluations and outcomes even when similar methods are used across projects. Closely related to this is the interoperability of integration of different methods and software/platforms/tools to execute retrofit evaluations.

Other key challenges highlighted included tenant disengagement, which presents both a complex problem, and a critical element. Tenants typically disengage through refusal to participate with retrofits, resistance to some types of retrofit measure(s), unwillingness to partake in planning and development stages of project through completion of surveys and interviews. No obvious solution seems to be in sight as the challenges also differs across housing providers. Also highlighted in the data was the need for a standardised approach to evaluations; even though inconsistencies in the capabilities of various technological tools for retrofit monitoring and evaluation exist which also hampers the robustness of evaluations; and inconsistencies in policy and regulations.

A surprising finding from the interviews was about the apparent layer of cost from following the industry retrofit guide/standard, PAS 2035. The PAS 2035 introduced specialised roles into the retrofitting process, which has subsequently led to skills shortages, especially in the key new roles driving up labour costs in ensuring the project secures the right persons to deliver the project, so it clears TrustMark/PAS 2035 standards. Closely related to this is the emphasis on the role of government funding to accelerate retrofitting work, especially within the social housing sector.

This empirical approach not only provides a more holistic view of the current state of retrofit evaluation methods but also adds a layer of practicality, making the research more applicable to industry stakeholders. It substantiates the findings from the literature review and helps pave the way for the subsequent objectives of developing a comprehensive framework and tools for retrofit evaluation.

9.2.3 Objective 3: To develop a benefits measurement framework based on the synthesis of existing literature, which defines criteria, indicators, and metrics.

The third objective focused on synthesizing findings from the first two objectives to develop a more comprehensive benefits measurement framework for evaluating retrofit projects in social housing settings. Building upon the knowledge gaps and shortcomings identified through the literature review and evaluation of existing methodologies, a new framework was conceived. A rigorous process of synthesis was followed, involving iterative cycles of design and expert feedback. The framework went through several drafts and refinements based on stakeholder feedback and the researcher's evaluations. Section 5.2 in Chapter 5 covered the expert review and results for the matrix framework. The key innovation was the development of a matrix-based approach that maps specific benefits to individual stakeholders, thus ensuring that the evaluation is both comprehensive and tailored, while also allowing for a more nuanced understanding of who gains what from retrofit projects.

A total of 60 wider benefits were identified. After a synthesis process, an abstracted list of 26 benefits remained, which went through expert review. Following the expert review and further iterations, the 26 were further aggregated into a final list of 23 indicators making up the multi-stakeholder matrix retrofit benefits indicator, divided into 7 Social benefits, 8 Environmental benefits and 8 Economic benefits.

Moreover, the framework is multi-dimensional, which means it inculcates both quantitative and qualitative metrics, offering a holistic view of a project's benefits. In addition, the framework is stakeholder-centric, so it encourages the active participation of all potential stakeholders. This ensures the framework is not only theoretically sound but also practically applicable.

An area where some interesting findings emerged from this research was around benefit indicators and the appropriate or relevant metrics to adopt for their measurement. The study concludes from expert reviews that all theoretical and methodologically sound metrics may be practically useful in assessing or measuring retrofit benefits. Specifically, while some benefit indicators had theoretically sound and rigorous metrics from the literature, they were found to be impractical in the context of home energy retrofits. For example, with the health and wellbeing of building occupant's indicator, the expert reviews concluded that DALYs and YOLLs are well recognised metrics used in public health studies to for wellbeing impacts assessment (e.g. disease burden impacts and premature mortality) among populations, because of their structured way of measuring. However, they can be very complex and may not always be clear or even directly relevant for all evaluation types. Using them in retrofits may require supplementary measures or a careful adaption as they may not easily communicate impacts in an easy-to-understand manner to non-experts (Gao *et al.*, 2015). That is, these metrics may not directly translate to the perceived immediate benefits in housing or retrofit contexts. Mont, (2007) for example has argued elsewhere that such metrics are more suitable for interventions that aim directly at disease prevention rather than those aimed at welfare and wellbeing improvements. Percentage improvements or increases/reductions in special health and wellbeing conditions has thus been adopted for the framework and tools.

Similarly, life years lost to PM2.5 and excess winter deaths and Morbidity (EWDs) as metrics for health and wellbeing have been criticised. The major concern with these metrics is the attribution problem. While PM2.5 is a significant indicator for air quality, it fails to account for the many environmental factors that influence health, and therefore could overestimate or underestimate impacts (Chen et al., 2020). EWD on the other hand deals with seasonal effects on mortality, morbidity, and exposure to cold or poor heating (which is prevalent in social homes), which again renders attribution of EWD to specific interventions, especially retrofitting, difficult (Almendra *et al.*, 2019).

Other key findings emerged from the empirical work on this objective. Studies by Malka, Kuriqi and Haxhimusa, (2022) and (Dong *et al.*, 2023) suggests that retrofitting measures reduces the usable space available to occupants, especially measures that involve addition of substantial insulation (wall, ceiling, or floor). The notion that space is gained from upgrades such as heating system changes is usually offset by the space lost due to insulation The impact of this effect should be thoroughly evaluated while strategizing and implementing retrofit projects. It is crucial to watch and communicate with renters to enhance transparency and assess the acceptability of renovated homes after the project.

A scale dimension is equally built into the framework, making it relevant for projects involving a single building or a multi-unit social housing project. Given that a single framework could not potentially be completely exhaustive, the benefits framework is designed to be able to adapt to new benefit indicators as more research becomes available or as project goals evolve, making it a dynamic tool for evaluation. Finally, a key guiding principle during the development of the framework was 'ease of use' (and this applied across all the other tools developed as part of this study). The framework was deemed to be intuitive enough for a user without deep technical expertise in retrofitting by industry practitioners during the reviews and this widens its potential adoption and use.

Achieving this objective has filled a critical gap in existing research and provided a foundational tool for more effectively measuring the wide-ranging benefits of residential retrofit projects (even if that is just beginning to think more about wider benefits). However, it's worth noting that some stakeholders felt that the matrix could become too complex if an excessive number of variables were included. There were also concerns about the potential for the matrix to be misused if not properly understood or applied, emphasizing the need for clear guidelines. The next two sets of objectives further refined and improved the effectiveness and practical use of the framework.

9.2.4 Objective 4: To develop a weighting or prioritisation methodology for ranking the different retrofit benefit indicators and criteria at different levels and scales of measurement.

To address this objective, an integrated Analytic Hierarchy Process (AHP) and Delphi method was employed for the theoretical development of a weighting or prioritization methodology. While the tool itself has not yet been applied in a live retrofit project, its construction and theoretical basis are designed to provide a robust framework for future applications. The rationale for the tool and methodology was to address the issues of complexity in benefit assessment, where equating the diverse benefits on a common scale for decision-making is challenging. It is meant to fulfil the need for prioritisation because not all benefits are equally important in every context or to every stakeholder. Stakeholders therefore need to make decisions aligned with their specific objectives.

The key takeaways from fulfilling this objective include the following. The combination of AHP and Delphi methods in the design lends theoretical rigidity and stakeholder inclusiveness to the tool (especially considering Group-AHP variant), although empirical validation is pending. A combination of the quantitative rigour of the Analytic Hierarchy Process (AHP) with the qualitative insights from experts via the Delphi method can result in a more balanced and comprehensive evaluation. Also, a user-friendly spreadsheet tool was built to facilitate the AHP-Delphi process, complete with guidelines for future users. The developed methodology also can account for varying stakeholder perspectives (emphasised from objectives 1 to 3, and which runs throughout this study), a feature that promises to add depth to future retrofit evaluations.

While the tool has been theoretically designed to be robust and flexible, it has not been empirically validated through a real-world project. This limits the current ability to assess its effectiveness and accuracy. Similarly, its usability has not been subjected to testing, making it an area that might require further refinement. Also, while designed to be user-friendly, the tool still has a learning curve, especially for those unfamiliar with the AHP-Delphi approach or the matrix-based system. These notwithstanding the methodology and tool offer promise for a more nuanced and stakeholder-specific approach to evaluating the wider benefits of residential retrofit projects. The tool aims to be particularly beneficial for social housing projects in the UK, given its designed adaptability to different scales and types of retrofit projects. Future research and application of the tool in live projects will be essential for its validation and possible refinement.

9.2.5 Objective 5: To develop a retrofit benefits scoring tool with criteria thresholds, data collection and implementation guidelines to assist the use of the tools.

This is a key objective of the study and is meant to operationalise all the key findings from the previous objectives into a practical and useful tool that can be used to assess retrofit projects. A comprehensive scoring tool was developed in spreadsheet format to operationalize the benefits measurement framework. Recognizing the necessity for practicality and focus, the scoring tool was designed to implement only a selected set of benefit indicators deemed relevant for basic post-retrofit evaluations (12 indicators out of the 23 in the final benefits framework). Intermediate and advanced evaluation-related benefits have been reserved for future iterations of the tool.

The tool was designed for ease of use, with straightforward data input fields and clear output results, making it accessible to a wide range of stakeholders. It also promotes transparency in the decision-making process by clearly outlining how each score is calculated and what each metric signifies, with an interpretation guide to aid results interpretation. An occupant questionnaire was developed as a part of the toolkit to facilitate the data collection process. This aligns with the research's human-centred approach to retrofit evaluations, emphasizing the importance of considering occupants' perspectives when assessing the benefits of retrofitting. The decision to focus initially on a subset of benefits allows for greater ease of use and faster implementation, with the built-in flexibility for the tool to be expanded in the future as needed.

Fundamentally, the REBAT is a qualitative evaluation tool that evaluates qualitatively the wider benefits of retrofit investments. This approach to the development of the tool appear to take away from its acceptability, because there is an inherent 'bias' towards quantitative and financial (or monetisation of) measures as outlined and discussed in chapter 3 earlier. This resonated again at the expert evaluation of the tool. Where expert questioned whether the tool had a financial strand to it and whether an economic indicator that measures the percentage reduction in rent payments being missed i.e. missed rental income from voids or decanting during retrofit projects. While quantitative (monetised) outputs or impacts is not the primary focus of the REBAT tool, this finding suggests that this can be a major setback. The suggestion has been made to integrate the REBAT tool with other tools or methods that generate such quantitative measurements. However, no exploration has been conducted as part of this thesis to establish which tools, systems or frameworks, the REBAT can easily plug into or integrate with. The assumption however is that such a system, tool or methodology will generate the values needed to use the REBAT tool.

These findings further reinforces aim of the research to make retrofit evaluations more human-centred and feasible for immediate usage, while allowing for future expansions and validations or evaluations (the focus of the next and final objective). Finally, while no compatibility and interoperability test/revies were performed for the REBAT, its modular structure and the ability to export outputs in CSV and other database formats should make it compatible with existing evaluation frameworks and tools makes it easier to integrate its data into these existing systems or data from other systems into REBAT for further analysis.

9.2.6 Objective 6: Evaluate and test the developed framework and tools to assess its effectiveness as well as issues for further improvement.

As with every research involved in the development of a model, tool, artefact or even a theory, there is the need to subject this to empirical evaluation and or validation. The final objective of the study was to evaluate the developed framework and tools to assess their effectiveness as well as issues for further improvement. The evaluation methodology relied on theoretical testing and expert input rather than empirical testing on live projects. Focus groups and expert interviews were conducted to gather feedback on the tool's usability, adaptability, and integration capabilities, including its effectiveness, practicality, and relevance among others and that has led to some key conclusions with potential implications for policy and practice.

The focus group and experts provided positive feedback, especially in terms of its coverage of wider benefits, multi-stakeholders and a human-centred approach and adaptability.

First, the empirical evaluation of the REBAT demonstrates it as an effective tool for evaluating retrofit benefits (especially in social housing). The potential versatility of the tool was highlighted with suggestions of its applicability beyond residential retrofit to commercial/industrial retrofits as well as other retrofit frameworks such as Passivhaus (with some amendments). However, the evolving nature of the sector coupled with a purported 'tarnished reputation of retrofit' means that any new tool or software will contend with reliability and trust issues, especially if it aims for wide-spread application/adoption. This is because, stakeholders are already locked-into some applications or systems and the switching costs can pose difficulties.

Akin to the above point is the issue of evaluation or measurement criteria, indicators, and metrics and how they (mis)align with industry standards and expectations and especially that of investors or funding bodies. Now the retrofit sector in the UK is presently largely funded by the government through special funding schemes such the LAD, HUG and SHDF (refer to chapter 2 section 2.2.3 for details on these). Besides there is a strong regulatory regime for retrofit again led by the government but also private sector and industry. The evaluation review established that the REBAT tool and its metrics are well aligned with industry expectations and standards, such incorporating EPC and SAP (which are the government-backed and recognised) measures for rating the efficiency of homes. Furthermore, the integration of the PAS 2035 retrofit process into the REBAT workflow process ensures that adopting the tool for an evaluation address assures compliance at least with the monitoring and evaluation requirements of the standard. However what this implies also that the tool at present is only useful for social housing retrofits and cannot be applied to other retrofit frameworks such as "Passivhaus" and "Enerphit", both of which are gaining traction in the industry.

Some suggestions for improvements were made which have been implemented, while other limitations were identified, including the need for empirical validation and further refinement based on real-world application. In summary, objective 6 was partially met through theoretical evaluation and expert feedback. The next steps would involve rigorous empirical testing to further refine and validate the framework and tools.

Overall, the research makes a significant contribution to the field by developing a comprehensive, human-centred framework and toolkits for measuring and evaluating the wider benefits of residential retrofit projects, particularly in the context of UK social housing, with a multi-stakeholder perspective.

9.3 Contribution to Knowledge

An important distinguishing element and requirement of doctoral research from other graduate levels (and research in general) is the requirement of a 'contribution to knowledge' (Baptista et al., 2015; Saunders, et al., 2016). To measure contribution, Corley and Gioia, (2011) proposed a two-dimensioned strategy[10] of 'originality' and 'utility'. Originality is described as the 'notions of advancing knowledge and moving' the thinking in a field of study 'forward, providing new connections among existing concepts, and exploring the practical implications of these connections (p. 15). Thus, originality can be seen as 'incremental' where research adds to or builds on existing knowledge or 'revelatory' where a contribution is more profound in that it offers a new 'theory' or perspective for explaining or making sense of a problem or phenomenon.

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[10] This work specifically addressed what constituted a contribution to theory development. However, their argument and ideas are deemed relevant and applicable to the general contribution of a piece of research, hence adopted for this section to explain the original contribution of this research to knowledge.

Table 9-2 Research knowledge contribution quadrant

		Utility	
		Scientifically useful	Practically useful
Originality	Revelatory	1	4
	Incremental	3	2

Source: Corley and Gioia, (2011)

The second dimension of 'utility' denotes a contribution that has usefulness for some purpose and is also divided into contributions with 'practical usefulness' and those with 'scientific usefulness'. To examine the knowledge contribution of this study, Corley, and Gioia's (2011) quadrant of dimensions of theoretical contribution is adapted and adopted (and demonstrated in Table 9-2 below). The discussion on contributions of this study is however restricted to the utility dimension of the quadrant.

9.3.1 Scientifically useful contributions (contributions to knowledge)

9.3.1.1 *Development of a comprehensive retrofit benefits framework:*

This research has already established that several frameworks for analysing benefits or impacts of projects exists, with some specifically tailored to retrofit benefits (see chapter 2, section 2.4). These include the IEA's multiple benefits framework (IEA, 2014) and the UKGBC's Build Upon framework (Fingleton, Jammet and Khayatt, 2021). However, the Multi-Stakeholder REBAT Framework developed for this study builds on and extends the shortfalls of these frameworks. For example, it extends the BU2's framework by integrating the perspectives of stakeholders and mapping of benefits to specific stakeholders and goes beyond to establish the level of relevance of the benefits to each stakeholder as well as the spatial scale at which the benefit accrues or should be evaluated (see the final framework in figures 5-2, 5-3, 5-4 in chapter 5). This makes it a multi-stakeholder framework, multidimensional, and incorporating both quantitative and qualitative metrics and focusing on only the metrics relevant and can be directly attributed to retrofit projects, unlike for example the IEA framework includes benefit indicators not specific to retrofit projects.

9.3.1.2 *Matrix-based approach to evaluation*:

The framework's adoption of a matrix-based approach to link specific benefits to individual stakeholders represents a significant shift, and one that offers a holistic view of a retrofit project's benefits. The added benefit of this approach is that for a particular stakeholder, the evaluation of benefits can be tailored to only those relevant to them if desired. Besides many frameworks typically only consider tenants and landlords, whereas the present REBAT framework extends the stakeholder list to include the supply chain partners (made up of manufacturers, installers, designers, consultants, building professionals, project managers etc.); local authority (councils and all government and parastatal bodies) and general society (utility providers, financial/capital providers, and the community at large). In essence, this approach ensures that evaluations are comprehensive, tailored, and allow for a nuanced understanding of who benefits from retrofit projects, and this was confirmed by the results of tool evaluation interviews.

9.3.1.3 *Focus on Occupant (Human)-Centred approach to Retrofits*:

While retrofits and indeed any other energy efficiency investment may be targeted at attaining environmental goals of reducing emissions (especially given the climate emergencies of the 21st century and the need to transition to Zero or Net-Zero Carbon), it is obvious that people will central and a key to attaining all these goals. Therefore buy-in from home occupants remains not only critical but a must. Besides, the tenet of sustainability requires that any form of development or business endeavour considers the people, the planet and profit – 3ps of sustainability also the triple bottom line and attaining profit is incumbent on prioritising and sustaining people and planet (Fisk, 2010; Soto-Acosta *et al.*, 2016). Thus, by emphasising a human-centred approach (see section 3.6) and the need to engage tenants from the beginning can shape research agendas in human-environment interactions and building science and aligns with the needs and perspectives of all stakeholders involved in retrofit projects. This approach is vital not only in ensuring tenant buy-in, engagement and participation, it also ensures that benefits of retrofits are equitably distributed and meet the actual needs of occupants or owners.

9.3.1.4 Dynamic and Adaptable Framework & Tools

Given the multifaceted nature of building retrofitting, and the ever-evolving nature of the sector, there is the need to expect and incorporate scaling abilities into the any evaluation methodology or tool to remain relevant. Therefore, the flexibility built into the REBAT framework and tools allowing them to adapt to new benefit indicators and project goals as research and industry evolves constitutes an important contribution by this research. This adaptability makes the tools/framework relevant for the needs of today and but also future proofs them against changes in the sector. The framework itself also can serves several purposes beyond guiding evaluations. For example, as a planning tool, it can be useful for encouraging teams to think holistically about benefits, their framing, and evaluations.

9.3.2 Practically useful contributions (Practical contributions to the field).

9.3.2.1 Operational Tools for the industry

Prioritisation Tool Using AHP-Delphi: Practically, this research has developed and added practical, user-friendly tools (attested to during the review with experts). The REBAT and prioritisation methodology provide industry stakeholders and academia with actionable resources to assess and enhance the benefits from their retrofit. Also, the qualitative scoring tool with its criteria and scoring thresholds represents a major contribution while the practical guides, including a sample occupant survey questionnaire, offer a useful toolkit for practitioners. In addition, guidance on using the tools as well as guidelines for collecting data are provided to aid decision makers, adding rigour to the process but also providing methodological clarity to users.

9.3.2.2 Enhancement of Policy and Practice

Through a careful alignment of the evaluation framework and tools with current industry standards and expectations (e.g. PAS 2035:2019), the research advocates for and supports compliance and enhances the robustness of retrofit evaluations (the aim of this research). Furthermore, the study introduced included two new benefit indicators to the framework and tools, that specifically address regularity compliance and the reputation or goodwill of a business involved in retrofits. Also, the retrofit evaluation process map or workflow developed as part of this research is heavily aligned to the monitoring and evaluation process of the PAS 2035, such that by following the methodology outlined in this thesis, users will be conforming to regulations. The workflow process also serves as a great planning tool for project teams to help with planning and scheduling tasks and activities in the project. This alignment helps streamline processes and ensures that projects meet both regulatory requirements and efficiency goals.

9.3.2.3 *Addressing* Industry Challenges:

Finally, the research is contributing to solving problems and challenges in the retrofit industry by helping to identify these (through literature and empirical reviews) and then addressing these specific industry challenges, such as the complexity of evaluations and the need for standardization. The tools developed directly help mitigate these issues, offering more consistent and reliable assessments of retrofit benefit as they get adopted for retrofit evaluations.

9.3.3 Summary of Academic contributions of the study

Assessing retrofit benefits lacks consensus and clarity on the definition of benefits their identification and evaluation. The proposed framework and methodology in this research are intended to fill this knowledge gap and assist in the systematic definition and categorisation of benefits and importantly the key indicators and metrics of measurement to inform the appropriate tools for evaluating them. It also has the potential to generate new or improved methods of assessing wider benefits and help inform the extended value of projects or programmes when retrofits are completed.

9.3.4 Summary of Practical contribution of the study

Making the business case for investment and policy acceptability of ambitious retrofitting necessitates highlighting benefits from a broader point of view beyond energy savings. Operationalising this requires the ability to collect and share evidence of retrofit project performance and best practices to support supply chain innovation, processes, technology, and construction methods. The resulting framework from this study will directly contribute to this reality. Also, systematically evaluating retrofit benefits will help identify the best ways to discuss these with householders as well as contribute to the achievement of carbon targets.

9.3.5 Implications of Research findings and Recommendations

The conclusions generated by this research have both research and policy implications and these are discussed in this section. The recommendations adopt the themes identified in chapter 5 from the analysis of expert interviews on retrofit evaluation challenges. Given the themes previously identified, the following implications and subsequent recommendations emerge. For simplicity, these are summarised Table 9-3 below.

The set of recommendations summarised below are to address the complexity of challenges uncovered in this research. A multi-faceted approach that involves all key stakeholders is needed. This will work if anchored on collaboration between retrofit industry supply chain partners, governmental bodies, and research/academic institutions to develop standardised evaluation methods to enhance the consistency and credibility of results across retrofit projects. Similarly, leaders of landlord or housing associations together with their technical and IT departments should prioritise development and maintaining integrated platforms or systems that can consolidate tools to encourage seamless data exchange and improve project management. Partnerships between landlords is another way this can be accomplished easily. This not only builds a critical base of users but also presents opportunities to leverage on the strengths of each other as well as streamline processes and share costs as well. Further, such a strategic consolidation can help ensure that all stakeholders, particularly occupants are well informed and actively engaged through effective communication, outreach and robust feedback mechanisms.

The set of recommendations further extend to fostering a supportive organisation culture within housing association staff to ensure a continuous inflow of skilled labour through partnerships with educational institutions. Government also has a crucial role in creating the enabling the right environment through sensible and sustainable policy development that foster growth of such partnerships. A good example of this is the recently launched Home Decarbonisation Skills Training Competition, which aims "to make progress towards the increased number of trained installers and other retrofit professionals needed to deliver the increase in energy efficiency installations that will be required to meet our Net Zero targets" (Department for Energy Security & Net Zero, 2023). The competition was open to all educational institutions to submit proposals of skills training courses to be supported by government to establish and deliver them to boost the skills shortage in not only the retrofit sector but also the construction industry as a whole.

Other recommendations put forward aim to address the financial and costs implications of evaluating retrofit projects. One representative of a social landlord indicated that their budget cost for project evaluation was nearly 10% of the total project budget in a funding scheme application they submitted to the SHDF wave 2 rounds. And now with evaluations now made mandatory, projects with limited budgets may be forced to cut budgets to evaluations. It is therefore recommended that the provisions for a minimum sum to be committed to evaluations efforts is applied to all funding schemes from the government or even from private financiers. A positive development in this regard is the growing awareness of and integration of ESG (environmental, social and governance) measures into many organisations' reporting systems. These will ensure that sufficient budget are made available for sufficient, credible and effective evaluations to be completed for projects.

Moreover, funding bodies and investors including landlords are encouraged to explore innovative funding mechanisms and advocate for governmental incentives to make retrofitting more accessible, financially. This can be done through monetising excellent or exceptional ESG performance or other green finance systems such as green loans or sustainability-linked loans or funding streams. The Green Finance Institute recently launched a resource – "Broker's Handbook" to guide and educate brokers offering advise and guidance on various green home retrofit solution on the market. Such resources are useful and recommended.

Lastly, regular engagement with regulatory bodies (e.g. BSI - British Standards Institution) as well as built environment professional bodies (RICS, CIOB, ICE, RIBA, CIBSE etc.) is crucially recommended to ensure that policies and regulations are responsive to the needs and practical realities of retrofit projects. Industry leaders and policy advocates must also push for the necessary updates or amendments to policy and regulations to align with the collective industry insights, as this will enhance the overall framework and execution of retrofit initiatives. An example of such engagements and revision of regulations is the consultations and subsequent amendments to the PAS 2035 standard that regulates all retrofit projects in the UK, especially if they are public funded. Industry engagements reveal some problems with the current standard, and so the BSI was petitioned and subsequently opened a national consultation to update the standard. The aim of the consultation was to improve the retrofit processes as well introduce changes to the qualification requirements for the job roles identified in the standard among others (for more details visit - Proposed Changes to PAS 2035).

Table 9-3 Overview of recommendations to enhance the evaluation of and outcomes of retrofit projects.

Area/Theme	Summary findings	Recommendations	Target Stakeholder	Specific Actions
Project Evaluation	Lack of standardized frameworks and inconsistent methodologies may undermine credibility	Develop a sector-wide standardized evaluation method. Regularly review and update evaluation metrics.	Public or government authorities, landlords (social housing owners); retrofit industry supply chain.	Collaborate on developing and implementing standard methods; ensure regular updates to keep pace with industry changes.
Tenant Engagement	Customer satisfaction and buy-in are critical; need for balance between customer autonomy and project needs.	Invest in community outreach and education; implement a feedback loop for continuous improvement.	Occupants, landlords (social housing owners); Retrofit industry supply chain (especially manufacturers and installers).	Engage tenants through outreach programs; establish feedback mechanisms to incorporate tenant insights.
Tools and Systems	No one-size-fits-all solution, leading to potential inefficiencies and fragmented tools resulting in data silos.	Develop or adopt an integrated platform that consolidates various tools; organize regular training sessions for staff.	Retrofit industry supply chain, energy suppliers and utilities	Prioritize development of integrated platforms; conduct training sessions for tool proficiency.
Cost Evaluations	Rising costs deter clients; industry faces wage inflation and escalating consultancy rates.	Explore alternative funding mechanisms; advocate for governmental incentives or tax breaks to reduce financial burdens.	Financial/capital providers/investors, public or government authorities	Identify and implement alternative funding solutions; lobby for supportive government policies.
Workforce and Training	Rising demand for specialized skills; insufficient training can lead to inefficiencies.	Foster a positive organizational culture with competitive compensation; partner with educational institutions for tailored training programs.	Retrofit industry supply chain, financial/capital providers/investors;' Public or government authorities	Create partnerships with educational institutions; enhance organizational culture and compensation strategies.
Regulation and Policy	Strict regulations can be a hurdle; disconnect between policy aspirations and real-world applications may lead to non-compliance.	Engage in regular dialogues with regulatory bodies; create an industry consortium to voice concerns and suggest policy amendments.	Public or government authorities, energy suppliers and utilities	Facilitate regular dialogues with regulators; form consortia for collective advocacy and policy improvement.

9.4 Limitations of the Study

Every piece of research is fretted with some form of limitations and in academic research, particularly in dissertations, acknowledging the limitations of the study is not only acceptable but also lends credibility to the work. It also ensures that the research audience or readers do not "overemphasize or minimize findings. A more complete presentation [of limitations to include mitigations implemented] will enrich the readers' understanding of the study's limitations…" (Ross and Bibler Zaidi, 2019, p.261). In addition, it serves as a transparent platform for stating what the research could and could not achieve, thereby setting the stage for future investigations. The following is a presentation of the limitations of this study.

9.4.1 Limitations on the Empirical Scope.

While this study has made significant strides in achieving its objectives, especially through the development of frameworks and tools based on extensive literature reviews and valuable expert feedback, there are notable limitations in its empirical scope. These are briefly outlined below.

- While the interviews in Chapter 5 provided valuable insights into real-world challenges in retrofit evaluation, they were limited to a specific set of stakeholders (particularly occupants who were not well-represented) and may not fully capture the broad spectrum of challenges and opportunities in retrofit evaluation.
- The interviews and engagement with experts to review the retrofit benefits framework, as well as the semi-structured interviews to review the scoring tool's criteria and thresholds, were limited in scale and scope. While these experts provided invaluable feedback, the relatively small sample size limits the generalizability of the findings.
- The single focus group used to evaluate the scoring tool provided initial qualitative feedback but lacked the depth that could be provided by multiple focus groups or quantitative analysis. Consequently, the findings and insights derived from this empirical work should be seen as preliminary and specific to the contexts and participants involved. This means that the empirical evidence at this stage is foundational rather than conclusive.

Importantly, the absence of real-world validation and empirical testing makes the evaluation largely theoretical at this juncture. This isn't so much a caveat as it is an open invitation for future research to validate and possibly refine these theoretical constructs. The narrow focus on social housing and home retrofits further restricts the applicability of the findings. These empirical limitations suggest that while the framework and tool provide a good starting point, additional, broader empirical work is needed to rigorously validate and possibly refine the tool and its underlying framework. Therefore, while this study can conclude its current phase by delivering substantial insights, the door is open for future research aimed at real-world application and empirical validation.

9.4.2 Other limitations on the scope of the study.

9.4.2.1 Social housing scope

The current study and the tools developed are focused on social housing, particularly within the context of the UK. While this focus allows for a more targeted and detailed examination of the specific challenges and opportunities associated with retrofitting in social housing, it also somewhat restricts the tool's generalizability to other types of housing or different geographical contexts (which was apparent in the evaluation in chapter 8). The unique regulatory, social, and economic conditions that characterize social housing in the UK may not be directly applicable to private housing sectors or social housing in other countries. Therefore, while the tool offers valuable insights for social housing retrofit projects in the UK, caution should be exercised when attempting to apply the tool's framework to other settings without appropriate modifications. However, the methodological foundation upon which the tool is built is designed to be adaptable, offering avenues for future research to extend its applicability to broader housing types and contexts.

9.4.2.2 Residential scope

Also, the framework and tools are specifically tailored to evaluate benefits arising from housing or home retrofit projects, which limits their applicability to other forms of building or infrastructure retrofits such as commercial buildings, educational institutions, or industrial facilities. The benefit indicators, metrics, and qualitative scoring methodology were designed with residential environments in mind, particularly the socio-economic and health-related aspects that are often primary concerns in residential retrofit projects. Therefore, while the tool may offer valuable insights and a structured approach for evaluating housing retrofits, its applicability to other types of retrofit projects would require substantial adaptation and validation. The current focus, while detailed, does not capture the broader spectrum of retrofit possibilities, and future adaptations would be necessary for the tool to be used in a wider range of contexts.

9.4.3 Practical Use of Toolkits

9.4.3.1 'Simplistic' spreadsheet implementation.

Another limitation concerns the tool's implementation as a spreadsheet, which inherently constrains its functionality. While spreadsheets are accessible and widely used, they lack certain features that would make the tool more robust. Specifically, the current spreadsheet implementation does not support multi-user functionality, a feature often required for collaborative project assessment. Moreover, the scoring and prioritization tools are separate, necessitating manual integration for a comprehensive evaluation. This simplicity, while advantageous in terms of user accessibility, limits the tool's scalability and collaborative potential.

9.4.3.2 Other limited features of the tools.

The retrofit benefits framework and scoring tool are also affected by the following limitations which users need to keep in mind when adopting it for use.

- **Complexity**: They both may become overwhelmingly complex if too many variables or stakeholders are involved, making it difficult to draw actionable conclusions.
- **Overlooking Interdependencies**: While multi-benefits and multi-stakeholder perspectives have been incorporated, the matrix format of the framework and the resulting scoring tool categorise benefits as distinct factors. This overlooks the reality that there are interdependent and synergistic relations and interactions between different benefits and/or stakeholders. These interactions have not been considered in this study.
- **Static Nature:** Closely related to the above limitation is the static nature of the framework and indeed the prioritisation and scoring tools. As explained earlier in 9.2.4

and 9.2.5, above, the tools and framework can be adaptable, yet they remain a snapshot in time. The realities are that the priorities of stakeholders and indeed what constitutes benefits can and do change, which will require frequent updating of the tools to ensure they remain relevant, which could be cumbersome. The cumbersomeness derives from the fact that the tools are built without any direct interoperability or compatibility with any existing tools and systems used by landlords or other stakeholders and so any such updating will need to be manual. Future iterations could consider this possibility.

9.4.3.3 Quantitative vs. Qualitative focus of the scoring tool

Also, the scoring tool is not intended to be a one-size-fits-all solution for retrofit benefits measurements. It is meant to focus on qualitative scoring. Yet this methodological choice also poses a limitation. Specifically, the tool does not provide quantitative measures for benefit indicators, which are commonly used for various kinds of analyses and comparisons. It was beyond the scope of this study to develop a tool that encompasses both qualitative and quantitative analyses.

However, it should not be overlooked that the scoring tool is part of a more comprehensive benefits measurement framework. This framework not only supports the scoring tool but together with the tool, also provides guidelines on data requirements for evaluating various benefit indicators. It outlines the types of data that should be collected, and collection methods, and even suggests metrics that can be used for a more nuanced analysis.

Therefore, though the tool may not directly offer quantitative measures, it prepares project teams for a holistic evaluation process. The tool's qualitative focus is not just a limitation, but a methodological choice aimed at filling a gap in current knowledge on human-centric evaluation of retrofit projects. As such, it can be effectively used in conjunction with other quantitative tools or any existing evaluation systems that the project team might have, enriching the depth and breadth of project evaluation.

9.5 Future Research

The following are potential research directions that can be explored following this study.

- **Empirical Validation through Real-World Case Studies**: While the study has made progress by developing a framework and scoring tool based on literature reviews and expert input, an obvious gap is the need for real-world testing of the developed frameworks and tools. Future research can focus on
  - Applying the tools and framework in diverse real-world retrofit projects involving different types of housing, various technologies, and numerous stakeholder groups.
  - Collecting comprehensive data on benefit indicators both pre- and post-retrofit, enabling a thorough evaluation of the tool's effectiveness.
  - Longitudinal studies not only look at immediate post-retrofit benefits but also evaluate long-term impacts.
  - Establishing precise metrics, understanding the magnitude of energy consumed in various retrofit scenarios, and integrating this understanding into a more holistic retrofit evaluation tool.
- **Exploring interdependencies and conflicts in retrofit benefits:** Given that the current work does not delve into the relationships between different retrofit benefits, future studies could introduce correlation analysis to determine not only the interdependencies between various retrofit benefits but also to identify areas of potential conflict between different stakeholder groups. The research could:
  - Use statistical methods to identify and quantify such conflicts and interdependencies.
  - Develop decision-support systems that can provide trade-off analyses for project teams.
  - Examine how different stakeholder priorities can influence the realization of specific benefits.
- **Standardized and Customizable Weights for Benefits Indicators:** The current study could not establish standardised weights for benefit indicators, even though there are obvious issues with doing so. Nonetheless, standard weights can be useful to aid benchmarking in certain circumstances. Future research could focus on;
  - creating a set of guidelines for standardized benefit indicator weights, informed by industry norms and expert input.

- the feasibility of allowing project teams to customize these weights according to the unique needs and priorities of their specific projects, and how such customization can be methodologically rigorous yet user-friendly.
- how various weights affect the outcome of a retrofit project evaluation and whether they align with stakeholder expectations and industry standards.

- **Multi-User Functionality**: The current tool is simplistic and is designed for use by an individual, which doesn't cater to the often-collaborative nature of retrofit projects. Future research directions could.
  - investigate the technical aspects of adding multi-user functionality to the tool for real-time collaboration.
  - conduct usability tests to understand the complexities and challenges of collective decision-making within the tool.
- **Alignment of benefits with funding priorities:** Most retrofit projects are funded by the government or RSLs in the UK, therefore any alignment (or misalignment) between wider benefits and the priorities of the funding body can significantly influence not just what gets measured, but what gets done in the first place. Research could therefore be directed to explore the extent to which the identified wider benefits align with the funding priorities of social landlords and government retrofit schemes. This could involve a comparative analysis between commonly funded retrofit benefits and those identified as important but less frequently funded. The goal would be to understand whether existing funding structures incentivize or disincentivize wider benefits measurement.

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