Development of an Artefact to Support Homeowner Decision-making for Housing Retrofit

Chamara Panakaduwa September 2024

Development of an Artefact to Support Homeowner Decision-making for Housing Retrofit

Chamara Panakaduwa

School of Science, Engineering, and Environment

University of Salford, United Kingdom.

Submitted in partial fulfilment of the requirements of the degree of Doctor of Philosophy, September 2024

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the University of Salford for providing me the opportunity to pursue a Doctor of Philosophy degree in Construction Management. My deepest thanks go to my supervisors, Dr. Paul Coates and Dr. Mustapha Munir, whose guidance and support were indispensable to the success of this endeavour. Their unwavering assistance, insightful advice, and encouragement helped me navigate the journey, identify opportunities, and avoid pitfalls. I believe I was fortunate to have the best supervisors for my PhD, with Dr. Paul offering visionary guidance and Dr. Mustapha contributing his technical expertise.

I also wish to extend my appreciation to the university administration, particularly the School of Science, Engineering and Environment, and the Doctoral School. Special thanks to Dr. Tanja Poppelreuter, Dr. Zeljka Krpetic, Dr. Katherine Yates, and Tracy Ireland. Additionally, I acknowledge the support from my internal examiners for the annual reviews, including Dr. Graeme Sherriff, Dr. Yingchun Ji, Dr. Justine Cooper, and Dr. Richard Fitton, whose reviews and feedback significantly enhanced the quality of my research. I am also grateful to my internal examiner Dr. Ozlem Duran and external examiner Professor Patricia Tzortzopoulos for their valuable contributions.

The support I received from the industry and stakeholders in housing retrofit for data collection was tremendous. Although too numerous to name individually, I am grateful to the hundreds of academics, industry experts, government officials, homeowners, and professionals who shared their expertise, time, and resources. Special thanks to Andrea Howe and Stacey Walker from Blackpool Council for allowing me to participate in the Cosy Homes in Lancashire initiative, providing practical exposure to resident engagement in housing retrofit. Many others contributed through industry qualifications, workshops, conferences, webinars, and various activities that enriched my knowledge and experience.

I cannot overlook the friendship and support from my fellow postgraduate researchers at the University of Salford and beyond. Their companionship made the often lonely and isolating PhD journey more interactive and colourful, offering moments of shared experiences, happiness, and solace. Starting my PhD in the UK was made easier by numerous people whose support was invaluable, even if there are too many to name individually.

My mother, a school teacher who values education above all, has been a source of immense motivation. I am confident that my PhD will bring her great joy. I also acknowledge the encouragement from my parents, parents-in-law, brother, and sister-in-law. Lastly, I owe a profound debt of gratitude to my immediate family. My wife worked tirelessly to support us while I focused on my studies, and my two young daughters showed incredible patience and understanding. This PhD journey was a collective effort, with my family sharing the responsibility to make it as smooth as possible for me.

Beyond the aforementioned, there are countless others who have supported me throughout my life. To all of them, I extend my heartfelt thanks for helping me reach this milestone.

DECLARATIONS

I declare that the research contained in this thesis was solely carried out by me. It has not been previously submitted in this or any other institute for the award of a degree or any other qualification.

ABBREVIATIONS

AEC	: Architectural, Engineering and Construction
AECB	: Association for Environment Conscious Building
AHP	: Analytical Hierarchy Process
ANOVA	: Analysis of Variance
APM	: Association for Project Managers
BIM	: Building Information Modelling
BPIE	: Building Performance Institute Europe
BRE	: Building Research Establishment
BREAAM	: Building Research Establishment Environmental Assessment Method
BSI	: British Standards Institute
CBA	: Choosing by Advantages
CCC	: Climate Change Committee
CFL	: Compact Fluorescent Lamp
CDM	: Construction, Design and Management
CIAT	: Chartered Institute of Architectural Technologists
CITB	: Construction Industry Training Board
CLC	: Construction Leadership Council
COP	: Conference of the Parties
CIBSE	: Chartered Institution of Building Services Engineers
CPAG	: Child Poverty Action Group
DBEIS	: Department for Business, Energy and Industrial Strategy
DCLG	: Department for Communities and Local Government
DESNZ	: Department for Energy Security and Net Zero
DLUHC	: Department for Levelling Up, Housing and Communities
DWP	: Department for Work and Pensions
EIR	: Environmental Impact Rating
EPA	: Environmental Protection Agency
EPC	: Energy Performance Certificate
ESCO	: Energy Service Companies
FAQ	: Frequently Asked Questions
GDP	: Gross Domestic Product
GHG	: Green House Gases
GW	: Giga Watt

GWP	: Global Warming Potential
HES Tool	: Home Energy Savings Tool
HHSRS	: Housing Health and Safety Rating System
HMRC	: HM Revenue & Customs
HSE	: Health and Safety Executive
IEA	: International Energy Agency
IET	: Institution of Engineering and Technology
IEMA	: Institute of Environmental Management and Assessment
IETA	: International Emissions Trading Association
JCT	: Joint Contracts Tribunal
LED	: Light Emitting Diode
LEED	: Leadership in Energy and Environmental Design
LETI	: London Energy Transformation Initiative
LILEE	: Low Income Low Energy Efficiency
LPOC	: Listed Property Owners Club
LRTR	: Land remediation tax relief
MCDM	: Multi-criteria decision-making
MEES	: Minimum Energy Efficiency Requirements
MHCLG	: Ministry of Housing, Communities and Local Government
MtCO2e	: Metric Tons of Carbon Dioxide equivalent
MVHR	: Machenical Ventilation and Heat Recovery
NDC	: Nationally Determined Contributions
NHS	: National Health Service
PAS	: Publicly Available Specifications
PMI	: Project Management Institute
POD	: Point of Departure
RIBA	: Royal Institute of British Architects
RICS	: Royal Institute of Chartered Surveyors
RII	: Relative Importance Index
SAP	: Standard Assessment Procedure
SDG	: Sustainable Development Goals
SEAI	: Sustainable Energy Authority Ireland
SHDF	: Social Housing Decarbonisation Fund
SME	: Small and Medium Enterprises
SMMT	: Society of Motor Manufacturers and Traders

SWOT	: Strengths, Weaknesses, Opportunities and Threats
TRA	: Theory of Reasoned Actions
UI & UX	: User Interface and User Experience
UK	: United Kingdom
UKEA	: United Kingdom Energy Assessors
UKGBC	: United Kingdom Green Building Council
UML	: Unified Modeling Language
UN	: United Nations
UNCED	: United Nations Conference on Environment and Development
UNEP	: United Nations Environmental Programme
UNFCC	: United Nations Framework Convention on Climate Change
USA	: United States of America
USEPA	: United States Environmental Protection Agency
VAT	: Value Added Tax
WCED	: World Commission on Environment and Development
WGBC	: World Green Building Council
WMO	: World Meteorological Organization

DEFINITIONS

Artefact	An artificial thing; A construct, model, method, or instantiation (Hevner & Chatterjee, 2010).
Decision	An irrevocable allocation of resources (Howard & Abbas, 2016).
House	A self-contained unit for residential purposes (Not a commercial or public building, mixed-use building or room) (Bre, 2014).
Quality of life	level of physical and mental health, wealth, comfort, necessities, and material goods available to a particular geographic area (World Population Review, 2022)
Retrofit	An intervention to a house to improve its energy efficiency, ventilation or to reduce carbon emissions (BSI, 2023b).
Sustainability	Three pillars of triple bottom line; Environmental sustainability, social sustainability and economic sustainability (James, 2015).

.

Development of an Artefact to Support Homeowner Decision-making for Housing Retrofit

Abstract

The sustainability in the UK housing sector is not adequate. Housing retrofit is reported to improve the sustainability. The progress of housing retrofit is low. The underlying reason can be suggested as the limited interest of the homeowners to retrofit their houses. The research aims to develop an artefact for an information system to encourage homeowners to undertake sustainable housing retrofit. The objectives of the research are to study the factors influencing homeowners' interest in housing retrofit, identify the requirements for an artefact to support homeowner decision-making, develop the artefact and validate the artefact for the intended capabilities.

The research process was approached from design science. Accordingly, the research was conducted by identifying the research problem, outlining the solution, defining the requirements, developing the artefact, validating the artefact, and contributing to the body of knowledge. The research problem and the solution were justified with a literature review. A mixed-method methodological choice was used with both interviews and a questionnaire survey to develop the artefact. Artefact validation was done by semi-structured interviews.

The research findings supported developing an artefact for an information system to encourage homeowners to retrofit their houses. Homeowner decision-making behaviour, the social system of the homeowner and the technical system of housing retrofit were focused for this purpose. Apart from the utility of the artefact, the study will contribute to the knowledge of developing artefacts for non-technical audiences. Further, the data collection by the system shall facilitate information for better sustainability policy decisions.

The research complements the stakeholder engagement model of "one stop shop" for housing retrofits. Research recommends a digital one stop shop localised to the homeowner's neighbourhood. Existing similar solutions have only basic capabilities compared with the proposal. The research also recommends reframing housing retrofit from an investment focus to a consumption focus. It also suggests considering a homeowner-centric approach to retrofit over the existing property-centric approach. There are total six recommendations to encourage homeowners to retrofit their houses.

Keywords: Decision-making, Housing retrofit, Information systems, One stop shop, Sustainability

This page was intentionally left blank

1. CHAPTER 01: INTRODUCTION

1.1. Background to the research

1.1.1. Housing retrofit and current approaches

According to the British Standard Institution, housing retrofit can be defined as installing measures in an existing house to improve energy efficiency, improve ventilation or reduce carbon emissions (BSI, 2023b). TrustMark, the government-endorsed quality assurance scheme for housing retrofit, also proposes a similar definition. Retrofit is making changes to the building to reduce energy consumption and carbon emissions. It also includes improving the health and comfort of the occupants (TrustMark, 2024a). Retrofit can also be recognised as “Modification to an asset in order to generate an improved condition” (International Standards Organisation, 2020). In general, retrofitting a house includes the installation of retrofit measures, such as insulation, ventilation, heating systems or renewables (BSI, 2023b). There can be more measures such as smart home systems or green walls. The final objective is to enhance the operational performance of the house. Further, retrofit shall reduce resource consumption as well.

The UK has an estimated housing stock of 30.1 million as of 2022 (ONS, 2022). More than 20% of houses are over 100 years old. Over 55% of the houses are more than 50 years old (BRETrust, 2020). The housing sector's operational carbon contributes around 19.76% of the total UK emissions. By retrofitting existing houses, 19.76 % of the UK emissions can be addressed (DESNZ, 2022).

According to RICS (2020), the required annual rate of decarbonising existing houses is 3%. However, the rate is only 0.8% in the UK per year. Considering the sustainability goals, it can be argued that almost all the houses will need some level of retrofit to reach 2050 targets for a decarbonised, comfortable and healthy residential stock (Holms, 2023). Heat pump installation is a key requirement for a decarbonised housing stock as an electrified heating system can be easily decarbonised with a decarbonised electricity supply (Skidmore & McWhirter, 2023). Considering the number of registered heat pump installations with MCS so far (<200,000), the UK can be considered at the beginning of retrofitting the housing stock (MCS, 2024). Proper mechanisms are required to promote housing retrofit in the UK. Apart from decarbonisation, retrofit is expected to give positive social, economic, and environmental outcomes (CLC, 2021). Retrofit shall reduce fuel poverty, improve the quality of life of the residents, improving the overall sustainability of the UK under the triple bottom line.

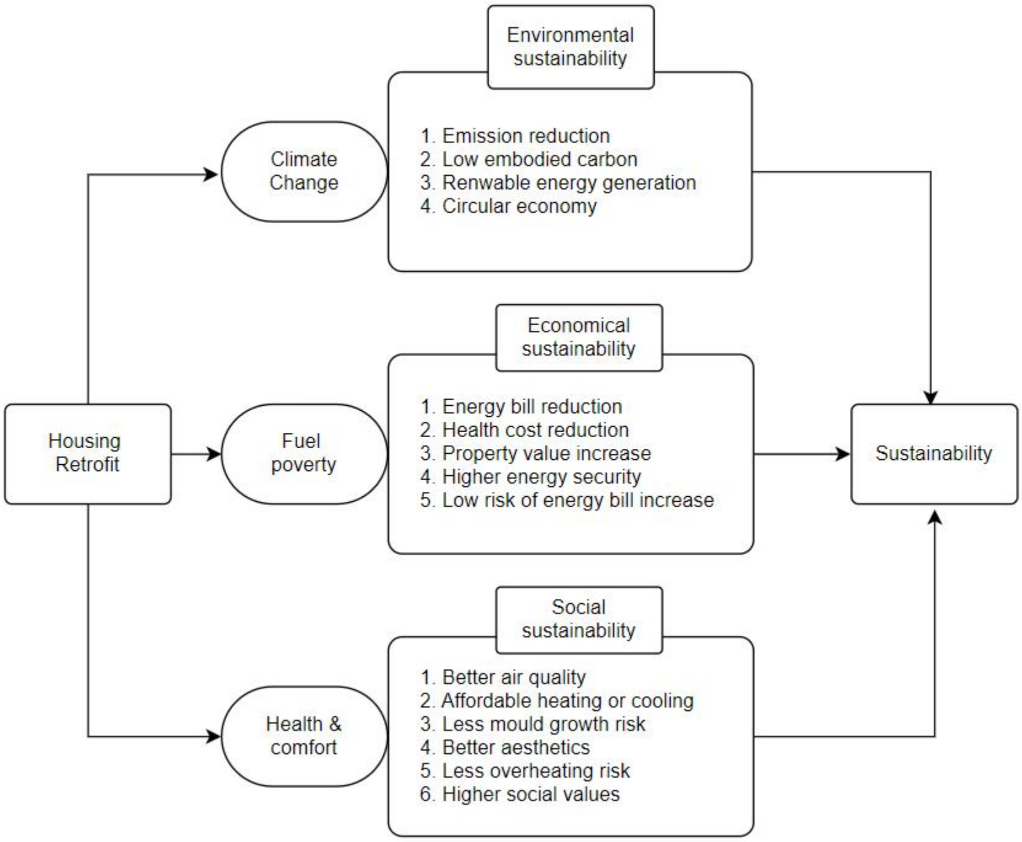

Figure 1: Housing retrofit leads to sustainability

Figure 1 explains a possible combination of housing retrofit leading to sustainability through the triple bottom line concept. May et al. (2019) also endorse the potential contribution of housing retrofit to sustainability. Retrofit contributes to addressing climate change by reducing operational carbon emissions as well as reducing embodied carbon from new builds (Price et al., 2021). Further, it contributes to a circular economy by reusing assets and may generate renewable energy. Considering the role of energy use in residential stock, low energy efficiency can be identified as waste in terms of lean principles (Awwal et al., 2024). Economical sustainability is mainly identified with reducing fuel poverty related benefits such as energy bill reduction and property value increases. Further, it reduces energy dependence and makes the property resilient to future energy shortages and price fluctuations. In terms of social sustainability, retrofit shall create better-performing houses with better air quality, comfortable temperatures, and higher social values. The health values of housing retrofit are invaluable. These are generally identified under the term "quality of life" (World Population Review, 2022).

1.1.2. The challenges of retrofitting houses

Retrofitting houses need to consider several aspects. According to LETI (2021), they are project management, retrofit design, homeowner engagement, funding and monitoring. Standards and best practices are another important aspect of retrofit delivery (BSI, 2023b; Panakaduwa et al., 2023; Rickaby, 2023). Further, there should be a sufficient workforce (Skidmore & McWhirter, 2023) and good supply chains (DBEIS, 2021b) to deliver the retrofit at a scale. The characteristics of the housing stock pose different challenges of retrofitting, such as balancing heritage values with energy efficiency (Panakaduwa et al., 2024d). There can be further aspects related to the delivery of retrofit in the UK.

As far as the above aspects of retrofit are concerned, the current technology is sufficient to retrofit a house to a higher level of sustainability with improved energy efficiency, better comfort and health (Higney & Gibb, 2024). This has been endorsed by certifications such as Passivhaus or Energiesprong (Energiesprong, 2019; Traynor, 2019). The supply chain is a problem as there are not enough supply chains to retrofit the UK housing stock at a scale (DBEIS, 2021b). Further, the UK does not have a sufficient workforce to handle the challenge of retrofitting all the existing houses (Brown & Bailey, 2022; Industrial Strategy Council, 2019). Without a proper demand for housing retrofit, it is unlikely to expect an increase in supply chains and workforce.

The management aspects of housing retrofit have been a challenge for some time. With the failure of Green Deal 2013 and the recommendations of the Each Home Counts report, PAS 2030 and PAS 2035 were introduced to improve the project management and the quality of housing retrofit (BSI, 2023a, 2023b; Rickaby, 2023). Although it has not yet become a mainstream standard yet, industry experts welcome the PAS initiatives as a means of ensuring the standardisation and best practices of housing retrofit in the UK (Edwards, 2021; Patterson, 2023).

Most of the challenges centre around the problem of poor demand for housing retrofit (Liu et al., 2024). This has been endorsed by several researchers in the literature (Bobrova et al., 2021; Holms, 2023; Skidmore & McWhirter, 2023). If there is a proper demand for housing retrofit from the homeowners, problems such as supply chain or workforce issues will be solved through the demand. Further, the government will be pressured to allocate more funds for housing retrofit and the industry will also be motivated to come up with innovative retrofit technologies. In this case, improving the demand for housing retrofit through homeowner engagement can be identified as a key priority (Shwashreh et al., 2024).

1.2. Research problem

1.2.1. The problem

The research problem of this study is presented as follows. The rationale for arriving at the particular research problem is given thereafter. The research problem of this study is:

The limited interest of the UK homeowners to retrofit their houses.

According to Saunders et al. (2019), identifying the problem is an important step in research methodology. As this research is conducted under the design science approach, the term “Explicating the problem” is used. There is a four-step method for explicating the problem according to Johannesson & Perjons (2021). These steps are defining the problem, positioning the problem, justifying the problem and finding the root causes.

1.2.1.1. Defining the problem

The following section is allocated to problem definition, problem positioning, problem justifying and finding root causes according to the guidelines by Johannesson & Perjons (2021). Highlighting the importance of the research problem is termed as explicating the problem under the design science research. The following Table 1 gives the key definitions of the problem. It will provide a basic idea of the scope of the problem and the research.

Table 1: Define the problem

	Keyword	Definition	Description
1	House	A self-contained unit (Not a commercial or public building, mixed-use building or room).	Any house comes under the definition of a dwelling according to SAP guidelines (Bre, 2014). Building regulations have the same definition.

2	Expected energy performance	Passivhaus Enerphit level (Traynor, 2019).	Primary energy demand above 135 kWh/m^{2}a. Heating demand is 20, 25 or 30 kWh/m^{2}a according to climate zone.
3	Scope of the artefact	Onboarding the homeowner to the retrofit process by providing decision support.	The artefact is a high-level framework for an information system which helps homeowners to proceed to a retrofit assessment and integrate with the technical process of retrofit.
4	Homeowner	Homeowner, client, landlord, tenant or any interested party.	The term "homeowner" has been used to refer to anyone interested in exploring housing retrofit options for a particular house.
5	Retrofit	According to PAS 2035:2023 definition (BSI, 2023b).	Energy performance improvement, ventilation improvement or reduction of carbon emissions. Retrofit measures and renovations.

Considering the house types, the UK has mainly five house types; terraced, semi-detached, detached, flats and bungalows (BRETrust, 2020). The research covers any house type coming under the definition of "dwelling". An energy performance certificate should be able to be generated for the house. Poor energy performance means when the primary energy demand of a house is over 135 kWh/m^{2}a for this study. This is the maximum primary energy demand expected by the Passivhaus certification for either new build or retrofit. The heating demand can vary according to the climate zone (Passivhaus Trust, 2021; Traynor, 2019). Primary energy is the energy in its natural form before human engineering conversions (RIBA, 2022).

Generally, the term "homeowner" can imply a person who owns a house. For the purpose of this research, anyone who is interested in retrofitting a house is considered. This can be an owner-occupier, private or social landlord, tenant or any party interested in exploring housing retrofit options. Even potential homeowners can come under this definition. The PAS 2035:2023 identifies a "Client" (BSI, 2023b). It is admitted that "homeowner" may not be the best term to use. The other terms also have their own pros and cons regarding the suitability for the term.

1.2.1.2. Positioning the problem

Emissions from the built environment are divided into two. The construction of the buildings contributes to embodied carbon and their operation contributes to operational carbon (LETI, 2021). Retrofit reduces the operational carbon emissions and avoids embodied carbon emissions by reusing assets in the first place. There are three types of buildings that can be identified. They are residential, commercial, and public (Passivhaus Trust, 2021). Residential building operations are reported to contribute around 19.76 % of the total carbon emissions in the UK. Technically, the research is focused on residential buildings. According to (LETI, 2021), retrofit can be further divided into project management, retrofit design, funding, monitoring and homeowner decision-making. The research focuses on homeowner decision-making while linking the process to other areas.

1.2.1.3. Justifying the problem

Johannesson & Perjons (2021) describe four criteria to justify a research problem. The problem should be significant, a problem of general interest, feasible and challenging. The problem addressed here is related to sustainability. The total contribution to carbon emission by the residential stock (operational carbon) is 19.76 % (DESNZ, 2022). Further, there are 5.6 million people in fuel poverty (National Energy Action, 2024) and poor quality of life associated with the housing stock (Buck & Gregory, 2018). Considering the above, the problem is significant.

As the earth is becoming unsustainable, humans still do not have an alternative planet (Still, there is no planet B for humans). Taking steps to keep the Earth habitable and sustainable is a significant problem. Further, the problem does not apply to a single entity. Sustainability is applied to the whole community of the world as well as all the flora and fauna, irrespective of how someone would see it. Accordingly, the problem is of general interest.

According to Johannesson & Perjons (2021), the problem should be feasible and challenging. Housing retrofit is a feasible solution. The existing technology is sufficient to address this problem. There are case studies of successful housing retrofit (Baeli, 2013; Torgal et al., 2017). This is also a challenging problem as there is no satisfactory progress observed in housing retrofit so far, despite all the efforts taken by various parties.

1.2.1.4. Finding the root causes

The five why technique was used to narrow down the poor sustainability issue to its root causes. The following Table 2 describes how the technique is adopted to find the root causes in this study.

Table 2: Five why technique to find the root cause

	Symptom	The current sustainability level of the housing stock is not sufficient in the UK (CCC, 2023b).
Why?	Visible problem	The rate of decarbonisation is only 0.8% (RICS, 2020). 5.6 million people are in fuel poverty (National Energy Action, 2024). The housing stock is not healthy and comfortable (Garrett et al., 2021; The Health foundation, 2017).
Why?	First level problem	Lack of progress in sustainable housing retrofit (RICS, 2020).
Why?	Second level problem	There is a lack of demand for housing retrofit in the UK (Bobrova et al., 2021; Fyhn & Baron, 2016; Holms, 2023).
Why?	Root cause	The limited interest of the homeowners to retrofit their houses.

The Climate Change Committee emphasises the poor sustainability in the residential sector (CCC, 2023b). This has been further validated with reference to the statistics of carbon emissions, fuel poverty and poor health/comfort in the UK housing stock (Garrett et al., 2021; The Health foundation, 2017). This is due to the poor progress in retrofitting houses, which could have improved the sustainability (RICS, 2020). Considering these aspects, the root cause for this problem was identified as the limited interest of the homeowners to retrofit their houses.

1.3. Aim and objectives

1.3.1. Research aim

To encourage homeowners to undertake sustainable housing retrofit through an information system artefact.

1.3.2. Research objectives

1. To study the factors influencing homeowners' interest in housing retrofit. (Problem)
2. To identify the requirements for an artefact to support homeowner retrofit decision-making. (Requirements)
3. To develop an artefact for homeowners to support retrofit decision-making. (Artefact development)
4. To validate the artefact for the intended capabilities. (Validation)

4.1. Research outline

4.1.1. Research scope

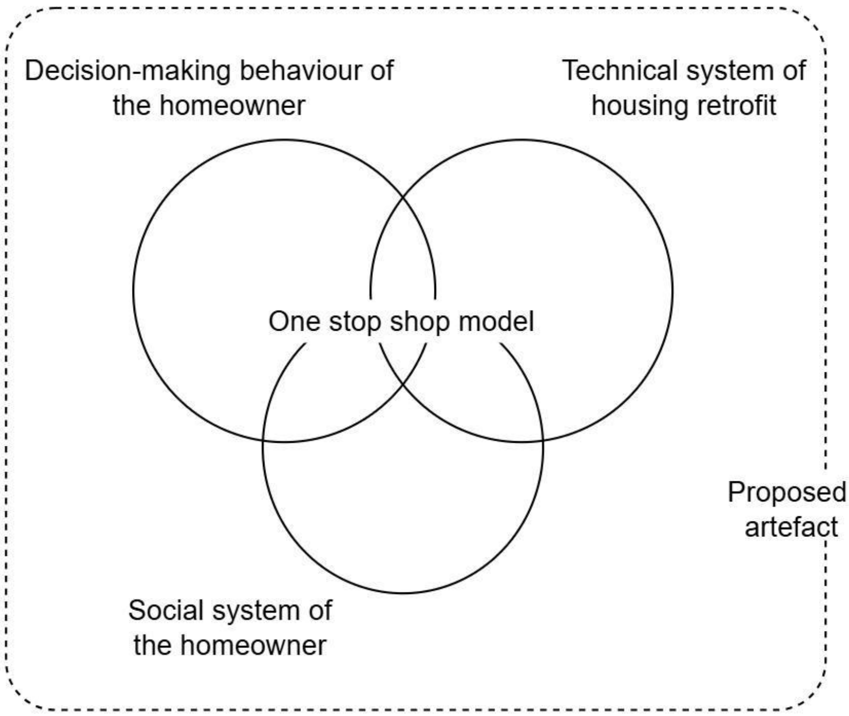

Figure 2: Research domains

The research scope is placed on three main domains according to Figure 2. They are the homeowner decision-making behaviour, the social system of the homeowner and the technical system of housing retrofit. The research focuses on developing an artefact under the one stop shop model to integrate these domains. The retrofit process has several steps, according to BSI (2023b). They are risk assessment, retrofit design, installation, testing & commissioning, handover, and monitoring/evaluation. The homeowner should have decided to retrofit the house to start this process. The proposed artefact of this research focuses on the point when the homeowner chooses to onboard to the retrofit process. After onboarding, there are other information systems already developed to manage the subsequent project management steps.

The study only focuses on houses in the United Kingdom. The artefact is developed only to answer the UK context for this research. It has the potential to be extended to other geographical areas. The domains of the research are scattered in several areas; decision-making, social science, housing retrofit and stakeholder engagement. In brief, the goal is to consolidate the technical aspects of housing retrofit with the social aspects of homeowner decision-making with the help of an information system. Considering these aspects, this research can be considered as multi-disciplinary research.

One of the limitations of the research is the inability to develop a practical system under the scope of this research. In this situation, the artefact is a high-level model which leads to the development of such a system. Homeowner behaviour in housing retrofit and the potential of the one stop shop are observed as under-researched areas. There are no explicit retrofit one stop shop solutions observed in the context of the UK at this moment. The study has done literature reviews and further data collection on this topic.

4.1.2. Outline the research methodology

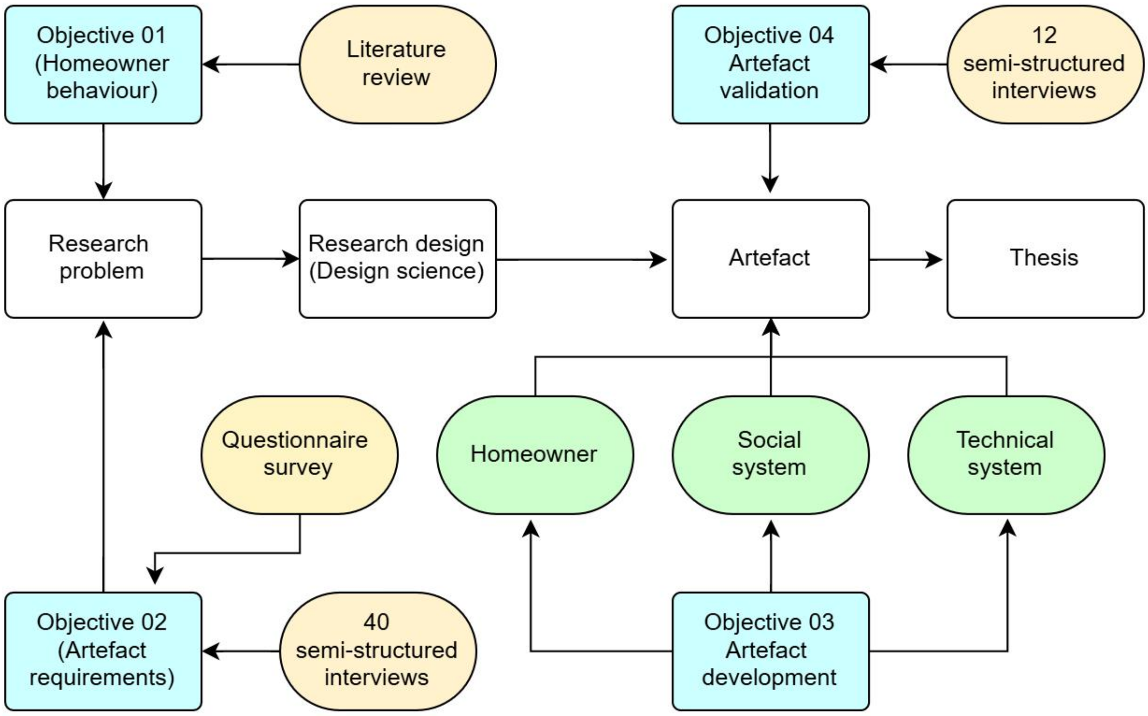

Figure 3 : Conceptual framework

Figure 3 depicts the basic conceptual framework of the research. There are four objectives of the research. Objectives one and two are respectively for the justification of the problem and collecting the requirements for the artefact. Objective three is to develop the artefact and objective four is to validate the artefact.

The research was conducted under the design science research methodology. The rationale behind using design science is that the research expects to design an artefact, to address a common problem and to contribute to the body of knowledge. When these three objectives are addressed, design science research is helpful (Dresch et al., 2015; Hevner & Chatterjee, 2010; Johannesson & Perjons, 2021; Vaishnavi & Kuechler, 2015; Wieringa, 2014). The research used a mixed method approach with quantitative and qualitative data analysis. The data was collected with interviews and a questionnaire survey. The research philosophy, theory development and other aspects are described in detail under the methodology section.

4.1.3. Research output

The aim of the research is to encourage homeowners to retrofit their houses through an information system artefact. This artefact will bridge the gap between the homeowner and the retrofit professional. According to PAS 2035 specification, this will be the retrofit coordinator. The artefact was developed under the design science research method, with contributions to both theory and practice. As far as the theoretical contribution is concerned, it has made six policy recommendations to encourage homeowners to retrofit their houses. They are related to the homeowner behaviour, the social system of the homeowner and the technical system of housing retrofit. The conclusion section presents these recommendations in detail.

The expected outcome of the artefact is that the homeowner contacted a retrofit assessor for an in-person retrofit assessment under PAS 2035: 2023. This is defined as “Lead generation”. Collecting data about the homeowner behaviour and the properties is a byproduct of the system operation. The success of the system depends on the number of leads generated and the amount of data collected. The level of homeowner encouragement is quantified with the number of leads and the amount of data collected by the system. This data is related to the homeowner behaviour and the characteristics of the property. The granularity of the data was not prescribed due to the high level of the artefact nature.

Beyond the scope of this research, this system can be integrated with the housing retrofit process under PAS 2035:2023, subject to practical development. It will be helpful to all the retrofit stakeholders to make the process more efficient and smoother. Getting the houses retrofitted and future-ready means the occupants will have more comfortable, safe, healthy, valuable, and cheaper-to-maintain houses. Technically, it will address the problems of carbon emissions, fuel poverty and poor quality of life in existing houses.

4.2. Thesis outline

Chapter 01: Introduction

This chapter focuses on the research problem and how this problem can be resolved. Further, an introduction to the proposed methodology for solving this problem. Accordingly, the poor sustainability of the United Kingdom was identified as the basic problem, and it was narrowed down to the limited interest of the homeowners to retrofit their houses. The importance of housing retrofit was elaborated. The chapter consists of the background to the research and introduction to the research problem, proposed solution, aim and objectives, research scope and research methodology.

Chapter 02: Literature Review

The second chapter focuses on the first objective of the research, which is studying the factors influencing homeowners' interest in housing retrofit. This is achieved as a literature review. Starting from the UK housing stock, the chapter continues to housing retrofit, homeowner decision-making behaviour and stakeholder engagement under one stop shop model. The background to the artefact was established in the literature review. However, a literature gap was found to identify the artefact requirements, which needed empirical data collection and anlysis.

Chapter 03: Research Methodology

The third chapter focuses on research methodology. The design science research method was introduced. This is followed by the selection and presentation of an appropriate methodology applicable to this research. The research design and artefact development are presented finally. This is to outline how the research objectives were achieved through both literature reviews and empirical studies. The design science research method was adopted, as the research addresses a class of problems, designs an artefact to solve the problem and contributes to the body of knowledge.

Chapter 04: Results

In this chapter, the artefact requirements were collected through semi-structured interviews and a questionnaire survey. Another data collection was conducted as semi-structured interviews to validate the artefact. The chapter presents data collection and analysis of the three empirical studies of the research.

Chapter 05: Discussion

The empirical data was collected and analysed in the previous chapter and this chapter critically discusses the findings of empirical studies. The existing literature referred to when and where required to understand whether the empirical data collection agrees or disagrees with the literature. The findings of the three empirical studies were discussed in this chapter. Further, the artefact was developed and validated. The chapter presents how the research achieved second, third and fourth objectives of the research.

Chapter 06: Conclusion

The final chapter of the thesis consists of several sections: conclusions, recommendations, claimed contributions and limitations. The conclusion section was to conclude the thesis, outlining how the research aim and objectives were achieved through the conducted studies. The recommendation section is to highlight the findings of the research. The research limitations and room for future research were also given in this chapter. The references follow this final chapter.

Annexures

The annexures section was used to present the documents related to the research, but not form a part of the thesis. The first one is ethics approval. The questionnaire used for data collection is also given under the annexures. The semi-structured interviews of this research used personalised questionnaires for participants. Due to the sensitive nature of the data and the number of questionnaires, they were not listed in the annexures. The demographics of the interview participants are given. Another annexation of the thesis is the list of publications by the student.

2. CHAPTER 02: LITERATURE REVIEW

2.1. Introduction to the chapter

The first objective is to study the factors influencing homeowners' interest in housing retrofit. This objective was achieved through a literature review. To achieve this objective, first, a general review of the UK housing stock was conducted. The poor sustainability of the housing stock in the UK was studied. This was approached through the triple bottom-line concept of sustainability, focusing on climate change, fuel poverty and the poor quality of life of the residents. After introducing the UK housing stock, literature related to housing retrofit was reviewed. Housing retrofit was identified as the required action to improve the sustainability of the housing stock. Considering the importance of homeowners' limited interest in retrofitting houses, the next section is to study the homeowner's retrofit decision-making behaviour and behavioural changes. Finally, the digital one stop shop model was studied as a viable solution. The research problem of limited homeowner interest in housing retrofit was established through the literature review.

2.2. Housing stock

2.2.1. Introduction to the UK housing stock

The UK has a total 66 million population. The total number of households in the UK is estimated at 27.828 million (BRETrust, 2020). According to the latest figures, the UK was reported to have a housing stock of 30.1 million as of 2023 (ONS, 2022). There is an average of 2.38 people in an occupied dwelling. Main household types in the UK can be identified as terraced, semi-detached, detached, bungalows and flats. Table 3 depicts the dwelling types in the United Kingdom and their characteristics, categorised under England, Scotland, Wales, and Northern Ireland (BRETrust, 2020).

Further, the UK housing stock is considered to be the worst-performing of all Europe (BRETrust, 2020; Butt et al., 2020; RICS, 2020). One in every five UK houses is reported to be below the standard of quality of life (The Health foundation, 2017). 4.5 million UK houses are reported to overheat during the summer (CCC, 2019). According to a study conducted by the Building Research Establishment (BRE), the direct NHS cost of poor housing is £1.4 billion for the year 2020 (Garrett et al., 2021). It is reported that between 4% - 25% of UK houses have dampness issues (May et al., 2019).

Around one of every five houses in the UK is considered to be of traditional construction with solid walls (CITB, 2021). Another report estimates that there are 7.7 million houses in Great Britain with un-insulated solid walls. Only 3% of the houses with solid walls have been installed insulation so far (Palmer & Terry, 2017). Usually, a house in the UK needs to be heated for 5.6 months per year from October to March/April (BRE, 2013). In general, UK houses are 40% smaller in size, compared with houses in other parts of Europe (Hilber, 2015; Hudson, 2015). The average size of a house has also reduced from 102 m^2 in 1919 to 92 m^2 in 2012 (Hudson, 2015).

According to the government heat and building strategy, there are more than 4 million houses in the off-gas grid in Great Britain (DBEIS, 2021a). From the total energy consumption, 31% of the energy is used by the housing stock as gas, electricity, oil, and renewables as of 2021 (Bolton & Stewart, 2023). As far as the emissions from buildings are concerned due to the use of fuel, 66.6% of the emissions are coming from residential buildings. As at 2022, 19.76 % of the total UK emissions are from the housing stock (DESNZ, 2022).

Although the general perception is that the older the house, the worse the performance, (Suhr & Hunt, 2019) suggest a different view. They say this is not always true. For example, an Edwardian or Victorian terraced house may perform well compared with a 1960 bungalow, due to the lesser building envelope.

The UK has a rich architectural heritage, and a significant number of buildings across the country are designated as buildings with historical value. These buildings are deemed to be of special architectural or historic interest and are therefore afforded legal protection by the government. This means that any changes or alterations to the building must be approved by the relevant authority to ensure that the building's character and historical significance are preserved (Historic, 2016; LPOC, 2021). There are approximately 400,000 listed buildings in the UK, and they can be found in both urban and rural areas (Historic, 2016). The preservation of listed buildings is essential to maintaining the country's cultural heritage and identity (Thornley & Waa, 2009). According to Panakaduwa et al. (2024d), one of the key challenges with historical buildings is to improve energy efficiency while protecting architectural heritage values.

Table 3: Demographics of the UK housing stock (BRETrust, 2020)

	England	Scotland	Wales	Northern Ireland[1]	UK
Dwelling age					
Pre 1919	4,972	467	351	82	5,871
1919-1944	3,793	291	133	68	4,284
1945-1964	4,582	544	219	126	5,472
1965-1980	4,689	515	304	189	5,698
1981-1990[2]	1,895	194[3]	99	99	2,287[4]
Post 1990	4,019	452[5]	235	216	4923[6]
Dwelling type					
Terrace	6,669	534	376	221	7,829
Semi-detached	6,100	481	369	180	7,129
Detached	4,093	554	296	164	5,107
Bungalow	2,195	inc. within other categories	154	164	2,512
Flat	4,864	895	147	52	5,958
Dwelling tenure					
Owner occupied	15,089	1,491	924	512	18,016
Private rented	4,789	346	180	146	5,460
Social rented	4,072	626	238	122	5,058
Location[7]					
Urban	19,796	2,055	900	503	23,254
Rural	4,154	409	441	277	5,281
Total dwelling stock	23,950	2,464	1,342	780	28,536
Average dwelling size	94m[2]	98m[2]	102m[2]	105m[2]	95m[2]
Dwelling age					
Pre 1919	20.8%	19.0%	26.2%	10.5%	20.6%
1919-1944	15.8%	11.8%	9.9%	8.7%	15.0%
1945-1964	19.1%	22.1%	16.3%	16.2%	19.2%
1965-1980	19.6%	20.9%	22.7%	24.3%	20.0%
1981-1990[2]	7.9%	7.9%[3]	7.4%	12.8%	8.0%[4]
Post 1990	16.8%	18.4%[5]	17.5%	27.7%	17.3%[6]
Dwelling type					
Terrace	28.0%	21.7%	28.0%	28.3%	27.4%
Semi-detached	25.5%	19.5%	27.5%	23.0%	25.0%
Detached	17.1%	22.5%	22.1%	21.0%	17.9%
Bungalow	9.2%	inc. within other categories	11.5%	21.0%	8.8%
Flat	20.3%	36.3%	11.0%	6.7%	20.9%
Dwelling tenure					
Owner occupied	63.0%	60.5%	68.9%	65.6%	63.1%
Private rented	20.0%	14.0%	13.4%	18.7%	19.1%
Social rented	17.0%	25.4%	17.7%	15.6%	17.7%
Location[7]					
Urban	82.7%	83.4%	67.1%	64.0%	81.5%
Rural	17.3%	16.6%	32.9%	36.0%	18.5%

Considering the UK housing stock, it is clear that the UK has an older housing stock compared with Europe. When it comes to sustainability, the literature highlights poor sustainable performance. The constraints due to the heritage values and the percentage of heritage buildings pose further challenges to achieving sustainability in the housing sector. Further, poor comfort, poor health and a number of households in fuel poverty further emphasise the dire need for sustainability in the housing sector. Due to the high number of poor-performing houses in the UK, the scope of the challenge is considerable at the national level. The following section focuses on achieving sustainability in the housing sector.

2.2.2. Achieving sustainability in the housing sector

The code for sustainable homes (Worthing et al., 2021) was introduced in 2007 as a response to Stern's review (Stern, 2006). It replaced the earlier EcoHomes assessment of BRE. The code was introduced as a voluntary standard but stated that it would be mandatory for all new homes from 2016. The code required all new homes from 2016 to be mandatorily net zero carbon (Worthing et al., 2021). The government withdrew this code in 2015 stating that it would impede the progress of the new house construction rate, which was a key priority of the government (Ares, 2016). Although there is progress in moving to sustainable new homes, the government has changed track several times and reversed some initiatives (Panakaduwa et al., 2024b; Worthing et al., 2021). For example, the government said it will allow 20% of gas boilers over the previous commitment to ban all new gas boilers from 2035 (CCC, 2023a).

Reducing carbon emissions is a need of the moment. New build is an opportunity to ensure the future built environment is compliant with sustainability. The future homes standard will come into effect in 2025 (RIBA, 2021). It will make all the newly built houses zero carbon ready. Characteristics of the Future homes standard will include no fossil fuel heating and high-level of low carbon heating (MHCLG, 2019). There are criticisms about the Future Homes Standard as it may not make the newly built houses completely future-proof. Houses built under this standard may require further retrofit at some point in the future (Ukgbc, 2022).

Zero Carbon Homes Relief is a land and stamp duty tax relief for zero carbon homes for first-time buyers in the UK. If a house is zero carbon, the tax need not to be paid for up to £ 500,000 in value. Over £ 500,000, there will be a £ 15,000 reduction. This was introduced by the budget 2007 in the UK. To become a house net zero, the house shall produce electricity more than it consumes over a year (HM Revenue & Customs, 2016).

Home Quality Mark by BRE is similar to the approach of Code for sustainable homes. The scheme targeted homeowners and occupiers. They use three indicators; my cost, my well-being and my footprint. Further, several policy initiatives regarding sustainable construction can be identified as site waste management plans, Landfill Tax, Aggregates Levy and LRTR (Land remediation tax relief) (Worthing et al., 2021).

According to the government heat and building strategy, they expect to initiate a few funding schemes towards housing retrofit such as SHDF (Social Housing Decarbonisation

Fund), Public sector decarbonisation Scheme and Boiler Upgrade Scheme. The purpose of the heat and building strategy is to outline the government's short-term goals and long-term ambitions, and how to manage the building stock in the UK to go for net zero 2050. (Emissions between 0 - 2 MTCO2e). In terms of residential houses, the strategy will help to increase the EPC C-rated house share up to 70% of the English housing stock. The strategy is based on five core approaches according to Table 4 (DBEIS, 2021a).

Table 4: Heat and building strategy key commitments (DBEIS, 2021a).

Area of Commitment	Description
Heat pumps	Promoting heat pumps by reducing prices through policy and economies of scale. 600,000 annual installation of heat pumps by 2028.
Hydrogen	Research and innovation in Hydrogen. Publishing the Hydrogen heating strategy by 2026.
Retrofit	Improving housing performance, supporting people in need and leading through the public sector. Long-term and short-term strategies.
Policy	Energy-related policy framework and managing regulations & subsidies.
Other	Workforce development, heat networks and biomethane.

Creating jobs is another expectation of the heat and building strategy. The strategy expects to create 175,000 additional direct and indirect jobs by 2030 and 240,000 jobs by 2035. The government needs to achieve net zero by 2050 without compromising the economic and social development of the country. Further, the studies have found that both objectives are complementary as the net zero can be achieved while achieving economic growth. As a piece of evidence, the UK has been able to reduce emissions by 44% while achieving 78% GDP growth from 1990 to 2021 (DBEIS, 2021a). Key principles of the heat and building strategy can be identified as a whole building approach, a continuation of research and innovation, no and low regret actions, clear communication about upcoming regulatory changes and making decarbonisation affordable to all (DBEIS, 2021a). A clear regulatory framework is important to drive the net zero journey to make the actions accessible, reliable, and achievable. A comprehensive strategy shall cover the areas including cost distribution, green finance, consumer protection, public engagement, monitoring and evaluation (Worthing et al., 2021).

The Climate Change Committee says that the policy measures and regulations are not good enough to support sustainability goals. Policy measures supporting low carbon uptake have been withdrawn. E.g., Zero carbon homes, Code for sustainable homes. Poor regulation, guidance, and communication with the householders have created policy gaps to drive cost-effective sustainable solutions. The building regulations are not aimed at climate action. Poor resources and power allocation to local authorities have hindered the potential housing sector's contribution to climate action (CCC, 2019; Morgan et al., 2024).

The sustainability can be considered under the triple bottom line: environmental sustainability, economic sustaiability and social sustainability. The sustainability related to the residential sector is further described under these three topics in the subsequent sections.

2.2.3. Environmental sustainability of the housing sector | Climate change

When it comes to the environmental sustainability of the residential sector, this can be viewed from both the operational carbon point as well as embodied carbon point. Linking back to the previous sections, the residential sector contributes around 19.76 % of the total emissions of the UK (DESNZ, 2022). When the operational emissions are concerned, it is split among the residential, commercial, and public respectively by 64%, 27% and 10% (CITB, 2021). Further, the construction sector is one of the main consumers of resources and contributors to waste. At the global level, the industry is responsible for one-third of carbon emissions (Tayeh et al., 2020). Preservation of the existing houses and reusing them can help to manage embodied carbon (Baker et al., 2021; LETI, 2020). The historical significance of traditional buildings in the UK creates more challenges when it comes to improving the energy efficiency of those buildings (Panakaduwa et al., 2024d). Considering the scope of this review, only the operational carbon emissions are considered.

The environmental sustainability of the residential stock is mainly associated with the energy efficiency of the house. Gas is mainly used for domestic heating and electricity generation. Domestic heating has used 37.1% of total gas demand in 2021, whereas electricity generation has used 29.6% (DBEIS, 2022). As justified in the introduction, decarbonising the electricity itself will not help to make the residential stock environmentally sustainable from an operational carbon perspective (LETI, 2021). Energy efficiency is the key aspect of reducing the energy demand from the housing stock.

One of the popular methods of understanding the environmental sustainability of residential houses is the EPC report. EPC (Energy Performance Certificate) is a rating given to a property regarding its energy performance. An EPC is required when a property is sold, rented, or constructed. A certificate is valid for 10 years. EIR (Environmental Impact Rating) is the rating with regard to the CO2 emissions of the property (Dclg, 2017; DLUHC, 2021a). New houses reflect 96% within the EIR bands from A to C. These figures are available for England only. In Wales, the situation is slightly improved with nearly 70% of houses within the A, B, and C bands. New dwellings reflect the same 96% within the ABC threshold (DLUHC, 2021a). It has been studied that the houses with higher EPC ratings have higher property values. Numerically, a typical EPC C rating house is valued more than 5% over a similar EPC D grade house (DLUHC, 2021a). Energy efficiency improvements can also increase the rent values of buildings and have positive cost benefit analysis figures (Duran & Lomas, 2021). According to the English housing survey, 52% of the owner-occupied and 48% of the private rented houses are "D" in rating. Further, nearly 18% of the houses are below the rating "E". The government's target is to make all the private rented houses to EPC rating "C" minimum by 2035 (RICS, 2020).

Figure 3: Demographics of EPC ratings in houses in England (DBEIS, 2021a).

The above Figure 3 numbers are only for England. It is noted that social rented houses are better than other tenures according to the energy performance. Private rented houses are slightly worse (DBEIS, 2021a; RIBA, 2020).

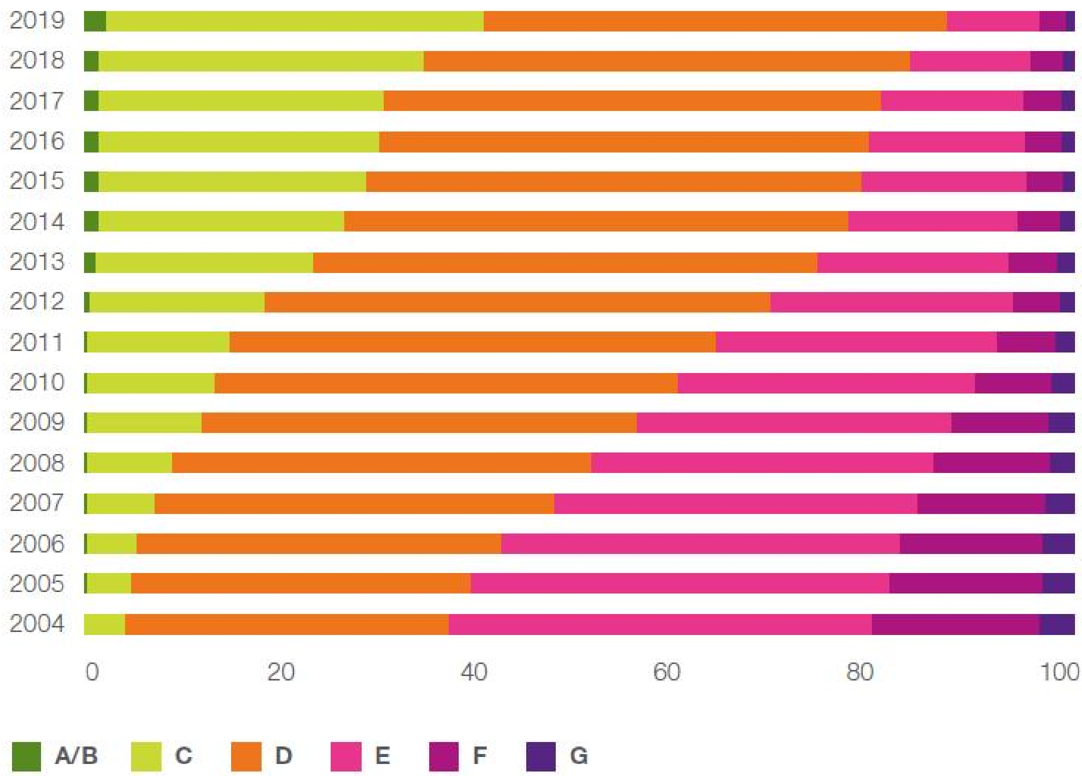

Figure 4: Changes in EPC rating over the years (DBEIS, 2021a).

The energy performance of the houses has been improved over time according to Figure 4. It is noted that the rating "C" has increased sharply. Further, rating F and G were declined sharply (DBEIS, 2021a). The UK already has a strong track record of improving energy performance, with 40% of the homes now above Energy Performance (EPC) Band C, up from just 9% in 2008 (UK Government, 2021).

As far as the energy performance and retrofit strategies of a house are concerned, heat loss from the building fabric is an important aspect (Tsang et al., 2024). Heat is lost in three ways; conduction, convection and radiation. In a sample building, heat is lost from different percentages from different building parts (Worthing et al., 2021). This is visualised in Figure 5.

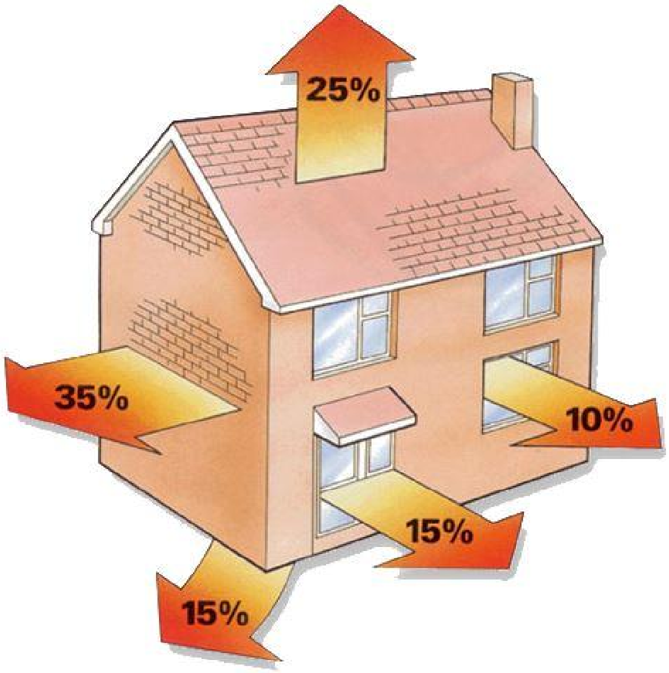

Figure 5: Heat loss in a typical underperforming house (RBKC, 2020)

When it comes to the energy efficiency of the houses in England, the SAP ratings have improved over time. Further, the Housing Health and Safety Rating System (HHSRS) has also been improved over time since 1990. 92% of the houses in England had central heating by 2020. In addition, 52% of the households had solid or cavity wall insulation, 87% of households had double glazing and 39% had 200mm or more loft insulation (DLUHC, 2021b). Current UK houses are not adequately performing, not only in terms of energy but in other areas such as comfort, summer overheating and future resilience. Around 4.5 million houses overheat even during cool summers. Emission and climate targets are not possible to achieve without decarbonising the existing housing stock (CCC, 2019).

2.2.4. Economic sustainability of the housing sector | Fuel poverty

There are several definitions for fuel poverty. The simplest definition can be considered as the one which identifies a household in fuel poverty if they pay more than 10% of their annual net income towards energy use (Cpag, 2022). Fuel poverty is measured in England by the government under the Low Income Low Energy Efficiency (LILEE) indicator. According to these criteria, the house should be with an EPC rating of D or below. Further, when the house is heated to the desired level and paid the energy bills, the household should come under the official poverty line (Desnz, 2013). According to the LILEE indicator, there are 3.17

million households (13%) in fuel poverty in England as of 2023 (Desnz, 2024). There are 5.6 million households in fuel poverty as of 2024 July under the 10% threshold indicator in the whole UK (National Energy Action, 2024). Fuel poverty becomes a critical issue in the housing sector as it causes further negative consequences. The fuel poverty forces the residents to stay in cold, damp and mouldy houses which leads to health issues and further complex societal problems. It will also become a burden to the government due to the increased health costs, reduced human development indexes and dissatisfaction of the people (Boardman, 2010; Simcock et al., 2016).

There are three causes of fuel poverty. They are the price of fuel, household income and energy efficiency. In order to address fuel poverty, a government shall strategically address all these three. As household income comes under a whole different topic, both the fuel price and energy efficiency of the house play a critical role in determining fuel poverty. Due to the sudden increase in fuel prices in the post-COVID era, most of the households fell into fuel poverty. According to the statistics, there is a 1.1 million increase in households in fuel poverty between October 2021 to July 2024 (National Energy Action, 2024). The government cannot totally control the energy price increase as the UK depends on fuel imports (DBEIS, 2022). The UK government enacted the energy price guarantee to keep the fuel prices under control. It is reported that the government spent nearly £ 66 billion on this (Deben, 2022). There are criticisms that the government is spending money on short-term measures such as energy price guarantees where there are more strategic solutions available with energy efficiency retrofits (Panakaduwa et al., 2024b). The government established a new ministry called the Department for Energy Security and Net Zero, considering the importance of achieving sustainable energy security (DESNZ, 2023a).

Apart from the fuel price, energy efficiency is another reason for fuel poverty. As far as the EPC reports are analysed, approximately 60% of the houses are below the EPC rating “C”. According to the government strategy, the minimum acceptable level of energy efficiency is “C”. That means at least 60% of the houses are observed with poor energy performance (UK Government, 2021). There are different arguments about the level of energy efficiency. For example, Citizens Advice suggests that every house in the UK is required to have energy efficiency upgrades (Holms, 2023). Further, housing retrofit approaches such as Passivhaus or Energiesprong have shown the potential of having zero energy bill houses (Energiesprong, 2023; Passivhaus Trust, 2021).

Although the UK could produce all the fuel they need, there is a price to pay. Because of this reason, energy efficiency will be the most sustainable solution to reduce fuel poverty (Avanzini et al., 2022; Ciardiello et al., 2023). Although there is a high initial cost, the results will be prolonged. Industry experts have also agreed that sustainability in the building sector will not be achieved without achieving energy efficiency (Dbeis, 2021c; Fathi, 2024; Skidmore & McWhirter, 2023).

The fuel poverty challenge can be allocated to economic sustainability considering the point of view of the residents. Addressing fuel poverty will directly contribute to the sustainable development goal of affordable and clean energy.

2.2.5. Social sustainability of the housing sector | Poor quality of life

The housing stock in the UK is considered the oldest and worst-performing. Improving housing performance can be expensive and the direct financial returns can be prolonged. Having a high-performing house has multiple indirect benefits as well. E.g., Good health, better comfort or asset value (BRETrust, 2020). In basic terms, a good house will give residents a high quality of life. The quality of life can be defined as the level of mental and physical health, income and savings, comfort, availability of necessities and other resources in a given geographical area (World Population Review, 2022).

The life expectancy of UK residents has risen over time. The healthy life expectancy has not risen in line. One reason is believed to be the poor quality of the housing, and this will be further worsened due to climate change with heat waves, floods and fuel poverty (CCC, 2019). The cooling demand has increased over the decades. According to the statistics, the use of air conditioners has also increased from 2012 to 2019 by 2% annually. This can be a sign of a trend of overheating (DBEIS, 2021a).

According to a special report about Rochdale Boroughwide Housing, the housing ombudsman highlighted the poor living conditions of the residents of the particular housing stock. In this case, Awaab Ishak, a 2 year old died in 2020 due to respiratory disease due to mould growth in the house. The ombudsman highlights further poor living conditions of the residents such as overcrowding due to unusable rooms, poor ventilation and fuel poverty due to the inefficiencies of the housing stock (Housing Ombudsman, 2023). The health foundation argues that one in every five houses in England is below the standards of quality of life and it is just a roof over the heads of the residents (The Health foundation, 2017). This is validated by a study conducted by the housing charity “Shelter” (Shelter, 2021).

Citizens Advice has found that 1.5 million children are living in mouldy, cold or damp private rented houses. This has caused severe illnesses in children (Citizens Advice, 2023). Poor quality of housing is a national issue, specifically in the Northern part of the UK. This has seriously affected the health and wellbeing of the residents (Avanzini et al., 2022; Hackett, 2019). On top of this, elders, minority groups and those with pre-existing health problems are at a major risk. In 2018, there were 17,000 deaths due to cold homes (Hackett, 2019). Overheating in summertime has become another critical problem associated with the UK housing stock. This can be best addressed with passive measures such as shading as well as active measures such as reversible heat pumps (Zahiri & Gupta, 2023). One of all five buildings is reported to overheat in the UK. It is predicted that around 50% of the properties will overheat by 2050 due to climate change. The UK health authorities have already identified summer overheating as a health issue and building regulations require modelling and attending overheating when designing buildings (Traynor, 2019). Research suggests that proper retrofitting of the houses shall reduce overheating risks (Lomas et al., 2024).

Housing performance is not always about energy consumption. It is also health-related. The “Sick building syndrome” is a condition where the condition of the house has a negative influence on the homeowner’s health. Residents’ health deteriorates due to low temperatures, low lighting, dampness, mould growth, air quality and pollutants such as asbestos, Radon, lead, redundant oils, and other chemicals. The symptoms can be nausea, headaches, fatigue and skin, nose, eye, and throat irritations (Kuylenstierna et al., 2020; Suhr & Hunt, 2019). One of the reasons for this is fuel poverty as discussed in the previous section. Residents find it difficult to heat their houses during the winter months due to the higher energy bills (Cpag, 2022; National Energy Action, 2024).

Apart from the problems such as mould growth, dampness and condensation, there are other health issues related to the houses. According to section 9 of the Housing Act 2004, there are 29 hazards related to housing. The Housing Health and Safety Rating System: HHSRS is a tool to identify these hazards and take necessary actions by the local authorities (Legislation.gov.uk, 2004). In terms of sustainable development goals, poor quality of housing is a direct threat to social sustainability aspects such as good health and well-being, reduced inequalities, sustainable cities and communities. This review identifies the overall aspects of social sustainability under the term “quality of life”.

2.3. Housing retrofit

2.3.1. What is housing retrofit?

Retrofit is installing one or more measures to improve energy efficiency, improve ventilation or reduce carbon emission. There are 41 such retrofit measures defined by the PAS 2035:2023 framework (BSI, 2023b).

The typical retrofit measures can be seen as insulation, mechanical ventilation and heat recovery systems, triple glazing, and solar panels. Further, growing plants, rainwater harvesting, use of sustainable materials, and solar roofs can be considered (Santander, 2022). According to Jafari & Valentin (2017), there are five types of main retrofit measures that can be considered in a housing retrofit. They are; 1. Controlling measures (E.g., optimal lighting) 2. Load reduction measures (E.g., upgrading appliances) 3. Enveloping measures (E.g., Insulation) 4. Renewable energy and 5. Human behaviour.

According to a study conducted in China, driving housing retrofit has been defined as a tripartite game among the government, the homeowners and the contractors. The government is to provide incentives and supervision (regulation), contractors to supply retrofit measures (supply side) and homeowners to adopt retrofit measures (demand side) (Guo et al., 2024). Another study, it was highlighted the importance of a balance between reducing energy consumption and reducing emissions with occupant health, comfort and architectural heritage (Galvin & Sunikka-Blank, 2017). Considering these aspects, the PAS 2035:2023 has highlighted the purpose of the retrofit standards, which is to reduce the risks to both the occupants and the dwelling (BSI, 2023b).

The earliest initiatives in retrofit can be seen after the 1970’s oil crisis. Those measures were improving insulation, draught proofing or changing the heating system (Morgan, 2018; Rickaby, 2023). When it comes to gas heating, they became popular after the 1960s when the North Sea gas deposits were discovered. Gas heating became very popular during the next couple of decades. Most houses were to accommodate gas central heating instead of coal (Obr, 2024).

When it comes to retrofit, this can be seen as a new word added to the vocabulary of the homeowners. The government has allocated relatively low funds to drive retrofit (Nanda et al., 2022). When the retrofit projects are completed under the auspices of the government, some of these projects are observed with a number of unintended consequences. Is this the mistake of the government or the problem of the contractor? For example, Hull, Preston and Middlesborough case studies. These can be considered large-scale critical failures (Rickaby, 2023). Due to the increased criticisms of the quality of retrofit projects, Each Home Counts Review was commissioned by the government and was published in 2016 by Peter Bonfield (Bonfield, 2016; BSI, 2023b). The recommendations were taken into consideration for the adoption of the PAS 2035 framework (BSI, 2023a, 2023b).

2010-2020 has been identified as the lost decade of insulation. The statistics show that the number of insulations done in this decade is 90% lower compared to the previous decade (Skidmore & McWhirter, 2023). As of 2022, 71% of cavity walls are insulated, which is 14.8 million houses. Only 9% of the solid walls are insulated, which is 260,000. When it comes to loft insulation, 67% of the lofts have over 125mm insulation, which is 17 million homes. There are a total of 5.8 million cavity walls to be insulated, where 3.8 million of them are easy to treat while 1.3 million are hard to treat (Bolton, 2024).

Housing retrofit became a matter of concern in the UK with the government's focus on reducing carbon emissions. The Climate Change Act 2008 was a major legislation in the UK, which put pressure on the government to take action on reducing emissions in different sectors. The Climate Change Committee was established under this act and now advising the government with plans to achieve net zero emissions by 2050 (CCC, 2017).

Considering the over 30 million housing stock in the UK, research suggests that most of the houses need some sort of retrofit (Rickaby, 2023; Rosenow et al., 2020). This means, around 3 houses to be retrofitted every two minutes between now and 2050 to achieve net zero by 2050 (TheIET, 2020). A zero-carbon ready housing stock by 2050 is important for net zero targets in the global scenario. The existing retrofit rate is less than 1% and this needs to be improved to 2.5% by 2030 in order to achieve net zero 2050 targets (IEA, 2021).

Retrofit in the UK is highly fragmented from the point of contractors. Usually, one contractor undertakes only one measure. Due to this reason, the homeowner needs to go to a number of contractors to get all the required retrofit measures installed. This is a hassle to the homeowner and the homeowner has to be a project manager to run the retrofit project

(Brown, 2018; Fylan & Glew, 2021). Most professional institutions recommend the whole-house approach to housing retrofit (BSI, 2019, 2023b; LETI, 2021; RIBA, 2022; TrustMark, 2022). Due to the fragmented nature of the retrofit market, it is difficult to drive a whole-house retrofit approach (Fylan & Glew, 2021).

Currently, the energy efficiency of the housing mainly comes under the auspice of the Department for Energy Security and Net Zero (DESNZ, 2023a). There are several other stakeholders as well. For example, the British Standards Institution is engaged in providing approaches to standards through specifications such as PAS 2030 or PAS 2035 (Rickaby, 2023). Trustmark is the government-endorsed quality scheme for suppliers and installers of housing retrofit (TrustMark, 2022). In addition, there are various institutional and government stakeholders who are involved with housing retrofit.

When it comes to the supply chain and installers, the industry is observed with a lack of skilled workforce to efficiently deliver the retrofits. Further, the retrofit supply chain is also not sufficient (DBEIS, 2021b). Currently, the problem does not seem to be much highlighted due to poor demand for housing retrofit. The annual average energy demand of a house has been reduced from 2008 to 2021. This is 390 kWh/m2 to 235 kWh/m2 by 40% (Bolton, 2024). The environmental audit committee has emphasised that the rate of progress in improving energy efficiency is critically poor, considering the climate change targets (Environmental Audit, 2021).

2.3.2. The need for retrofit

According to the sixth carbon budget, the emissions are to be curtailed by 68% by 2030, 78% by 2035 and 100% by 2050 (UK Government, 2020). The COP28 summit also placed a strong emphasis on starting the stop of the fossil fuel era and taking promises into action (Unfcc, 2023). The Climate Change Committee has said that the failure to decarbonise the housing stock is not an option (Morgan et al., 2023). A road map is required to retrofit 50% of existing buildings by 2040. This needs to be increased to 85% by 2050. Once retrofitted, the houses need to be at least zero carbon ready. The International Energy Association (IEA) estimates that all the technologies required to achieve deep reductions in global emissions exist today, with real-world examples of policies to drive their adoption (IEA, 2021). Apart from these environmental sustainability matters, millions of people are in fuel poverty, suffering from dampness, mould, condensation and cold (Cpag, 2022; Desnz, 2024; National

Energy Action, 2024). Further, this is a problem of equal opportunities. The UK housing stock is generally not comfortable and healthy. The NHS cost due to poor housing is in the British pound millions (Nicol et al., 2016). Several millions of houses overheat in summer (CCC, 2019).

If the housing retrofit starts now, it is required to fully retrofit three houses every two minutes until 2050 to achieve the net zero 2050 targets (TheIET, 2020). (TheIET, 2020) also suggests clear policy initiatives, access to low-cost finance, a whole house retrofit approach, large-scale retrofit projects (aggregation to realise economies of scale) and a single point of contact with enhanced trust for owners and users to engage throughout the process.

Figure 6: Sustainable development goals (United Nations, 2015)

According to Figure 6, There are seventeen sustainable development goals (SDG) according to United Nations (2015), under the Paris Agreement. United Nations expect to achieve these goals by 2030 and the participating countries need to develop their strategies to achieve these goals. They are called nationally determined contributions (NDC). It is noteworthy to see how housing retrofit can contribute to the above sustainable development goals. Only the direct benefits of retrofit are considered.

Table 5: Aligning SDGs with housing retrofit

	SDG	Housing retrofit contribution
1	No Poverty	Directly contributing to eliminating fuel poverty, leading to reducing poverty.
2	Zero hunger	-
3	Good health and well-being	Directly contribute to healthy and comfortable houses.
4	Quality education	-
5	Gender equality	-
6	Clean water and sanitation	Ensuring clean water and high sanitary standards should be a part of the retrofit objectives.
7	Affordable and clean energy	Retrofit directly addresses zero-emission energy with the lowest energy bills.
8	Decent work and economic growth	Retrofit shall provide employment and business opportunities for the next three decades.
9	Industry, innovation and infrastructure	Compliment with industry, innovation and infrastructure in achieving retrofit objectives.
10	Reduced inequalities	Promotes comfortable, safe and healthy households for everyone, including low-income groups.
11	Sustainable cities and communities	Creating sustainable cities and communities through high-performing houses.
12	Responsible consumption and production	Reducing the need for resource consumption (including raw materials and fossil fuels) and reducing waste generation.
13	Climate action	One of the main purposes of retrofit is to reduce emissions.
14	Life below water	-
15	Life on land	-
16	Peace, justice and strong institutions	-
17	Partnerships for the goal	Will create strong partnerships with other institutions, and countries with shared knowledge, technology and resources.

According to above Table 5, housing retrofit is complimentary with at least eleven United Nations sustainable development goals. This includes sustainability goals related to the triple bottom line concept. When it comes to sustainability in the housing sector, it is not possible just to consider the physical buildings, but the people living in these houses and their socio-economic background need to be concerned (Xu et al., 2023). Considering these factors, it can be concluded that there is a critical requirement to retrofit the housing stock in the UK for sustainability.

2.3.3. Regulations, certifications and ratings

2.3.3.1. PAS 2030:2023 and PAS 2035:2023

This is a specification of best practice guidance for housing retrofits. PAS is not a British standard, it will form the basis of a standard which will later become a British Standard. The housing retrofit can comply with this specification until the British Standard published (BSI, 2019). There are four key objectives of retrofit standards that can be identified. They shall provide clear processes to minimise risks, making retrofit a professional work, explicit definitions of intended outcomes with responsibility and ensuring clients' confidence (Rickaby, 2023). PAS is reviewed and updated at least every two years until it becomes a standard (BSI, 2023b).

The PAS 2035 can be rather identified as a retrofit project delivery framework. It expects to answer structural problems in housing retrofit such as defects of retrofit works, unintended consequences, shallow retrofit (installing retrofit measures at the wrong time and place), poor accountability of the stakeholders, performance gap (not meeting expected energy savings) and poor retrofit design (Liyanage et al., 2024; The Retrofit Academy, 2021). PAS 2030: 2023 is the specification which goes together with PAS 2035: 2023. PAS 2030 provides specifications for installing energy efficiency measures in existing houses. The purpose of PAS 2030 is to provide a robust and standardised framework for the energy efficiency installation process to the installers in line with clients' expectations (BSI, 2023a).

Other than PAS specifications, building regulations, listed buildings and buildings in conservation areas, there are several regulations applicable to housing retrofit. These regulations can be seen at a glance in PAS 2030 and PAS 2035 documents (BSI, 2019). Further, general regulations applicable to construction work such as health and safety regulations applicable for the retrofit projects as well. E.g., Construction (Design and Management) Regulations 2015 (HSE, 2015). Although PAS 2030 was there for some time, PAS 2030 and 2035 can be identified as the children of Each Home Counts review. The idea is to change the retrofit culture which was unprofessional and neglected the risks to the people and their homes (Rickaby, 2023).

In contrast, (Fylan & Glew, 2021) argue that the retrofit standards have not improved the retrofit quality. They further argue that the retrofit standards have increased the complexity of the installers' work. Due to this reason, it has increased the project costs. The installers are not quite happy with PAS as that will create additional responsibilities for them to ensure that the retrofit is free from unintended consequences. Nanda (2022) also highlights the problem of unintended consequences due to the poor installation of retrofit measures. This is due to the poor workmanship of the installers (Nanda et al., 2022). The PAS framework is to train and accredit people to ensure they are fit for the purpose, improving retrofit quality and reducing risks to both the properties and the occupants (BSI, 2023b). In conclusion, it is expected that the installers are not happy with the standard due to the additional accountability. Compliance with PAS 2035 shall bring professionalism and responsibility into housing retrofit.

2.3.3.2. Government regulations

The UK government is legally bound to achieve net zero emissions by the year 2050. This was first under the provisions of the Climate Change Act of 2008. Earlier, the government was required to achieve an 80% reduction in greenhouse gas emissions by 2050. This was tightened to achieve net zero by 2050 in 2019. Accordingly, the UK became the first major economy to pass Net Zero 2050 laws (Gov.uk, 2019).

According to EcoMerchant (2022), building regulations apply to both new buildings and retrofits. Any new work which comes to the definition of “Building Work”, should comply with the building regulations. Most retrofit works can be subject to building regulations. For example, Part L - Energy efficiency, Part F - Ventilation and Part O - Overheating.

When the use of a building is changed, the thermal element is renovated, an extension is added, controlled service/fitting is installed or consequential requirements (heating demand increase), building regulations are required to be complied with. Further, if the building is listed or situated in a conservation area, it comes under the provisions in sections 16 & 66 of the Planning (Listed Buildings and Conservation Areas) Act 1990 as well as the usual building regulations. There are special provisions applied to the retrofit works in these buildings (HistoricEngland, 2014).

Minimum energy efficiency standards (MEES) require retrofitting existing houses to a higher energy efficiency. According to the existing MEES regulations applicable to renting out residential houses, there should be a minimum EPC rating of E (Gov.uk, 2017). Further, the Social Housing (Regulation) Act 2023 or Awaab's law requires specific procedures to follow up on poor conditions of the social houses, putting more responsibilities on the social landlords (Legislation.gov.uk, 2023). This legislation is built in line with the Housing Health and Safety Rating System (HHSRS) under the Housing Act 2004 (Legislation.gov.uk, 2004).

2.3.3.3. Certifications and ratings

Passivhaus Enerphit: According to Traynor (2019), the purpose of Passivhaus is to improve thermal comfort for the residents and reduce carbon emissions in the building sector. This will directly contribute to the 2015 Paris Agreement (Welch et al., 2023). The first Passivhaus was built in 1991 (Traynor, 2019). Enerphit is the certification offered to the existing house retrofits under the Passivhaus scheme. It is understood that upgrading the existing buildings to the Passivhaus certification may not be feasible. In this case, the Passivhaus planning package and methods are used to arrive at the EnerPhit certification, which is recommended for retrofits. The heating demand for the Passivhaus new build is below 15 kWh/m2a whereas the heating demand for Enerphit can be below 20 to 30 kWh/m2a, depending on the region (Passivhaus Trust, 2021).

Energiesprong: This is a complete retrofit approach with origins in the Netherlands. This method ensures a net zero energy house with 40 years of assurance. They are not only energy efficient, but they also provide superior indoor environment comfort. The Energiesprong approach uses a combination of insulation, prefabricated facades, solar panels, smart heating, insulated rooftops, smart ventilation, and cooling methods (Energiesprong, 2019). Energiesprong UK has recently completed two projects with 10 houses each in London. Further, they have been offered a 38 flat five-storey block to retrofit. It can be noticed that Energiesprong UK is making progress (Energiesprong, 2023).

EPC report: This is a certificate issued by a professional energy assessor with regard to a residential property. Once issued, they are valid for ten years. There is a register of energy performance certificates, usually to which anyone has access. It is a legal requirement to have an EPC when a residential property is built, sold, or rented. The EPC gives a rating in between A to G, A is the best. Further, it gives recommendations about how to improve energy performance. The EPCs are governed by the Department for Levelling Up, Housing and Communities (Dclg, 2017; UK Government, 2021).

Currently, the energy performance rating does not recognise a net zero or net plus energy house. In this case, “mission zero”, the government’s journey to net zero in 2050 needs to take the shortcomings of EPC into account (Skidmore, 2023). The standard assessment procedure 11 (SAP 11) is underway (MHCLG, 2019). A revision of the rating system is due to be published in 2025 together with the new Future Homes Standard. It will recognise the net zero energy performance of a house. It will be more accurate and include broader recommendations about the overall energy performance of the house (Heyn, 2023). An energy performance certificate has not been proven to drive retrofit in the UK (Nanda et al., 2022).

The consistency and accuracy of EPC data are influenced by factors such as incorrect assumptions, lack of knowledge about the EPC process of assessors and conflict of interests of the assessors due to different uses of EPCs. Although there are such problems associated with it, EPC is regarded as a main method of data collection about the performance of the housing stock for both professional and academic purposes (Gledhill et al., 2023).

Table 6: Comparison of certification schemes (Passivhaus Trust, 2021).

Criteria	Passivhaus Classic new build	EnerPHit	AECB Retrofit	LETI Retrofit (Guidance)*
Space heating demand	≤ **15** kWh/m^2.year	≤ **20**, **25** or **30** kWh/m^2.year *or circa 20-60 for component approach*	≤ **50** kWh/m^2.year *with exemption up to 100*	≤ **50** kWh/m^2.year *exemption up to 60 with an exemplar target of* ***≤ 25***

The above space heating demand comparison in Table 6 is about the different certification schemes. The Passivhaus new build has the highest level of performance. Due to practical constraints, the Enerphit certification for the retrofit has not been that stringent. It can be understood that the building regulations are far more flexible in this case. According to CIBSE (2022), there is an update to Part L building regulations in 2021, which expects a 27% carbon reduction compared with 2013. Part L was implemented in 2022. The purpose of this update is to go for Future homes standards by 2025.

Due to the regulatory requirements, cost and simplicity, EPC is the widely used method of assessing the energy performance of a house although the accuracy is in question (Hardy & Glew, 2019). Passivhaus and Energiesprong are getting the attention of the market, although they are not widely popular. By 2022, there were around 1500 Passivhaus-certified buildings in the UK (Ciat, 2023). The number of Energiesprong-certified projects is not available. According to Energiesprong (2023), this would be less than 100.

2.3.4. Retrofit measures

2.3.4.1. Introduction

According to PAS 2035: 2023, there are forty-one housing retrofit measures (BSI, 2023b). Apart from these PAS recognised retrofit measures, there are further measures that can be identified in relation to the building's performance. For example, Green walls systems are not considered as a retrofit measure by PAS 2023 (Korol & Shushunova, 2022).

Table 7: Retrofit measures common categories

	Measures	Description
1	Fabric measures	Retrofit measures related to the building fabric. For example, internal wall insulation or loft insulation.
2	Ventilation, airtightness and draught proofing	Measures related to the ventilation of the buildings. For example, mechanical ventilation with heat recovery.
3	Heating and hot water	Building services related to heating and hot water. For example, heat pump installation.
4	Windows/doors and glazing	Installation of doors, windows and glazing. For example, double-glazed or triple-glazed windows.
5	Thermal bridges/ Cold bridges	Construction techniques related to avoiding thermal bridges and improving energy efficiency.
6	Lighting, appliances & systems	For example, LED lighting, A-rated appliances or smart energy meters.
7	Renewables	Measures such as solar photovoltaic panels, solar hot water, wind turbines or biogas units.

Table 7 shows a summary of the main retrofit categories. The following section is reserved to discuss the main categories of retrofit measures. Considering a typical home retrofit project, one or more retrofit measures can be installed in a housing retrofit project.

2.3.4.2. Fabric insulation

As far as the insulation is concerned, loft insulation and cavity wall insulation are observed to be popular, although there are problems with dampness due to poor installation. Solid wall insulation was not widely popular and the problems were observed with thermal bridges when poorly installed. Ground floor insulation is also very rare although there are more than 10 million uninsulated suspended timber floors. Evidence suggests that floor insulation can reduce heat loss by up to 20% (Glew et al., 2021). As far as the past two decades are concerned, 2013 - 2023 can be considered the lost decade of insulation. The insulation rates dropped by 90% during this decade compared to the previous decade (Skidmore & McWhirter, 2023). The following Table 8 compares Passivhaus insulation levels and Part L building regulation insulation levels.

Table 8: Comparison of Passivhaus and Part L regulations (CIBSE, 2022)

Parameter		Part L2A 2013 Limiting Value	Part L2A 2021 Limiting Value	Part L 2021 – Notional Values	Passive House	2025 Future Buildings Standard
U-values	Wall	0.35 W/m²K	0.26 W/m²K	0.18 W/m²K	0.15 W/m²K	Under consultation in **2023**
	Roof	0.25 W/m²K	0.18 W/m²K	0.15 W/m²K	0.15 W/m²K	
	Floor	0.25 W/m²K	0.18 W/m²K	0.15 W/m²K	0.15 W/m²K	
	Curtain wall	2.2 W/m²K	1.6 W/m²K	1.4 W/m²K*	0.85 W/m²K	
Glazing U-value		2.2 W/m²K	1.6 W/m²K	1.4 W/m²K	0.85 W/m²K	

Fabric insulation is an important concept of housing retrofit as the whole purpose of insulation is to reduce heat loss. For this purpose, the Passivhaus certification recommends a maximum U value of 0.15 W/m2 K for roofs, floors and walls. For doors and windows, it is 0.85 W/m2 K overall. The Passivhaus levels are relatively tighter than the building regulations. The notional value is the target value and the limiting value is the maximum in the above table (CIBSE, 2022; HM Government, 2021a; Traynor, 2019).

2.3.4.3. Ventilation, airtightness and draught proofing

As far as the ventilation is concerned, Part L designates the required ventilation levels for both existing and new buildings. Further, it recommends to use of mechanical ventilation with heat recovery (MVHR) wherever technically feasible (CIBSE, 2022; HM Government, 2021a). Ventilation and air tightness strategy is a mandatory aspect under PAS 2030/2035 specifications. The whole purpose of this is to avoid unintended consequences (dampness and mould growth) due to poor ventilation and other reasons such as thermal bridges (BSI, 2023b; Rickaby, 2023).

When it comes to Passivhaus certification, Air tightness is a major requirement to prevent heat loss. Air tightness goes together with the ventilation. Mechanical Ventilation and Heat Recovery (MVHR) is an obvious requirement in Passivhaus buildings, which should ensure a minimum of 75% heat recovery. Passivhaus new build requires an air tightness of 0.6 n50 1/h or lower and retrofit requires at least 1.0 n50 1/h or lower (Traynor, 2019). Due to the specific characteristics of the houses, some houses have high levels of air leakages (E.g., Steel frame houses). This excessive air infiltration can undermine the energy efficiency of a house.

According to Historic England (2016), draught is the air leakage through the building envelope. This mainly happens through the windows and doors. It also can happen through the cracks and gaps of the envelope, which could be developed over time. Ideally, draught-proofing is one of the cost-effective, energy-efficient and aesthetically neutral retrofit measures (Pickles, 2016). Avoiding thermal bridges is another important work during the retrofits. A thermal bridge occurs when there is a discontinuation of the insulation, creating a bridge where the heat can escape (Zhang et al., 2022).

2.3.4.4. Heating and hot water

According to the English Housing Survey, 89% of the houses have a boiler heating system with radiators (including heat pumps). Further, 5% of the houses have a storage radiator, which stores heat during off-peak electricity and releases it during peak hours. Further, there are 3% room heaters and 2% communal heating systems (Dluhc, 2023). According to the fuel type, gas central heating is the most common in the UK, which is 86% in England (DBEIS, 2021a).

The government published the heat and building strategy in 2021 to state the government's plan how to achieve decarbonisation in the way the buildings are heated. The strategy highlights that the future heating will be a mix of electricity and Hydrogen, supported by a reduced demand with building retrofits (DBEIS, 2021a). As Hydrogen is not yet commercially available and viable (H. M. Government, 2021), the existing heating and hot water strategies are mainly expected with heat pumps.

Heat pumps have been identified as a new focus in housing retrofit literature (Serin, 2023). Further evidence shows that, in order to achieve decarbonisation goals (both embodied and operational), mass-scale heat pump deployment can be highly helpful (Li et al., 2022). The government is ambitious about promoting heat pumps to alter the way of heating in the UK buildings. It is not clear whether the recent government strategy for investing in heat pumps is backed by a clear rationale. The heat pump investment strategy report says 90% of the UK buildings are already suitable for installing heat pumps (Desnz, 2023b), which is doubtful of accuracy. Another research suggests that the UK should insulate at least 9.7 million houses including all the solid wall homes to effectively drive heat pumps in the UK (Lingard, 2020). Further, the Climate Change Committee estimates that there should be 19 million heat pump installations to meet net zero emissions in 2050. 74% of the houses will be suitable to install heat pumps by 2050 (Skidmore & McWhirter, 2023). To achieve the 2030 goal of 68% emissions reductions, at least 10% of the housing stock needs to be heated by heat pumps (CCC, 2024).

2.3.4.5. Windows, doors and glazing

Passivhaus retrofit recommends windows with an overall 0.85 W/m2 K U value (Traynor, 2019) while 2021 Part L Building regulations recommend a maximum U value of 1.6 W/m2 K (HM Government, 2021a). An average UK house is reported to lose 20% of its heat through the windows. this can be mitigated considerably with curtains and blinds (Fitton et al., 2017). The innovations in windows have contributed a lot to sustainability. For example, there are coatings applied to the window glazing which will reduce the U values. Further, there are options where the photovoltaic can be integrated into windows (Aguilar-Santana et al., 2020). Aerogel window glazing has been found to be highly efficient in reducing heat losses with lower U values down to 0.381 W/m2K. Further, the monolithic aerogel glazing can allow daylight up to 69% visual transmittance (Khaled Mohammad & Ghosh, 2023). Upgrading windows to double-glazed or triple-glazed is a common retrofit measure in most housing retrofit projects (Alabid et al., 2022). Considering the high amount of heat loss through the windows, this would considerably improve the energy efficiency of the house.

2.3.4.6. Thermal bridges/ Cold bridges

Cold bridges or thermal bridges are the points, lines or areas where the temperature is lower than the other areas of the insulation. This happens due to the unavailability of continuous insulation in the insulation envelope. The cold bridges let the heat escape from the envelope. The main problem is mould growth associated with cold bridges (Day, 2015). Thermal bridges usually occur in windows, doors and junctions of the walls predominantly. If there are balconies, thermal bridges can occur in balconies too (Zhang et al., 2022). Passivhaus retrofit recommends a thermal bridge-free construction as their main criterion to achieve the standard (Schoenefeldt, 2014). Thermal bridges can be effectively identified with thermal images. The thermal images are one of the integral parts of a retrofit assessment (Mayer et al., 2021).

2.3.4.7. Energy-efficient lighting, appliances & systems

As far as the net zero houses are concerned, lighting and appliances can consume a larger amount of electricity. Appliances such as washing machines, dryers, dishwashers, fridge freezers and cookers consume a higher amount of electricity. EU energy label shows the energy efficiency level of these appliances, which is mandatory in the UK (Cotswold District, 2021). By choosing higher energy-efficient products, the overall energy efficiency of the house can be increased.

Since the invention of the incandescent light bulb in 1879 by Thomas Edison, the bulb has come a long journey. The CFL bulbs were introduced in 1976 and were highly efficient. They became popular after around 30 years. Now there are LED bulbs, which are far more efficient than their predecessors (Matulka & Wood, 2013). Further, there are smart systems to optimise energy consumption in houses.

2.3.4.8. Renewables

Renewable energy plays a key role in making the homes net zero or even net positive. As the energy efficiency measures can only reduce the energy consumption to the lowest level, renewable energy measures are required to set off the residual energy consumption of the house (Passivhaus, 2023; Santander, 2022). The most popular renewable energy can be identified as wind power in the UK. Further, biomass and solar power share relatively equal percentages (National, 2022). Further, there are other renewable energy technologies applicable to houses such as solar hot water systems, mini wind turbines, biogas units (Miao et al., 2020).

The total share of solar electricity generation is around 2.3% in the UK. There are around 1.3 million houses with solar PV units in the United Kingdom as of 2023. Roughly, this is 4.1% of the total housing stock (Howell, 2019). The Greater Manchester Combined Authority estimates that the Solar PV systems may not be productive after 2038 with a fully decarbonised electricity grid. The efficiency of solar PV in homes can have a lower cost-benefit ratio compared with a decarbonised electricity grid (Greater Manchester CA, 2021).

The government supports the installation of renewable technologies for both retrofits and new builds through VAT concessions (HM Revenue & Customs, 2023). Further, homeowners can claim tax credits between 26% - 30% for renewable energy installation in their homes (Skidmore, 2023). Relevant adjustments to the Energy performance certificate are reported to be on the way with its newest review (Heyn, 2023).

2.3.5. Retrofit process

2.3.5.1. Retrofit approaches

Housing energy retrofit projects can be different from one to another due to the unique characteristics of each retrofit project. In this situation, whole-house retrofit approaches can be good for large-scale retrofits (James et al., 2024). For individual retrofits, a phased and incremental retrofit approach is recommended as one-off initiatives have fairly failed in the past in Europe (Saffari & Beagon, 2022). Glew et al. (2021) argue that the industry has still not properly identified how multiple retrofit measures behave jointly. As there are a number of retrofit measures and the uniqueness of house types, different combinations of measures can result in different outcomes, which is quite hard to predict (Glew et al., 2021; Liyanage et al., 2024).

Most of the best practices recommend fabric first approach, including PAS 2035:2023 specification (BSI, 2023b). When the building fabric is addressed first, it helps to reduce the energy demand of the house first. There are some arguments about this approach. For example, heritage building retrofit may not follow fabric first approach due to the less flexible nature of retrofitting the building fabric (Eyre et al., 2023). Further, there are some other arguments such as fabric fifth, where the other measures such as heating or ventilation are approached first (Banks, 2024). In general, the industry-accepted approach is the fabric first. Researchers recommend easy and cheaper retrofit measures first (Menconi et al., 2024).

Standard retrofit approaches without integration have caused unintended consequences such as interstitial condensation. In this case, the most important approach is people-first over fabric first according to Petsou et al. (2023). Technically, this does not challenge the idea of fabric first from the technical point of view. The idea is to protect the interests of both the occupants and the property.

2.3.5.2. Awareness and option evaluation

UK residents are not observed to be much aware of energy efficiency. A study conducted by Citizens Advice UK has found that 73% of homeowners do not know about their energy performance rating. The study highlights the importance of homeowner awareness about the benefits and way forward to energy efficiency (Holms, 2023; Santander, 2022).

Sometimes, it is difficult to convince people to do things even if they are beneficial to them. For example, some people chose not to get vaccinated during the COVID-19 pandemic even though that was a matter of life and death (Han et al., 2022). In this case, awareness is important, but it is not everything. Under practice theories, people make decisions that they are doing as a routine. Considering these aspects, there is a timely need to make people aware of the benefits of retrofit as well as understand their decision-making to influence behavioural changes (Bartiaux et al., 2014; Fyhn & Baron, 2017; Judson & Maller, 2014).

Awareness of the residents will be the first priority in the retrofit delivery. Even if they choose to retrofit or not, the journey will start with awareness and proceed to the next stages.

2.3.5.3. Onboarding and assessment

According to a study conducted at the University of Salford, there are eight aspects of a retrofit assessment identified. They are simple data points, condition assessment, ventilation assessment, high-resolution photographs, energy performance certificate, measured survey, sizes of the openings and occupancy assessment (Fitton & Swan, 2023). The retrofit assessment tools can be divided into three categories. They are to make awareness, to assess the technical aspects and to assess the financial aspects (Patterson, 2023). Proper retrofit assessment is the key to a successful retrofit project. If things are not properly assessed, this can lead to controversies and disagreements when the project is ongoing (Pender, 2021). According to the PAS 2035:2023 specification, there is a professional role as a “retrofit assessor” who can assess a property for retrofit work (BSI, 2023b).

When it comes to onboarding homeowners for housing retrofit, retrofit assessment plays a key role. With the retrofit assessment, digital data is generated and they can be deposited in a digital repository (Pernetti et al., 2021). From one point, this will help the homeowner to better evaluate retrofit options and plan the retrofit process from their end (Chen et al., 2020). On the other point, retrofit assessments shall collate digital data about retrofitting the housing stock (Gouveia & Palma, 2019). This will help the authorities to better plan retrofit projects and make better policy decisions. For these reasons, onboarding homeowners with a retrofit assessment plays a key role in driving housing retrofit at a scale.

One of the suggestions to promote retrofit is to avail the retrofit assessment free to the homeowners. This will better improve the awareness of the residents over the EPC report. Further, retrofit assessment should not create an obligation for homeowners to retrofit their houses until they enter into a contract.

2.3.5.4. Decision-making and contract administration

According to DBEIS (2021a); Nanda et al. (2022); Skidmore & McWhirter (2023), it is not possible to force homeowners to retrofit their houses. The interest should be cultivated within themselves. If homeowners are forced to retrofit their houses by means of regulatory tools, there is a risk of people changing the government which will not make them mandatory. For example, the previous UK prime minister abolished Minimum Energy Efficiency Standards (MEES) laws in 2023 for private landlords, claiming that the landlords are having a financial hard time (Sunak, 2023). Conclusively, housing retrofit is difficult to force on the residents and their positive engagement is important (Tozer et al., 2023).

The awareness, option evaluation and retrofit assessment shall help the homeowner to make a decision to retrofit or not to retrofit the house. If the homeowner decides to retrofit the house after evaluating the options and a formal retrofit assessment, the next step will be the contract administration. The PAS 2035 does not clearly recognise this as a step (BSI, 2023b). The retrofit standard published by the Royal Institute of Chartered Surveyors (RICS) has recognised the requirement of contract administration in housing retrofit projects. They have proposed the role of a "Retrofit contract administrator". In general, there should be a contract between the client and the contractor in the retrofit project in the same way as a general construction project. One example is the standard form of contract by the Joint Contract Tribunal (JCT) for homeowners and occupants (RICS, 2024).

2.3.5.5. Retrofit design and installation of the measures

The design of the retrofit measures and installation are to be done by the retrofit designer and retrofit installer according to the PAS 2035:2023 specification. The retrofit design should be done according to PAS 2030:2023 (BSI, 2023b). There are digital tools that can be used for the design purpose of retrofit plans. For example, the Passivhaus designers use the Passivhaus planning package (PHPP) which can simulate the retrofit scenario (Traynor, 2019). Poor design and installation of retrofit measures have been a critical problem in driving housing retrofit in the UK due to the lack of professionalism and workmanship of designers and installers. This has been now addressed with the PAS 2035/2030 specification (BSI, 2023b; Rickaby, 2023).

When the retrofit design is concerned, thermal and occupant comfort comes first. The designer should have a good idea of building physics for this purpose. Lighting, hygrothermal behaviour, heating and hot water, ventilation and air tightness, project management and quality assurance are some other factors to be considered during the retrofit design and installation (Hopfe & McLeod, 2015).

2.3.5.6. Post retrofit monitoring and evaluation

Evaluation of the retrofit measures is to be done under the British Standard BS 40101: Performance of occupied and operational buildings. The standard is applicable during the operational period of the building (Bsi, 2022). When it comes to monitoring and evaluation after the retrofit project is completed, a study has found that different reviews have taken different approaches (Carratt et al., 2020). Automated monitoring of post-retrofit performance can be easily done by using Wot/IoT (Ibaseta et al., 2021). There are several such data collection points suggested as electricity meter, internal temperature, humidity (Ho et al., 2021). The retrofit evaluation is to be carried out by a professional retrofit evaluator under PAS 2035. The post-retrofit evaluation is a rigorous process to ensure that the retrofit has achieved the expected objectives and whether there are any unintended consequences (BSI, 2023b; Stevenson & Leaman, 2010; The Retrofit Academy, 2021).

2.3.6. Stakeholders

Retrofit is ideally viewed from a multi-stakeholder approach where everyone is happy. It is all about making an old building more sustainable, more comfortable, more enjoyable, more valuable, more energy efficient, more aesthetic, and cheaper to use (Suhr & Hunt, 2019). Improvements to the buildings require a considerable level of labourers and trade people. In this case, the government expects to create an additional 240,000 jobs by 2035 with the drive of retrofit (DBEIS, 2021a).

Currently, there is no national trajectory pathway to decarbonise homes and energy systems. This has created uncertainty among the stakeholders (UKGBC, 2021). Local authorities play a key role in promoting and delivering retrofits. Most of the local authorities do not have enough resources to deliver such retrofit projects and develop business cases for retrofit delivery plans (Local Partnerships LLP, 2021).

The homeowner can be identified as the most prominent stakeholder in driving energy retrofits (DBEIS, 2021a). First, they own most of the residential buildings. 63.1% of the house tenures are owner-occupiers and a further 19.1% of house tenures are private rented (BRETrust, 2020). Second, they are the ones who ultimately decide whether to invest in retrofit measures or not, as they are responsible for the cost and implementation of such upgrades (Seddiki et al., 2021). The poor trust and lack of awareness about housing retrofit have diminished the demand for housing retrofit by homeowners (Environmental Audit, 2022a).

When it comes to the landlords and tenants, there are both social landlords and private landlords. Social landlords own 17.7% of the housing stock and private landlords own 19.1% of the houses in the UK (BRETrust, 2020). Social landlords may be more motivated to invest in retrofitting than individual homeowners, as they may have a larger portfolio of properties and may be able to achieve economies of scale through bulk purchasing and installation. This can be a reason why social houses are more energy efficient in England (DBEIS, 2021a). Further, as the direct benefits of housing retrofits are to be enjoyed by the tenant, landlords are not motivated to invest in retrofits. They can see the retrofit as an additional cost, which results in split incentives (Melvin, 2018; Wood et al., 2012).

According to the PAS 2035:2023 specification, there are five retrofit professional roles. They are the retrofit assessor, retrofit coordinator, retrofit designer, retrofit installer, and retrofit evaluator. Practically, one professional may carry out work under several roles. E.g., A retrofit coordinator can work as an assessor or evaluator (BSI, 2023b). The following Table 9 shows the professional roles under PAS 2035 and their responsibilities.

Table 9: Roles and descriptions under PAS 2035:2023 (BSI, 2023b)

Role	Description
Assessor	Carrying out physical assessment for retrofit
Coordinator	Coordinating parties and risk management
Designer	Designing the required retrofit measures, tailor-made to the house
Installer	Installing the measures according to the design. (Construction)
Evaluator	Ensuring the retrofit measures are properly installed

In addition to these professional roles, there are other stakeholders such as the client, government, local authority, professional organisations. Further, there is a role as the main contractor in PAS 2035:2023 which is optional and contextual. It is not considered a professional role under the specification (BSI, 2023b). As the nature of the retrofit supply chain is concerned, it is highly fragmented. One contractor may install one or a few measures. There is no collaboration among the supply chain/contractors (DBEIS, 2021b; Tan et al., 2023). In this case, the whole-house approach proposed by PAS 2035:2023 plays are vital role in creating the required collaboration of the retrofit measures provided by various supply chains (The Retrofit Academy, 2021). Trustmark is the only government-endorsed scheme to register construction businesses and tradespeople for housing retrofit. Trustmark ensures the retrofit installers are fit for the purpose and they comply with the standards, best practices, customer service and continuous professional development (TrustMark, 2022).

Considering the high initial costs of housing retrofit, a viable financial model is a prerequisite for a successful retrofit. According to Brown et al. (2019), the main three financial sources can be identified as homeowner's savings, loans from financial institutions and government grants. Ideally, a retrofit project may be financed with a combination of the above (Environmental Audit, 2021). The Netherlands housing retrofit model "Energiesprong" has their own financing model with the arrangements of how the finance is recovered (Energiesprong, 2019). Further, there are popular retrofit models with financing arrangements in Europe such as (ESCO) Energy service companies (Innovate, 2020).

Santander Bank has focused on the housing retrofit market. They provide free energy analysis reports for the houses and finance to retrofit the houses at concessionary conditions (Santander, 2022). Further, there are zero-interest loans, green mortgages and property-linked finance designed for funding retrofit (Skidmore & McWhirter, 2023). None of these financial models seem to be popular in the UK for housing retrofit (Holms, 2023). The Green Finance Institute was established in 2019 to develop financial strategies to support a low-carbon economy. This institute is backed by the government and supported by the lenders (Green Finance Institute, 2019).

According to the government's clean heat and buildings strategy, existing gas boilers will be phased out from 2035. Either they will be used with Hydrogen, or they will be out of use from 2050 (Assuming the average lifetime of a boiler is 15 years). Further, the government expects to install 600,000 heat pumps per year from 2028 onwards (DBEIS, 2021a). The purpose of Future Homes Standard 2025 is to make homes zero carbon ready by reducing carbon emissions by 75%-80% compared to existing building regulations (RIBA, 2021). This may reduce any further retrofit requirements.

The government policy and action seem to be lacking consistency. Policies and actions are changed and halted all the time. This has created uncertainties and a lack of confidence in policy measures in the industry (Panakaduwa et al., 2024b). Ex-Prime Minister Rishi Sunak abolished the minimum energy efficiency requirements (MEES) for renting houses as the landlords were already experiencing financial hardships. This has caused a lot of landlords to dump their retrofit plans which were already prepared (Bourke, 2023). According to minimum energy efficiency standards (MEES), the landlords were required to upgrade EPCs at least up to "C" for new tenancies by 2025 and existing tenancies by 2028 (Carey, 2023).

Further, the Ex-Prime minister said that the mandatory withdrawal of gas boilers and petrol/diesel vehicles would be postponed (Sunak, 2023). This has frustrated the hopes of climate enthusiasts. Even with the withdrawal of gas boilers and fossil fuel vehicles, the UK was not on the trajectory of achieving net zero intermediate targets. These reversals will critically influence 2030/2035 UK climate change targets (CCC, 2023a). These U-turns are observed all over history. For example, the withdrawal of the 2013 Green Deal and abolishing the code for sustainable homes in 2015 (Rosenow & Eyre, 2016).

The importance of investing in housing retrofit by the government is that the government can recoup back the investment through tax revenue and budget savings due to higher economic prosperity. It is calculated that the government can earn £1.43 as tax revenue for every £1 spent by the government (Skidmore & McWhirter, 2023). Writing a letter to the Government, the Climate Change Committee says that the biggest gap in existing energy policies is about reducing the energy demand of existing buildings (Deben, 2022).

It is doubtful whether the government policies regarding housing retrofit have achieved much success. This is due to the poor strategies which mainly focused on financial aspects but not social and behavioural aspects of housing retrofit (Royapoor et al., 2023). The government policy should be framed to recognise energy efficiency as an infrastructure. New business models and decentralised financial institutions are required for this. The government should have a strategic plan to make energy efficiency investments attractive to both householders and investors (Bergman & Foxon, 2020).

Natural gas is four times cheaper than electricity in the UK. This has become a key challenge in driving households away from fossil fuels. The other regulatory challenge is the tax. Currently, newly built homes are given VAT-free concessions while this is not available for housing retrofit (Nanda et al., 2022; Panakaduwa et al., 2024b). By understanding these problems, the government has now given certain VAT concessions to some of the energy efficiency measures including insulation, heat pumps or solar panels (HM Revenue & Customs, 2023).

Recent policy measures have focused on blanket solutions to retrofit. The characteristics of each building are different and retrofit approaches should be tailor-made to each building separately. The total cost of net zero retrofits would be approximately one trillion pounds. This retrofit scale will not be practical with a business-as-usual approach and there should be a specially designed strategy to achieve net zero by 2050 under the built environment sector (CITB, 2021). Further, it is important to make sure there will be no regrets of the policy decisions (DBEIS, 2021a).

The government is reported to spend £25 billion for the first six months of the energy price guarantee 2022/2023. The next year 2023/2024 cost was estimated to incur a further £13 billion (Frost, 2024). Writing a special letter to the government, the Climate Change Committee warned the cost of energy price guarantee and other measures will be over £66 billion (Deben, 2022). The government's interest seems to be in the short-term measures of the problem as (Deben, 2022) emphasised that the government needs to shift their strategy from subsidies to energy efficiency.

2.3.7. Justification for housing retrofit

2.3.7.1. Why housing retrofit?

The housing stock contribution to the UK emissions is 19.76 % (DESNZ, 2022). More than 5.6 million households cannot afford sufficient heat as they are in fuel poverty (National Energy Action, 2024). Further, there are millions of houses which are not healthy to live (Garrett et al., 2021). Finally, the houses are not adaptable to a decarbonised electricity grid (Passivhaus Trust, 2021).

As already highlighted, the UK government is legally bound to achieve net zero emissions by 2050. Decarbonising the housing stock is a clear priority in this regard (DBEIS, 2021a). The UK has set targets to reduce emissions by 68% by 2030, 78% by 2035 and net zero by 2050 from 1990 levels (Environmental Audit, 2022b). This will not be able to achieve without decarbonising the existing buildings. The Committee on Climate Change noted that there has been minimal progress in improving energy efficiency in our buildings in recent years (CCC, 2023b).

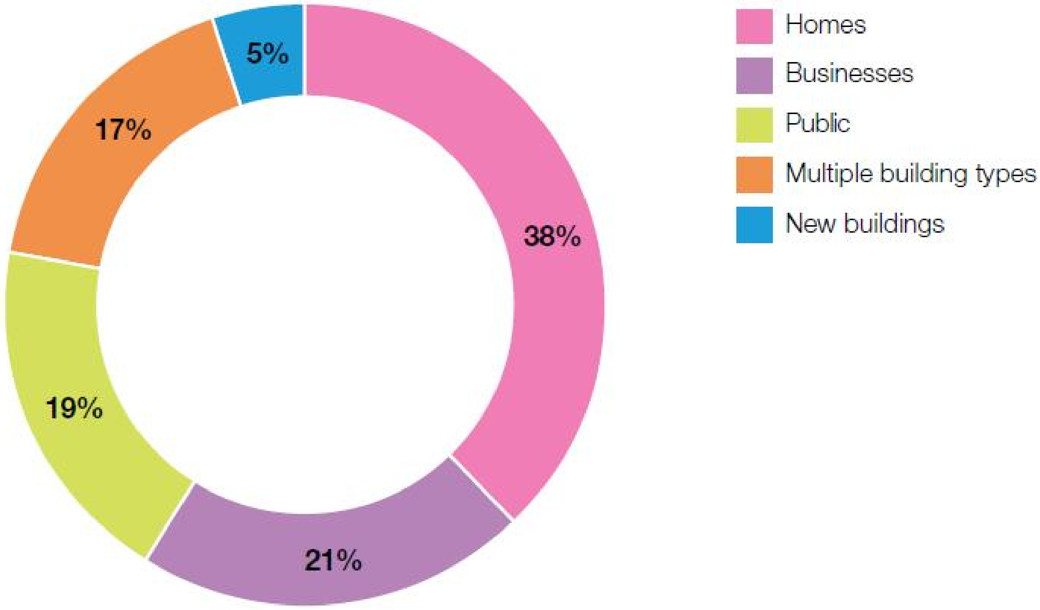

Figure 7: Potential emission savings from building heating by 2030 (DBEIS, 2021a).

By considering the above Figure 7, it can be noted that most of the emission reduction is expected from homes. Public and businesses together expect to reduce a similar amount of carbon in homes. In this case, it is clear that the existing homes should be the focus of attention of decarbonisation (DBEIS, 2021a). 80% of the buildings that will exist in 2050 are already constructed by now. By 2050, around 95% of the operational carbon will come from the existing buildings today (Unless retrofitted). That means that 95% of the problem is already there (CITB, 2021). Low carbon heat is not possible to deliver to the existing buildings in a cost-efficient manner without upgrading the insulation of the existing building stock (Environmental Audit, 2022b; UK Parliament, 2021).

2.3.7.2. Why not rebuild?

Rebuilding can be identified as demolishing the existing building and constructing the building from scratch. (Not to be confused with digitally modelling buildings with images or any other data). (Ferreira et al., 2015) suggest that rebuilding also contributes to the renewal of the built environment, the same as retrofit. Unless otherwise the demolished materials are reused, recycled or remanufactured, typically they are wasted in landfills. According to LETI (2021), 80% of the embodied carbon is emitted during the construction stage. Further, one of the earliest definitions of sustainability in the Brundtland report talks about resource utilisation (WCED, 1987). According to that definition, rebuild shall mainly use virgin materials while the retrofit tries to keep the existing materials as much as possible.

Rebuild is not sustainable for several reasons. One is construction waste, which is a critical threat to sustainability. Construction waste needs to be properly managed and should seek the possibilities of reduce, reuse and recycle (Hossain et al., 2017). Further, rebuilding needs fresh materials, unless recycled materials are used. This will reduce the future generations' ability to consume the resources as today's generations do. This is not sustainable. According to a study conducted in the social housing context, it has been found that retrofit has lower lifecycle costs than rebuilding (Bell et al., 2014; Mohammadpourkarbasi et al., 2023). Environmental Audit Committee also stated that the retrofit should be prioritised due to the lower embodied carbon, waste generation and conservation of natural resources (Environmental Audit, 2022a).

According to Branson (2021), there are still arguments about whether it is more sustainable to retrofit or rebuild buildings. This is highly debatable as the justification significantly differs from one context to another. According to Oyedele et al. (2014), there is no proper construction waste reuse or recycling methodology in the UK. Most construction waste goes to landfills. Considering these facts, retrofit shall ideally consume less resources than rebuilding (Hardy & Glew, 2019). Some technologies exist to achieve a high level of retrofit performance (Branson, 2021; Higney & Gibb, 2024). In this case, retrofit can be more sustainable than rebuilding at this moment, as there are no proper construction waste reuse or recycling opportunities.

2.3.7.3. Why not decarbonising electricity?

On the face of it, if the building energy is fully converted to electricity and the electricity is sourced from renewable methods, there is no need to retrofit the houses (Passivhaus Trust, 2021). The UK expects to go for a fully decarbonised electricity supply by 2038 (U. K. Government, 2021). Arguably, it is a matter of electrification of heating, not energy efficiency in the housing stock. This is not a realistic assumption. There is a peak load limit to the national electricity grid. The grid cannot handle the expected electricity demand increase expected from space heating and electric vehicle charging. Electrification is only a part of the solution. Further, the heat pump provides low heat, which is only compatible with a satisfactory energy-efficient house (E.g., EPC "C" rating). The cost of renewables is also high.

Electricity decarbonisation does not answer the problem of fuel poverty (Passivhaus Trust, 2021). The most sustainable energy will be the energy that is not used.

2.3.7.4. Why not innovation?

The UK presented their Hydrogen strategy, setting goals up to 2030. The government expects Hydrogen will be a key player in the energy mix of 2050 (HM Government, 2021b). The government follows a "No regret" strategy in deciding the fuel mix. Hydrogen is expected to play a significant role in residential heating after 2028 (DBEIS, 2021a). The government is considering several measures for Hydrogen. E.g., Blending Hydrogen into the Gas grid, Making Hydrogen-ready boilers, Seeking the potential of using Hydrogen in buildings (UK Government, 2020). Currently, there is no infrastructure to generate, store and distribute low carbon Hydrogen to the required scale at cheaper prices. It is more feasible to convert Hydrogen into electricity and use heat pumps (CITB, 2021).

According to IEA (2021), to achieve Net Zero 2050, there should be innovation, international cooperation, investment, policy and infrastructure at a scale. They further highlight that although there are sufficient technologies up to 2030 on the Net Zero trajectory, beyond 2030 up to 2050 Net Zero requires innovations which do not exist today. For example, the UK is still new to Geothermal energy. Other European countries such as France or Germany have been using deep geothermal energy for district heating effectively (Huculak et al., 2015).

The importance of innovation in the construction industry is highlighted by (Ellis et al., 2021) in their report through the Green Construction Board to improve carbon reduction potential. New outcomes will not be able to achieve without innovations. Just the technology will not realise the decarbonisation, but innovations are important. According to the UK prime minister's ten-point plan for the green industrial revolution, one point has been reserved only for finance and innovation. Further, the importance of innovation has been highlighted all over the strategy, as the industrial revolution in the UK was pioneered by the innovation about two centuries ago (UK Government, 2020).

Despite this fact, the level and potential of the innovation are not predictable. It is important to continue with the existing strategies of decarbonisation, while rigorously proceeding with the innovations. Further, the strategies should be designed in a way of "No regrets". If there are revolutionary innovations that change the decarbonisation path, the adaptability of the strategy is important. Retrofitting is not all about heating houses. Even in the case of Hydrogen or any other innovation, reducing the demand matters. The Climate Change Committee recently advised the government to go for rapid electrification without waiting (CCC, 2023b). Further, the United Nations also warned member states to stop using fossil fuels as a priority in COP 28 (Unfcc, 2023). The message is to move forward with what is already have.

2.3.8. Housing retrofit challenges and recommendations

2.3.8.1. Retrofit challenges

Housing retrofit challenges can be considered at different levels. Although there was no proper classification of levels found in the literature, they can be presented according to the project management body of knowledge (APM, 2012). The lowest level that could be identified was the energy efficiency measure level. According to PAS 2035, there are 41 such measures (BSI, 2023b). Internal wall insulation can be given as an example. Further, there are dwelling-level challenges, project-level challenges, programme-level challenges and portfolio-level challenges. Portfolio-level challenges can be given as the national-level challenges aimed at retrofitting the whole housing portfolio in the UK.

The business case for retrofit is already there. The problem is that the homeowners do not find it as the people do not make decisions rationally as suggested by (Lutzenhiser, 2014). In this case, this should not be considered as a barrier to drive retrofit, but as the nature of the driving retrofit (Lutzenhiser, 2014). Decarbonising the housing stock is one of the main challenges in the transition to net zero 2050. The reasons can be identified as no systems approach to net zero in national policy, difficulties in convincing the homeowners to create a demand for retrofit and the lack of business models to support sustainability (UKGBC, 2021).

The Institution of Engineering and Technology identifies four main challenges of retrofit. They are the limited user demand, unclear government policies, higher cost of retrofit and lack of finance (TheIET, 2020). According to DBEIS (2021b), the current lack of retrofit professionals such as installers, designers, assessors and coordinators is a critical problem in driving sustainable retrofit. Further, one of the main challenges in driving retrofit is to change the focus on the retrofit. Currently, investment in retrofit is viewed under energy bill savings and investment value creation. The health and environmental benefits of retrofit are often ignored (Alabid et al., 2022).

A study conducted in China has assessed barriers to housing retrofit under four themes. They are financial challenges, governance challenges, impact on the dwelling and inconvenience (Ma et al., 2022). According to a study conducted in the Netherlands, there are four main reasons identified why energy retrofit is not adopted by the owner-occupiers. Number one reason is that they believed their houses were adequately energy efficient. Second is the lack of finance. Third is the uncertainty of how much more time they will live in the house. Fourth is long payback periods. The last one is the inconvenience or disruption during the retrofit (Murphy, 2014).

A study conducted in Israel has found few barriers to housing retrofit. They are; poor availability of information and poor awareness, financial barriers, non-measurable benefits such as aesthetics, regulatory barriers, behavioural and social barriers as well as technical barriers. The main observation of this study is that the homeowners are aware of the retrofit, but the willingness to adopt retrofit is poor (Friedman et al., 2017). Citizens Advice has identified the largest barrier for homeowners to adopt housing retrofit as the high upfront costs (Skidmore, 2023). Almost all the houses in the UK will need some sort of retrofit to achieve net zero. The most prominent challenge to retrofit is not the financial barriers although the finance is also a challenge. The lack of personalised advice has been identified as the most critical barrier. Homeowners need personalised support throughout their journey of retrofit. The main three challenges are lack of awareness, upfront costs and lack of incentives. To drive retrofit at a scale, improving awareness, providing personalised advice and creating triggers (E.g., incentives) will be required (Holms, 2023; Simcock & Bouzarovski, 2023). Lack of awareness and consumer protection will be required to ensure consumer confidence to move forward to low-carbonised heat (Environmental Audit, 2022b).

The literature regarding housing retrofit has increased during the past five years (2018 – 2023) while 90% of the literature is published within the last decade. It is noted that the literature regarding ventilation systems and thermal comfort are low (Serin, 2023). Long payback periods and high upfront costs are identified as two of the critical financial barriers to housing retrofit (Liu et al., 2024; Menicou et al., 2016).

The rebound effect has been identified as another challenge in achieving decarbonisation targets of housing retrofit. The rebound effect can be defined as the percentage of target reversal due to behavioural changes. For example, a homeowner may ignore energy-saving behaviour due to lower energy bills after the retrofit. That would reduce the full potential of energy efficiency expected with housing retrofit (Castro et al., 2022). Another challenge can be identified as the prebound effect which was coined by Ray Galvin and Sunikka-Blank. When the actual energy consumption before the retrofit is less than the estimated energy consumption, the retrofit will not show the expected energy efficiency (Sunikka-Blank & Galvin, 2012). This can discourage the homeowners who may spread negative word of mouth.

2.3.8.2. Addressing retrofit challenges

As far as the above retrofit challenges are concerned at the national level, they can be segregated into six themes. They are the technology, finance, supply chain, workforce, management and demand. The technology required to retrofit houses is already available according to the current level of maturity of the retrofit technology. Retrofit models such as Passivhaus EnerPhit or Energiesprong have proven the availability of the right technology with real case studies (Energiesprong, 2023; Passivhaus Trust, 2021; Traynor, 2019). Although there are some further challenges with the heritage buildings, the challenge is mainly under the other themes, but not with the technology (Panakaduwa et al., 2024d).

According to the estimates of the Climate Change Committee, the UK will have to install at least 19 million heat pumps to achieve net zero by 2050. The UK installed only 40,000 heat pumps in retrofitted houses in 2022. This is far below progress in reaching the heat pump installation targets (Skidmore & McWhirter, 2023). As far as government grants are concerned, allocated grant schemes are underutilised. For example, more than half of the local authorities that received funding under the Social Housing Decarbonisation Fund (SDHF) have failed to retrofit a single house (Heath, 2022).

The supply chain is a problem to a certain level. The industry is suffering from supply chain issues (DBEIS, 2021b). There are problems with value-added tax on the retrofit supply chains. Value-added tax benefits are not available to the retrofit products as the new build is entitled (Panakaduwa et al., 2024b). It can be observed that now there are some retrofit supply chains starting to emerge. The workforce is also the same. The industry is highly suffering from a lack of workforce to carry out the work, even at the current slow level of progress. According to the Industry Strategy Council, the building and construction industry suffers the most due to a lack of skilled workforce, which is 22% (Industrial Strategy Council, 2019). In order to bring 26.2 million houses to EPC C rating, there will be a need for 260,000 new workers and 230,000 indirect workers. Another 223,000 existing workers to be further trained (Brown & Bailey, 2022).

Although the other problems are solved, without a strategic focus with proper management and leadership, housing retrofit may not move on. Luckily, there is a considerable level of enthusiasm can be observed in the government (Skidmore & McWhirter, 2023). Local authorities show a satisfactory interest in housing retrofit projects under the government grant funds (Local Partnerships LLP, 2021). Some local authorities have failed to run these projects (Heath, 2022) and some setbacks were observed with the wrong approaches to national-level retrofit drives (Panakaduwa et al., 2024b). In general, management and leadership have shown a level of responsibility and enthusiasm to promote housing retrofit.

Technology, finance, supply chain, workforce and management and limited homeowner demand are challenges to drive retrofit at the national level. Arguably, if the homeowner-limited demand challenge is properly managed, the other challenges will be easier to manage through the demand. According to the demand curve, the price increases when the demand increases subject to the supply remaining the same. According to the supply curve, when the price increases, the supply also increases if the price remains the same (Pinkasovitch, 2023). It can be argued that if there is a right demand for retrofit, supply chain problems and workforce shortages will be solved. Further, the supply chain and workforce can be imported.

Housing retrofit will not happen without the consent of the homeowner (Liu et al., 2024). It can be argued that why retrofitting houses cannot be made a legal requirement by the government. The answer is that the people can change the government. The very reason that pushed the 2023 government to abolish minimum energy efficiency standard (MEES) laws, mandatory gas boiler phase-out and mandatory fossil fuel vehicle phase-out in 2035 (Sunak, 2023). The legal provisions may be used for the laggards segment of homeowners when 84% of the housing stock is retrofitted according to the diffusion of innovations theory (Rogers, 1983).

Considering the same, it is recommended to go for soft measures to promote housing retrofit by winning the hearts of the homeowners, not by forcing it on them. It is important to understand the homeowners’ retrofit decision-making behaviour and strategically plan the delivery of housing retrofit accordingly.

2.4. Homeowner decision-making behaviour

2.4.1. Introduction

As far as the decision-making in housing retrofit is concerned, several layers of decision-making can be understood. The research problem is positioned at the layer of homeowner decision-making in housing retrofit. This review will first understand how people make decisions to understand the decision-making behaviour of the homeowners in housing retrofit. Importantly, the review is about the decision-making by the homeowners, not the retrofit professionals. There is a whole different area of research about retrofit decision-making related to the technical aspects of retrofit, which is not focused on here.

Decision-making is a main part of life. People must make different natures of decisions with different levels of impact in their lives (Howard & Abbas, 2016). Some of this decision-making may not have a substantial influence on life. E.g., Buying medium-sliced bread or thick-sliced bread. Some decisions can have a strong influence on their lives. E.g., Getting married or buying a house. Apart from these personal decisions, there is decision-making in businesses, organisations or even at national and international levels. Considering the purpose of this study, decision-making at the individual level is focused.

Decision-making is difficult due to four reasons. One is the complexity level of the problem. Second is the uncertainty of the solution. Third is that working on one solution may hinder the progress of the others. Fourth is looking at the problem from different perspectives, which will lead to different conclusions. To make the decision-making easy, the process needs to be properly structured. First, identify the values of the decision maker and structure them. Secondly, structure the elements of the decision situation into a logical framework. Thirdly, refine and define the elements in the decision framework (Clemen, 1996). The quality of the decision is not reflected by the outcome. The outcome can be unlucky or lucky either, regardless of the quality of the decision. A quality decision is systematically arrived at, considering all the alternatives by analysing important information (Clemen, 1996; Howard & Abbas, 2016).

Problems are an inevitable part of people's lives. Problems can be classified based on their complexity, and the type of solution that is applicable (Spetzler et al., 2016). Simple problems are those that have a clear and straightforward solution. E.g., fixing a leaky faucet or deciding what to wear for the day. Complex problems are those that require a more intricate and involved approach. These problems often have multiple possible solutions, and finding the best option requires careful understanding and evaluation of different alternatives. E.g., deciding on a career path or retrofitting the house. All these problems require some level of decision-making workload.

One way to approach decision-making is through a rational perspective, where decisions are made based on a logical and systematic evaluation of available information (Spetzler et al., 2016). Rational decision-making involves identifying the problem, gathering, and analysing data, identifying possible solutions, weighing the pros and cons of each option, and selecting the best alternative based on a set of objective criteria (Howard & Abbas, 2016).

Decision-making is not always a purely rational process, and non-rational factors can also play a role in shaping decisions (Bolton et al., 2023; Ebrahimigharehbaghi, 2022; Todd & Gigerenzer, 2000). Emotions, biases, and intuition can influence our decision-making, even when people try to make choices based on rational decision making. Non-rational decision-making can be beneficial in some situations, such as when there is limited time or incomplete information. Heuristics can be used to arrive at productive solutions efficiently. It can also lead to errors, mistakes, and suboptimal outcomes (Todd & Gigerenzer, 2000).

2.4.2. Rational decision-making

One of the severe criticisms of housing retrofit policymaking is the overreliance on technical rational models. Several retrofit initiatives were reported to fail as they have only focused on the rational decision-making of the homeowners (Bolton et al., 2023; Panakaduwa et al., 2024b; Rosenow & Eyre, 2016). In reality, people do not seem to be making decisions 100% rationally. It is important to study the rational side of human decision-making to get the complete picture. As far as the rationality of decision-making is concerned, the following areas of literature in Table 10 were identified.

Table 10: Theoretical aspects of rational decision-making

Theory	Description
Bounded rationality	Limitations in being rational (Todd & Gigerenzer, 2000).
Generations theory	Different generations and their characteristics (Strauss & Howe, 1991).
Diffusion of innovation	How innovations are diffused in the society (Rogers, 1983).
Expected utility theory	Decision-making under uncertainty (Clemen, 1996).

2.4.2.1. Bounded rationality

When making decisions, humans make use of computational power, knowledge, and limited time for that. All of these resources are limited, and they have different levels of boundaries. This makes the concept of bounded rationality, as rationality has boundaries related to knowledge, time, and computations. In this case, people make decisions based on satisfaction, rather than perfect rationality (Kerr, 2018; Liu et al., 2021; Todd & Gigerenzer, 2000). Policymakers cannot interpret all the evidence for decision-making. In this situation, the aim relies on satisfactory outcomes, rather than optimal outcomes (Kerr, 2018). In the context of homeowners, they often make decisions based on heuristics and based on incomplete information due to the bounded rationality in the decision-making process (DellaValle et al., 2018).

2.4.2.2. Generations theory

There are four lifestyle stages of a person from birth to death. They are youth (0-21), rising (22-43), midlife (44-65) and elder (66-87). The experiences faced during their childhood are believed to shape the characteristics, traits, and personalities of their generations (Strauss & Howe, 1991). Table 11 gives a synthesis of generations according to two main literature sources.

Table 11: Generations (McCrindle & Wolfinger, 2014; Strauss & Howe, 1991)

	Generation	Period	Notes
1	Silent	1925 - 1942	Low birth rates
2	Baby boomers	1943 - 1960	Increased birth rates
3	Generation X	1961 - 1980	Work-life balance
4	Generation Y (Millenials)	1981 - 1995	Climate change
5	Generation Z	1996 - 2009	Social media
6	Generation alpha	2010 - Unspecified	-

Generation Y has their own needs and expectations. To attract them and make the best use of them for an organization, it is important to satisfy their needs and expectations. Usually, Gen X and Y people are highly self-confident, and they do not hesitate to ask questions if things are not clear. They need to make an impact on their job and are typically not motivated by money (Steiner, 2016). (Howe & Strauss, 2000) describe the millennials (Gen Y) as a generation with positive social habits, better conduct, well-educated, modest, achievement-oriented and prefers teamwork. Identifying these differences is important to plan behavioural interventions for different age groups (Strauss & Howe, 1991). Since Generation X, there have been different definitions and categorisations in the literature.

Identifying these characteristics of different generations shall help to determine the best strategy to approach these segments. For example, the best way to approach a homeowner of Generation X can be through email or text while approaching the person from the Baby Boomer generation can be through personal visits or letters. A person from Generation Y can be better approached through social media (Steiner, 2016).

A study conducted by (Liu et al., 2022), has noted that retrofit decision-making behaviour is influenced by demographic factors such as age. For example, younger homeowners are more likely to adopt energy efficiency measures. The study states that the results are not conclusive. (Huang et al., 2021) has found that elder homeowners are more reluctant to pay for energy efficiency improvements.

2.4.2.3. Diffusion of innovations theory

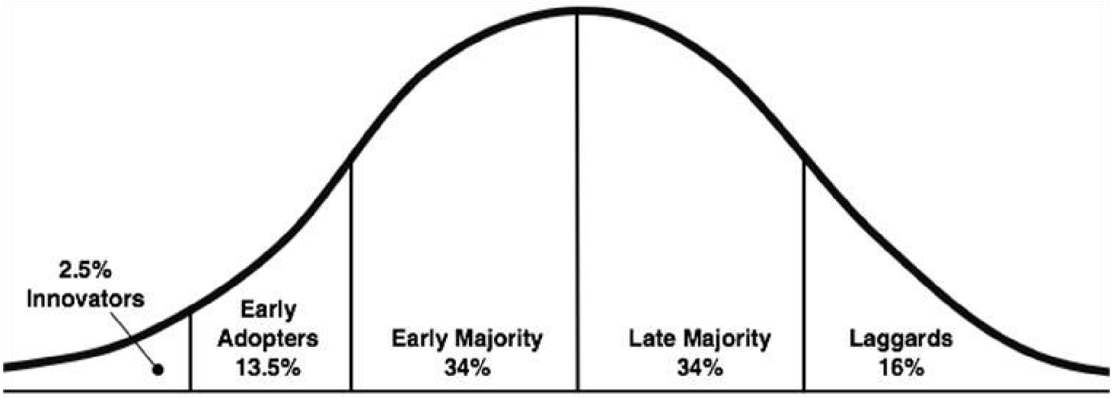

Figure 8: The curve of diffusion of innovation (Rogers, 1983)

The diffusion of innovation theory was proposed by Everett M. Rogers in 1962 in his book "Diffusion of Innovations" after a lot of publications about the topic. This theory proposes how general people will respond to an innovation, in terms of adoption. There is a normal curve assumed about the level of adoption of innovations (Rogers, 1983), which is shown in Figure 8. The following analysis has been done by adapting the theory to drive housing retrofit.

There are 2.5% of innovators who will instantly grab housing retrofit. Considering the UK housing stock, there will be around 750,000 households in this segment. They have the interest, financial capacity and appetite to take risks. They can be the homeowners who installed heat pumps as they were introduced the first. Considering the current level of heat pump installations, the UK does not seem to reach even half of the innovators so far (ONS, 2022; Rogers, 1983).

Early adopters also have some interest and capacity. But they take some time and thought. Mistakes can happen with this segment. Importantly, they need to be rectified. Because the other segments depend on the recommendations and testimonials of early adopters. There will be around 3.75 million households in this segment. The early majority do not have the same level of capacity as the previous groups. They may need financial assistance or borrowing. In this case, they will wait some time until the innovators and early adopters show some results. The technology, strategy, workforce, supply chain and all the resources need to be ready when this segment is addressed. There will be no excuses for mistakes. It is estimated that there will be around 10.25 million households in this segment and this will be the easiest segment to manage if the other segments are approached properly (ONS, 2022; Rogers, 1983).

The late majority have a highly limited capacity to adopt innovations and they are sceptical about the returns as they cannot afford to be unsuccessful. They will not be interested in retrofitting houses. Even if they are interested, it will be impossible for them to retrofit without government grants. They will have a neutral response to retrofit. There will be again around 10.25 million households in this segment. This segment will not be difficult to convince subject to government grants, regulatory measures and the majority of retrofitted houses. Laggards are the last group which consists of approximately 16% of the population. They will never look at housing retrofit positively, unless they are forced by the law. For example, (MEES) minimum energy efficiency regulations (Gov.uk, 2017; ONS, 2022; Rogers, 1983).

Simon Sinek says the most important group in these five groups are the early adopters, which consists of 13.5% of the population. Because there is nothing to concern about the innovators. The early majority is looking at the early adopters. Without the early adopters giving positive feedback, case studies and recommendations, the early majority and late majority will not go for it. Accordingly, early adopters are the most important group of people when driving innovations (Sinek, 2020).

(Mlecnik, 2010; UKGBC, 2021) have studied the importance of considering the diffusion of innovations theory in promoting housing retrofit. (Mlecnik, 2010) also has verified the problem of the homeowner’s stake in retrofit decision-making despite the availability of other resources required for residential retrofit. To stimulate the market segments, the relative advantage of retrofit, simplifying the complexity of retrofit, trialability and observability of the process as well as compatibility of the stakeholders are highlighted.

(Zaunbrecher et al., 2021) has highlighted the importance of the intermediaries of the retrofit process for driving sustainable housing retrofit. According to the diffusion of innovations theory, the intermediaries are acting as the early adopters in the retrofit process as their advice is highly recognised by the potential homeowners.

2.4.2.4. Expected utility theory

According to the expected utility theory, under a risky situation, people make decisions based on the expected utility and the risk of each option. The payoff of each option is uncertain and there are several possibilities. Expected utility is calculated by the weighted sum of these possibilities, multiplied by their respective probabilities. People choose the option with the highest expected utility (Clemen, 1996). E.g., There are two options to install insulation material A and material B. Material A has performance 10 and B has performance 8. The cost is the same. The probability of getting the intended performance of material A is 0.3 and it is 0.5 for the material B. The expected utility for material A is 3. (10 x 0.3) The expected utility of material B is 4. (8 x 0.5) Accordingly, material B is chosen as it has the highest expected utility.

Marginal utility is also applicable in this theory. When people expect higher potential gains, people change from risk-averse behaviour to risk-seeking behaviour. In brief, marginal utility improves the risk appetite (Clemen, 1996). E.g., A person with £100 will sell a lottery ticket for 500 with a 50% probability of winning £1000. But a rich person with £100,000 will not sell the same lottery for £500. Prospect theory assumes a non-rational decision-maker and the expected utility theory assumes a rational decision-maker (Ebrahimigharehbaghi et al., 2022b). This means, according to expected utility theory, people are indifferent about loss and gains. According to prospect theory, people are biased between loss and gain. They show a risk-averse situation for losses and risk-seeking behaviour for gains (Levy, 1992; Mittelstaedt, 2020). By adopting this into housing retrofit, it can be suggested that a homeowner is motivated to retrofit a house through loss framing (Li et al., 2023). For example, rather than talking about potential energy bill savings possible with retrofitting, talking about existing losses incurred due to not retrofitting the house can be more influential.

An empirical study has validated the applicability of expected utility theory in housing retrofit. Two homeowner groups were selected. One group was given comfort-weighted information while the other was given finance-weighted information. The comfort group has shown a willingness to adopt retrofit while the finance group has shown a negative willingness. This may be because of the unimpressive financial proposition of housing retrofit. This proves the need to communicate retrofit benefits from the perspective of comfort, avoiding financial benefits (Ossokina et al., 2021). The expected utility or value should be estimated accurately. For example, the overestimation of energy savings from retrofit measures and the need for accounting for the uncertainty were highlighted by academics when the failed 2013 Green Deal was introduced (Booth & Choudhary, 2013).

2.4.3. Non-rational decision-making

(Howard & Abbas, 2016) mention two types of decision-making; rational or emotional. According to Hoffeld (2016), emotions play a key role in the decision-making of the people. There is a famous saying that "People buy on emotions and justify with logic". Emotions are used to value things as good or bad by the brain. Although it is not purely emotions, there is another term coming under non-rationality as the relational aspect of decision-making (Bolton et al., 2023). The best way to name this is non-rational decision-making as emotions are not the only way of making decisions. For example, heuristics play a critical role in non-rational decision-making according to Todd & Gigerenzer (2000). Further, there is irrational decision-making. This signposts decision-making without any logic or even an emotional purpose. Non-rational means, there is a justification although this cannot be outlined as a rule (Simon, 1993). The theories listed in Table 12 are studied for this purpose.

Table 12: Non-rational decision-making theories

Theory	Description
Prospect theory	Explain how people value losses and gains differently (Mittelstaedt, 2020).
Heuristics	Mental shortcuts to make quick decisions (Todd & Gigerenzer, 2000).
Cognitive bias	Deviation patterns in human decision-making away from reasonable rationality (Ramos, 2018).
Social identity theory	The sense of a person belonging to a social group (Hatch & Schultz, 2004; Leaper, 2011).
Practice theories	Routine or habitual practices influence decision-making (Oerther & Oerther, 2018).

2.4.3.1. Prospect theory

The prospect theory explains consumer behaviour about losses and gains. Consumers do not experience these two in the same way. They are hurt more by the loss than by the pleasure of the same level. They feel more fear of loss than the appetite for the gain. This is called loss aversion behaviour (Levy, 1992; Mittelstaedt, 2020). The endowment effect comes with the prospect theory. According to this effect, people love what they already have over what they can possess. Due to this reason, they do not need to lose what they already have but take risks for gains that they can have (Mittelstaedt, 2020).

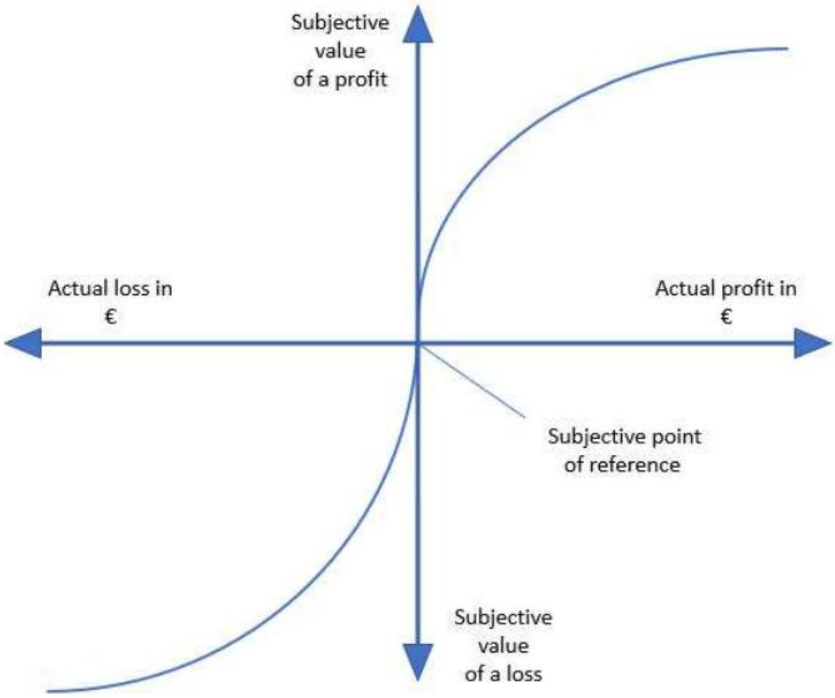

Figure 9: Loss aversion behaviour (Mittelstaedt, 2020)

According to Figure 9, as far as energy efficiency investments are concerned, there is a level of energy efficiency investments expected from homeowners due to the potential benefits. The actual energy efficiency investments are lower than the rationally predicted level. Research has empirically explained this gap using expected utility theory and cumulative prospect theory (Häckel et al., 2017). Further, (Ebrahimigharehbaghi et al., 2022a) have also studied the application of cumulative prospect theory in housing retrofit, compared with the expected utility theory. Although the expected utility theory provides a simple generalisation of homeowner decision-making, it was only able to correctly predict 48% of the homeowner retrofit decisions. In contrast, the cumulative prospect theory was reported to correctly predict 86% of homeowner decisions. Conclusively, homeowners show a rather non-rational behaviour in retrofit decision-making.

2.4.3.2. Heuristics

Issac Newton said, *"Nature is pleased with simplicity. And nature is no dummy."* (Steen, 2015). Simple heuristics can be used for decision-making when time is not a choice. Quantitative information can be avoided by using yes or no answers. E.g., If the blood pressure is below 91, the patient is at high risk. Further, rather than finding information, which is interconnected, a simple decision tree might be cheaper and quicker. E.g., If one item on a checklist is positive, that means the patient is in the high-risk category (Kahneman, 2011; Todd & Gigerenzer, 2000). Heuristics is required to make decisions due to the limitations suggested by bounded rationality. As time, knowledge and computational power are limited, the rationality of making decisions has boundaries. One way of making decisions in such a situation is making the most satisfying decision among a set of alternatives. The other way is fast and frugal heuristics. In this method, a simple yes or no type of checklist can be used without using complex quantitative calculations (Todd & Gigerenzer, 2000).

The System 1 thinking presented by Kahneman has focused on the heuristics in decision-making (Kahneman, 2011). Heuristics are highly affected by cognitive biases. In this case, decision-making under heuristics can be either beneficial or vulnerable depending on the context. System 1 & 2 thinking and cognitive biases are discussed in detail later in this chapter. (DellaValle et al., 2018) suggest that homeowners often use heuristics to make retrofit decisions. Poor technical awareness about the retrofit process and the benefits can be a reason for this. Another explanation is the non-rational decision-making behaviour of the homeowners in housing retrofit (Ebrahimigharehbaghi et al., 2022a).

2.4.3.3. Cognitive biases

The term cognitive bias was reported to be introduced by Tversky and Kahneman in the early 1970s. According to them, the deviation patterns in human judgement are called cognitive biases. They are the wrong inferences about other people or situations, based on irrational arguments (Ramos, 2018). According to Ellis (2018), when people use heuristics to make decisions without using rational judgements, they tend to make mistakes. These errors in judgements are called cognitive biases. Cognition can be identified as the process of transferring perceptions into beliefs. If the perception is wrong, the beliefs are also wrong. They would be making decisions thinking they are right, but they are wrong due to the cognitive biases which influenced their perceptions (Howard & Abbas, 2016).

People use cognitive bias for social engineering. Social engineering is termed as a method that can influence to change the behaviour of a person (Hadnagy, 2018). There are common four cognitive biases that impede the power of creativity in decision-making. They are the fear of taking risks, status quo bias, reality vs fantasy, judgement & criticism. People are risk averse, and they try to avoid risk. When there is at least one alternative that does not go with the status quo, people need to be creative in their decision-making. Finally, people have their own values which influence their judgement and criticism. That will make them less creative (Clemen, 1996).

Visualisation is one of the main functions of the brain. The visuals recognised by the brain are not exactly the things captured by the eyes. The brain synthesises the memories with the visuals captured by the eyes and tries to predict the situation or create meanings for them. E.g., If a soldier is on a battlefield, he would see a man with a stick as a camouflaged guerrilla with a gun (Barrett, 2020). The following Table 13 describes some of the key cognitive biases with examples.

Table 13: Examples of cognitive biases according to Hadnagy (2018)

	Principle	Description	Example
1	Reciprocity	Indebtedness is when a gift or favour received	You are given a toffee when going to a shop.
2	Obligation	Indebtedness under social norms	Allowing a motorist to merge in front of you in traffic.
3	Concession	First denial and second consent	Charity asked for higher donations and reduced lower which was their actual target.
4	Scarcity	Fear of losing something	No fuel in fuel stations will rush people to buy and stock fuel.
5	Authority	Confidence and prompt	Saying something straightforward to build up confidence.
6	Consistency and commitment	Being confident about what is saying	This cream will make you beautiful.
7	Liking	People like who likes them	I like your fashion, madam. You can buy a lot of them in our store.
8	Social proof	Proving that other people already trusted	These people are already using our service plan. Why don't you?

Antonio Damasio in 1996 proposed his Somatic Maker theory of decision-making. According to this theory, emotions can influence decision-making either consciously or unconsciously. Somatic makers are changes in the body or brain, which create emotions. The decisions can sometimes be driven by emotions without being rationally justified. A lot of cognitive biases can outperform at this level to divert the person from making a sound and rational decision (Ramos, 2018). The literature suggests hundreds of cognitive biases observed in human behaviour. It is exhaustive to list all of them. For a given situation, it is important to check what are the potential cognitive biases that can influence decision-making.

2.4.3.4. Social identity theory

People tend to group themselves with others based on various criteria such as religion, occupation, favourite football team or something else. With this division, they tend to identify their group and others differently. People try to find similarities within their group and differences among their group and other groups. This is termed as in-group (we) and out-group (them) in social identity theory. This theory was first introduced by Henri Tajfel and his colleagues in 1979 (Hatch & Schultz, 2004). Social identity is suggested as a bias when people are making decisions. People can be pushed to make decisions without evaluating facts, but purely based on the social identity they like to maintain. They prefer to be stuck in their group norms. Ideas of the other groups are viewed as threats. These reasons influence rational and impartial decision-making (Leaper, 2011).

If there are people with pro-environmental behaviours in a neighbourhood, that makes others positively engage with energy efficiency and retrofit. This also goes in line with the concept of place attachment as the residents are attached to their homes and neighbourhood (Cinderby et al., 2021; Fransman & Timmeren, 2017). (Bartiaux et al., 2014) point out the presence of retrofit professionals in homeowners' social networks. Homeowners can be influenced by these social networks. In general, the social identity theory was not directly referred to in most of the literature. The idea of social identity theory was observed abundantly. For example, (Akhatova & Kranzl, 2022; He & Qian, 2023; Pardalis, Mahapatra, et al., 2021).

2.4.3.5. Practice theories

Practice theories provide a useful way to understand how everyday activities impact social life and societal change. These theories have been applied to various social phenomena such as consumption, work, health, and environmentalism. Bourdieu's theory of practice highlights the significance of habitus, a set of dispositions and embodied practices that influence individual and collective behaviour. This is a broader concept than the concepts of individual agency and social structure, which were told to be shaping human decision-making behaviour previously (Oerther & Oerther, 2018). The theory proposed by Theodore Schatzki highlights the significance of viewing social practices as the fundamental component of social existence, rather than being centred exclusively on individuals or establishments. According to this view, social practices serve as the foundation of social life since they entail a complicated interaction among material, social, and cultural elements (Loscher et al., 2019).

Anthony Giddens' sociological framework of structuration highlights the relationship between social structures and individual agency in shaping social life. Giddens posits that social structures are both the means and results of social action and that they are continually being created and changed through human agency (Chatterjee et al., 2019). The overall idea of practice theory is that human behaviour is highly influenced by daily practices and habits. As logical thinking and emotions influence behaviour, daily practices also influence behaviour alike. People prefer to do things in the same way as they are used to do.

(Karvonen, 2013) argues that the existing rule-based retrofit programs are not effective. He proposes to use a practice-based approach through community partnerships. Theoretically, current retrofit approaches focus on the structure, while the author recommends focusing on social practices. In agreement with (Gram-Hanssen, 2014), (Judson & Maller, 2014) also criticise the current technical and rational models of promoting housing retrofit. They recommend retrofit interventions focusing on the everyday life of the homeowners under social practice theories.

2.4.4. Homeowner behaviour in housing retrofit

One way of understanding explicit human behaviour is through their decision-making. The decision-making can be identified under rational decision-making and non-rational decision-making. People make rational decisions based on available information. This includes understanding the problem, collecting information, identifying alternatives, evaluating the alternatives using information, and making the decision. According to the expected utility theory, people try to maximise their utility when selecting the best alternative. Multi-criteria decision-making methods can be used to evaluate the alternatives. The concept of bounded rationality argues that the rationality of decision-making is limited. Especially, there are limits to collecting and evaluating information. Practically it is difficult to be 100% rational.

Although not directly related to decision-making, some models and concepts are useful in understanding decision-making. For example, the diffusion of innovation theory proposes how a new idea is adopted by the general public. Generations theory proposes different characteristics and values of people born during specific times. These are valuable in understanding the decision-making behaviour of the people. In brief, information seems to be the key player in rational decision-making. To improve the quality of decision-making, quality and timely information is the main requirement.

On the other perspective, non-rational decision-making does not depend on the availability or quantity of information. It is based on the subjective judgment of the individual. There are theories and concepts to understand the behaviour of a non-rational decision-maker to predict and influence the potential decision to be made by the individual.

Other two important concepts in non-rational decision-making are practice theories and social identity theory. Practice theories propose that the behaviour of an individual is shaped by their routine practices. Social identity theory proposes that the social relations of the person influence individual behaviour. As the decision-maker's behaviour is influenced by different factors as mentioned above, it is important to understand them for behavioural changes.

Apart from the individual differences in decision-making, there are different behaviours of the brains of males and females. Men usually concentrate on one thing at a time while women can engage a lot of things at the same time. Men can make sense of spatial things more easily while women are not. Men tend not to speak a lot and do not expect lengthy reactions. Women try to communicate a lot and expect a lot of intuitive communication. Men prefer short wordings while women prefer a lot of vocabulary (Pease & Pease, 2001). These differences are important to note in terms of behavioural change interventions.

In brief, unlike rational decision-making situations, non-rational decision-making is difficult to model systematically. Accordingly, motivation is a key factor in influencing decision-making behaviour according to the COM-B model (Michie et al., 2011). By synthesizing the characteristics of non-rational decision-making with motivational theories, the decision-making behaviour can be intervened.

It is to be noted that an individual is not totally rational or non-rational. Rationality and non-rationality share decision-making behaviour in different combinations. The combination of these two depends on several factors including the demographics of the decision-maker. Examples can be drawn as availability of information, reliability of information, social background, daily practices, generation, personality, or persuasion. Bourdieu calls this "the habitus", which is the complex background of the decision-maker, including both the agency and the structure (Oerther & Oerther, 2018; Saffari & Beagon, 2022).

2.5. Addressing limited homeowner interest through behavioural changes

2.5.1. COM-B model for behavioural changes

The model was developed by a British academic, Susan Michie of University College London. In the COM-B model, "C" refers to capability, "O" refers to opportunity and "M" refers to motivation. They influence the target behaviour "B" (Michie et al., 2011). COM-B model is a similar approach to Fogg's behaviour model (Fogg, 2009). Although Fogg's model is popular in the business context, the COM-B model is widely observed in academia. They both show relatively the same criteria which influence target human behaviour. The prompts in Fogg's behaviour share a similar idea to opportunity in the Com-B model. Motivation and capability are self-explanatory. The COM-B model was chosen in this study due to the higher academic rigour.

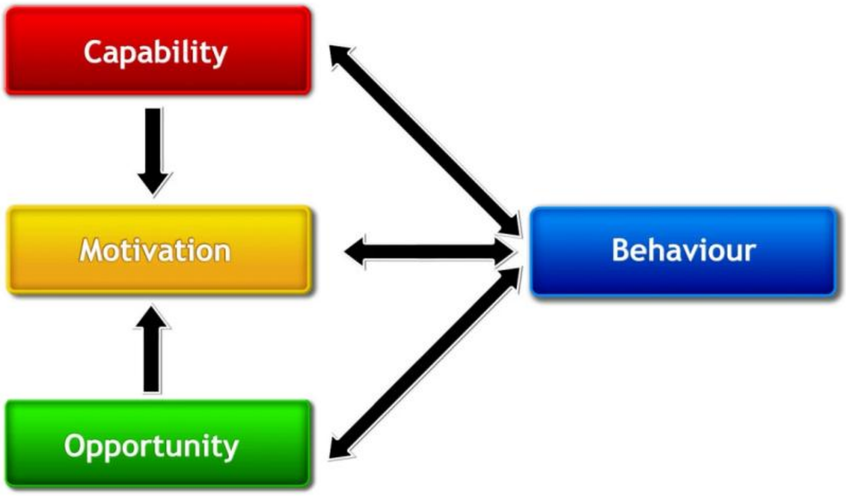

Figure 10: COM-B Framework of behavioural change (Michie et al., 2011)

According to Figure 10, the capability, opportunity and motivation shall lead to a target behaviour under the COM-B model. Capability can be either physical or psychological (Michie et al., 2011). When it comes to housing retrofit decision-making, this can include the homeowner's knowledge and awareness about housing retrofit. Although the homeowners could decide to retrofit the house and have the financial capability, they need to have an opportunity. This includes factors such as the availability of technology, supply chain, finance, workforce, information, culture or government grants. Motivation is the psychological influence to satisfy a motive (Kotler & Armstrong, 2018). Even if the homeowner has the capability and opportunity, if there is no motivation to retrofit their houses, the action will not happen. For example, most of the homeowners (59%) believe they live in a better-performing house and there is no requirement to retrofit their house, although it is otherwise in objective evaluation (Lewis, 2023). In such a situation, there will not be a motivation for a homeowner to retrofit their house. The motivational challenges of housing retrofit shall include disruption, poor reputation of retrofit, unintended consequences or poor regulatory incentives (Joanna Hale, 2022; Panakaduwa et al., 2023). By putting all these three together, the action of retrofit can be expected.

2.5.1.1. Capability building of homeowners

Undertaking housing retrofit is a challenging task for a homeowner due to the existing fragmented nature of the housing retrofit industry (Brown, 2018). The decision to retrofit a house comes with a certain level of requirements for the capability of the homeowner. Some of these capabilities can be identified under decision-making, financial, technical, management, problem-solving and mental domains. (Joanna Hale, 2022) suggest the main capabilities are with information and awareness. An information system shall help capacity building of the users apart from being human centred and focusing on user experience (Panakaduwa et al., 2024a).

An information system itself will not build the financial capability of a homeowner. It will be helpful for a homeowner to understand their financial capability. This can be either assessing the eligibility for loans or government grants. The technical capability of the homeowner is required to a certain level to understand the retrofit process and benefits. An information system can simplify and present this information more efficiently and cheaper to the users (Duah & Syal, 2016). Managing a retrofit project will not be the main responsibility of a homeowner. They will have to manage their lifestyle and disruption in line with the retrofit. This needs some skills and capabilities. An information system shall help homeowners to be informed and updated about the project.

Another requirement is the capability for problem-solving. A project is a temporary and unique endeavour with defined objectives (PMI, 2017). When the homeowner is associated with a retrofit project, there can be problems where their intervention is required. Apart from all, the challenges during a retrofit project can be stressful to a homeowner. They need to have sound mental capabilities to face them. An information system shall make housing retrofit information simpler and clearer for easy digestion by the homeowner, which will help to improve awareness and collaboration. Overall, an information system shall support the homeowner in better decision-making (Elaine et al., 2014). Arguably, these things can also be supported with human contact. That would be expensive, less efficient and poor consistent (Ebrahimigharehbaghi, 2022; Seddiki et al., 2021).

2.5.1.2. Opportunity through an information system

One of the main advantages expected from an information system for homeowners is to provide an opportunity to engage with housing retrofit. This can be viewed from different perspectives such as awareness, assessment, engagement, management or evaluation. Most of the homeowners (59%) in the UK believe that they live in a satisfactorily energy-efficient house. They live in poor energy-efficient houses, which are rated "D" or below according to the EPC report (Lewis, 2023). They do not have an idea about the benefits of a highly energy-efficient house. An information system shall allow them to understand the energy efficiency of their houses and compare them with the others. Further, the homeowners can be allowed to be aware of the overall benefits and process of housing retrofit through an information system.

Apart from this, the homeowners will have the opportunity to engage with the other stakeholders of housing retrofit with the help of an information system (Elaine et al., 2014). This can include, engaging with the banks to explore funding opportunities, engaging with grant agencies to explore government grant eligibility, engaging with designers and project managers to understand retrofit measures, retrofit process and their benefits and engage with installers to find out the costs. The homeowner can also be allowed to engage with the project management of the retrofit project. According to the stakeholder engagement matrix (Johnson et al., 2008), a homeowner can be identified as a high-power, high-interest stakeholder, who needs to be kept closely engaged. Further, information systems may also be helpful in the retrofit evaluation process to minimise the requirement of a retrofit evaluator to frequently visit the property.

Due to the fragmented nature of the housing retrofit industry (Brown, 2018), the homeowners do not get the chance to easily evaluate their housing retrofit options. In this case, an information system can be helpful for homeowners to evaluate housing retrofit options efficiently. The capabilities of the existing information systems for this purpose are further investigated in subsequent sections.

2.5.1.3. Motivating homeowners to retrofit their houses

According to a study conducted in the Netherlands, the decision-making behaviour of the homeowners in housing retrofit can be better defined with the cumulative prospect theory, which assumes a non-rational decision-maker (Ebrahimigharehbaghi et al., 2022a). Whether the decision-making is rational or non-rational, motivation has a clear role to play. It is difficult to understand how homeowners are motivated to retrofit their houses. The housing retrofit decision-making behaviour contrastingly differs from one homeowner to another (Bolton et al., 2023). The use of motivational theories can be helpful to understand and predict how the homeowners are motivated. Some homeowners prefer to engage in person while some homeowners prefer online platforms (Rodrigues et al., 2020). The Homeowners are more likely to be persuaded to retrofit their houses through their social networks and neighbourhood (Chen et al., 2023; Kerstens & Greco, 2023; Saffari & Beagon, 2022). Considering the same, it can be recommended to avail a level of human engagement even with the presence of an information system. A hybrid approach with both an information system and a social system may work better.

Motivational theories suggest different dimensions to understand the motivational behaviour of people. This can be useful in determining the strategy for motivating homeowners. Starting with the basics, the instrumentality theories suggest carrot-and-stick methods, although they are not well-received nowadays (Armstrong, 2006). For example, government grants will be a prominent eye-catcher which will motivate people to retrofit their houses. Further, regulatory measures such as carbon tax, high council tax or minimum energy efficiency standards can be considered as punishments for not retrofitting houses (Panakaduwa et al., 2024b). The importance of government grants and incentives is widely recommended in the literature.

Another important branch of motivational theories is need or content theories. One of the most popular theories is Maslow's hierarchy of needs. They are physiological, safety, social, esteem and self-actualisation needs (Armstrong, 2006). Housing retrofit can be attributed to all the first four needs. Comfortable heating or cooling is clearly a physiological need. Safety applies to the 29 risks under (HHSRS) Housing Health and Safety Risk System (Legislation.gov.uk, 2004). When neighbours have a better-retrofitted house, homeowners will also be interested in getting their house retrofitted (Bolton et al., 2023; Leaper, 2011). Further, esteem needs also can be attributed to a high-performing house. A homeowner in a well-retrofitted house can become a messenger of retrofit in their social networks (Ebrahimigharehbaghi et al., 2022c; Zaunbrecher et al., 2021).

There are further process theories in motivation. For example, expectancy theory or goal theory can be considered. When there is an expectancy for a better-performing house, homeowners will be motivated to engage in housing retrofit. Goal setting theory suggests having an achievable goal which will motivate people to pursue these goals (Armstrong, 2006). An information system will show homeowners what a high-performing house looks like, creating an expectation of a better quality of life. Further, it will be able to set achievable goals of reaching a high level of energy efficiency. This was observed with the housing retrofit decision support system "Snugg" (Snugg, 2022). The system motivates and encourages homeowners to contact installers and install retrofit measures one by one. It sets achievable targets and follows up the user through the retrofit process, facilitating required information and support.

2.5.2. The What, How and Why approach to the problem

The research problem is the limited interest of UK homeowners to retrofit their houses. The research aim is to encourage homeowners to retrofit their houses through an information system artefact. The problem is influenced by various factors, including financial barriers, lack of awareness, and the complexity of decision-making processes. To address this multifaceted challenge, a structured framework such as the Golden Circle by Simon Sinek offers valuable insights into the underlying causes and potential solutions. Following table 14 shows the concept of Golden Circle concept. There is another concept called five “W”, where the origin is unknown but commonly used. However, the Golden Circle concept was used considering the better applicability to the context.

Table 14: The Golden Circle by Simon Sinek (Sinek, 2011)

	Introduction	Description
What	Retrofit outcome	The homeowners will need to know what is the scenario after retrofitting. This will include factors such as benefits, risks, case studies or costs.
How	Retrofit process	The homeowners will need to know how this retrofit process happens. What to expect when and who will do it.
Why	Justification	Why they should retrofit their houses?

First, the homeowner needs to be made aware of what is retrofit. Then how this retrofit process works. According to Sinek (2011), the most important point is “Why”. The homeowners need to be convinced why they should retrofit their houses. In a situation of encouraging the homeowners to retrofit their houses, arguably these three questions need to be answered.

2.5.3. Intuition for an information system

The UK needs to retrofit their housing stock to achieve climate change goals. Further, retrofitting houses is not only about climate change. It includes improving the health, comfort, safety, aesthetics and overall quality of life of the residents. Further, it ensures the energy security of the UK and reduces fuel poverty.

Considering the nature of the problem, cause and effect are clear in the problem of what is retrofit and how to retrofit. This can be identified as a problem of information deficit, as rational decision-making can be supported with information. This a complicated problem under the Cynefin framework, which can be addressed with expert knowledge (Snowden & Boone, 2007). Information can be sourced from different stakeholders of housing retrofit, which can be easily done in digital formats. According to Coulentianos et al. (2024), data and data modelling play a critical role in retrofit decision-making. An information system can solve this problem by modelling this information according to the user requirements.

The problem of “why retrofit” will not have a clear cause and effect as the information deficit does. It will be difficult to understand how people justify decisions. Different people have different personal values. The action of retrofitting houses is proposed to be influenced by capacity, opportunity and motivation according to the COM-B model (Michie et al., 2011). According to the Cynefin framework, this is ideally a complex problem which the cause and effect is not clear (Snowden & Boone, 2007).

When it comes to addressing the problem of limited homeowner interest in housing retrofit, stakeholder engagement also plays a critical role. If these stakeholders are not effectively managed, that can lead to various issues and the projects can face severe risks. A successful project manager shall manage the stakeholders well over the project lifecycle (Chinyio & Olomolaiye, 2010). The current nature of the retrofit industry does not provide an opportunity for homeowners to obtain the information in a user-friendly, efficient, and cost-effective manner. According to McGinley et al. (2020), this is because of the current fragmented industry culture where different information is available with different stakeholders in the retrofit process.

By summarising the above, it can be argued that the solution to the problem can be a collaborative stakeholder engagement model where the parties can get together. In this model, information deficit (what is retrofit and how to retrofit) and limited homeowner interest (why retrofit) problems are to be addressed. It can be further argued that the information deficit and stakeholder engagement can be satisfactorily addressed with a digital platform, ideally as an information system which helps homeowners evaluate housing retrofit decisions. There is a concern about how to address the “why retrofit” problem. This may be better addressed with humans. An information system can help humans to deliver retrofit advice effectively and efficiently. The subsequent empirical studies will further evaluate the potential of an information system to address the research problem.

2.5.4. Recommendation for a socio-technical system

Socio-technical systems focus on the interactions between the social system (people) and the technical system (technology) of an organisational setting. The early idea of the theory was to achieve both job satisfaction and business performance (Appelbaum, 1997; Morgan & Liker, 2006). The theory was later used in designing optimal information systems. The designers should focus on the user needs and the complex environment around the users when designing the systems. This includes the people, processes, and technology as well as the goals, culture and infrastructure (Leeds University Business, 2023). The need to think of retrofit from a socio-technical system perspective has been noted by (Swan, 2013). The role of the homeowner in a socio-technical system of housing retrofit has been highlighted by (Galvin & Sunikka-Blank, 2014). In general, housing retrofit is a complex process involving technology, society and several other stakeholders (Galvin & Sunikka-Blank, 2014; Vergragt & Brown, 2012). In achieving the objectives, both the technical system and the social system need to be optimised to achieve their objectives together.

In simple terms, housing retrofit can be viewed from two perspectives. One is through the lens of the house and the other is through the lens of the homeowner. Considering housing retrofit under the socio-technical system theory, these two perspectives can be defined under the technical system and the social system. Neither the house nor the homeowner can be compromised. From one perspective, the housing retrofit shall be technically robust. On the other perspective, the homeowner’s interest needs to be cared for, including the social system to which the homeowner belongs. The social system is mainly useful to motivate the homeowner through social relations. This includes disseminating the message of housing retrofit, building confidence, providing examples or influencing through cognitive biases.

An information system shall be designed as a socio-technical system, by addressing user requirements, while catering to the broader requirements of promoters. For example, the system shall allow the users to evaluate retrofit options for their houses and to understand the process of housing retrofit. This will help the homeowners to enjoy a house with low energy bills, more comfortable and healthier. Meanwhile, society can achieve decarbonisation targets through the reduced environmental impact of the retrofitted houses. Considering these aspects, an information system is recommended to answer the research problem of limited homeowner interest in housing retrofit.

2.6. Digital one stop shop model for housing retrofit

2.6.1. Introduction

The traditional retrofit model is fragmented. Various parties to retrofit play their own role. The one stop model gives a single interface to the customer, eliminating the requirement of the homeowners to manage various building professionals and parties. The one stop model supports the smooth retrofit decision-making process. Retrofit one stop shop delivers tailored retrofit projects to suit the client's requirements (Brown, 2018; McGinley et al., 2020).

To answer the problem of industry fragmentation, the one stop shop model is recommended (Innovate, 2020; SEAI, 2022). (BPIE, 2021) identifies this as “TurnKey Retrofit”. This centrally coordinated stakeholder engagement model is becoming popular in the European context and has also reached the United Kingdom (Brown, 2018). A one stop shop is a digital or physical point of contact. The clients can find all the information and services about their housing retrofits in this single point of contact (Innovate, 2020; McGinley et al., 2020).

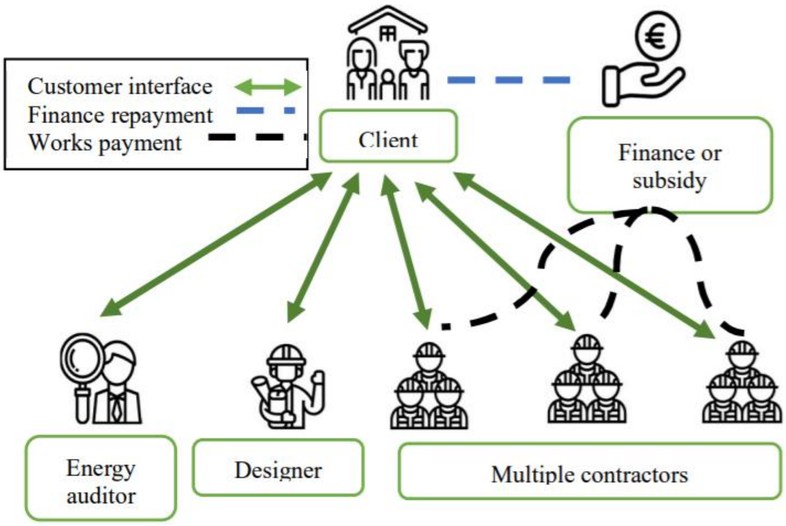

Figure 11: Existing fragmented model (McGinley et al., 2020)

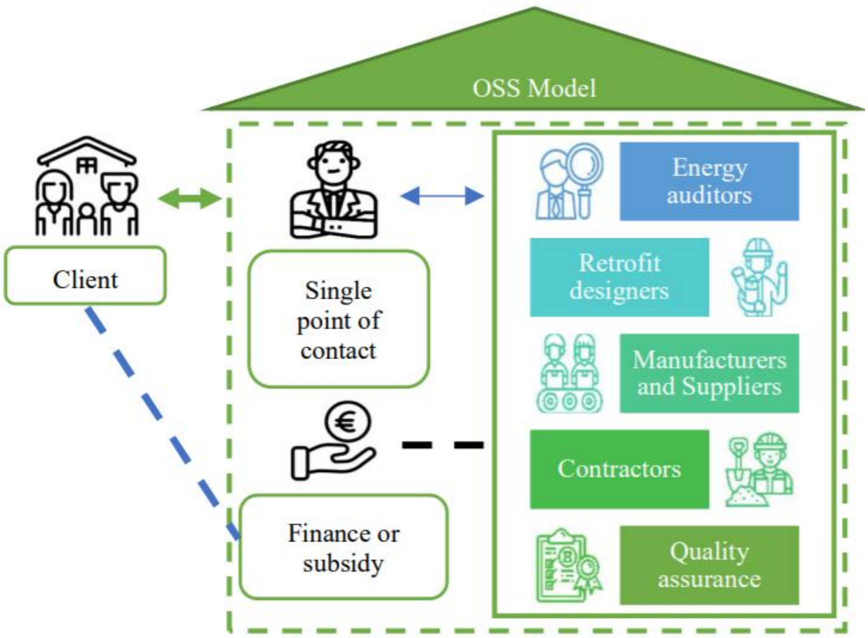

Figure 12: one stop shop model (McGinley et al., 2020)

The above Figure 11 and Figure 12 show the existing fragmented model of housing retrofit and the one stop shop model of retrofit. A one stop shop stakeholder engagement model has been introduced by (Innovate, 2020). It describes four models of how a one stop shop can engage with the stakeholders. These four models of one stop shop distribute the cost from lowest to highest. When the cost increases, retrofit support increases, and the uncertainty reduces. In another study, the Sustainable Energy Authority of Ireland also suggests the "One stop shop" stakeholder model for housing retrofit. This one stop process eliminates most of the doubts of the homeowner, including most of the hassles of retrofit works, while ensuring the expected outcomes (SEAI, 2022).

There are five potential business models in residential retrofit. First is the atomised mode, which is the fragmented approach of retrofit currently in place. Second is the market intermediation model. This is the model currently used in government grants. There is a level of interaction among the parties and usually delivers a single measure. one stop shop is the third model. The customer approaches the one stop shop which coordinates all the project parties. Energy services agreement is the fourth model. Apart from deliverables in a one stop shop, there is a guarantee of energy savings in this model. The managed energy savings agreement is the final model. Apart from the guaranteed energy savings, the model facilitator ensures the payment of the energy bill (Brown, 2018).

2.6.2. Potential of a digital one stop shop

Retrofit project delivery in the UK and Europe is also highly fragmented from the contract management point of view (Bertoldi et al., 2021; Brown, 2018). Most subcontractors involved in retrofit are installing only a few retrofit measures. For this reason, the clients will have to go for each retrofit sub-contractor to install the required retrofit measures (Mlecnik et al., 2012; Zuhaib et al., 2017). The main problem is the absence of a whole house approach. When the retrofit is approached without a whole house approach, it is doubtful whether the client will achieve the desired benefits from the retrofit (Simpson et al., 2015). For example, if the insulation is done without considering the ventilation or if a heat pump is installed without improving the building fabric first, the client will have a damper and colder house.

As this fragmented nature of the retrofit is further concerned, studies have found that the installers do not take the risk of a whole house approach due to various reasons. E.g., The hassle of engaging with a diverse range of installers or the responsibility taking of final retrofit benefits. These subcontractors prefer to do what they know the best. The ultimate outcome of all the retrofit measures is doubtful to be received by the client and there is no guarantee. In PAS 2035:2023 specification, most of these problems are addressed. It expects to reduce the risk to both the people and property, thus improving the stakeholder confidence in housing retrofit. Finally, the retrofit will be free from unintended consequences (BSI, 2023b; Rickaby, 2023).

As a response to this problem, researchers have recommended a more collaborative approach to housing retrofit (Ebrahimigharehbaghi, 2022; Mlecnik et al., 2012). PAS 2035:

2023 specification discuss the role of a retrofit coordinator, whose work includes retrofit advice, coordination and risk management. This specification prescribes the whole house retrofit approach and a proper risk management methodology. The retrofit coordinator collaborates with all the project parties and ensures the smooth flow of the retrofit process and information sharing (BSI, 2023b). After approaching the retrofit in the whole house approach and sequencing the retrofit measures, they can be installed by different installers one by one (Pardalis, Talmar, et al., 2021). This incremental phase-by-phase approach to retrofit has been recommended as some projects are not practical to complete at once due to resource constraints (Saffari & Beagon, 2022).

This one stop shop model approach is identified as a productive method to drive sustainable housing retrofit. With a single point of contact, the homeowner is managed from the decision-making to do the retrofit and to ensure the agreed outcomes are delivered. Further, the retrofit coordinator is supposed to handle the other stakeholders collaboratively to deliver the agreed outcomes of the retrofit (Innovate, 2020). This one stop shop model shares the features of the construction management procurement route (Brook, 2004). In the construction management procurement route, there is a single construction manager who reports to the client. The construction manager coordinates with the contractors and designers to deliver the project on behalf of the client.

British Standards Institution presented PAS 2035:2023 for the purpose of driving retrofit in the whole house approach under the supervision of the retrofit coordinator. Further, to obtain government subsidies, it is a must to appoint a retrofit coordinator and conduct the retrofit process under PAS 2035:2023 guidelines. All the installers should be PAS 2030:2023 certified under TrustMark, which is the government certified quality assurance scheme. This standardised approach seems to be more collaborative but still adapted to the current UK construction market conditions (BSI, 2023b).

The one stop shop model of retrofit can be the ideal model of stakeholder engagement in the housing retrofit (Pardalis, Mahapatra, et al., 2021). The one stop shop model and PAS 2030/2035 specifications can be promoted in harmony as they complement each other (UKEA, 2021). Further, in order to meet the challenges of a physical one stop shop (E.g., High cost, longer turnaround time, subjective bias of the advisors), a digital platform can be used for this purpose. According to Ebrahimigharehbaghi (2022), such a digital platform will present itself as more independent and impartial, which increases the homeowner's trust.

2.6.3. Outlining the general requirements

The proposed information system needs to consolidate some general requirements of different information system archetypes to answer the research problem. The literature review was helpful in identifying these characteristics. These archetypes of information systems can be given as one stop shop model, socio-technical system and decision support system. This section expects to outline the requirements of the proposed information system according to the given archetypes. Following Table 15 shows the concepts considered in the proposed artefact.

Table 15: Concepts considered for the proposed artefact

	Concept	Description
1	One stop shop model	Providing a single interface to the homeowner.
2	Socio-technical system	Engaging the homeowner, society and technology.
3	Decision support system	Supporting decision-making with information.

One stop shop model: Considering the problem of the fragmented nature of the housing retrofit industry in the UK, the literature has recommended the model of one stop shop, which provides all the information through a single interface. In general, the homeowner should be able to manage the whole housing retrofit experience with this single interface. The proposed system shall facilitate the homeowner with the convenience of a one stop shop for housing retrofit.

Socio-technical system: As far as the theory is concerned, the proposed system shall be an integration of the technical system and the social system of the homeowner. This means the system shall focus on both the technical aspects of housing retrofit related to the house and the social aspects of housing retrofit related to the homeowner. The existing systems related to housing retrofit are mainly for retrofit professionals to manage the technical deliverables of housing retrofit. They have not focused on an interface to the homeowner. Although there are some available systems to homeowners, their effectiveness is in question.

Decision support system: To answer the problem of limited homeowner interest in housing retrofit, the proposed system shall support the homeowners in learning what housing retrofit is, and the process of housing retrofit (how to retrofit). This is to address the problem of information deficit under a rational decision-making approach. Importantly, the scope of the proposed system is limited to decision support for the homeowners. It will not facilitate project management as there are existing systems available for that purpose. The system needs to be scalable enough to integrate with the existing project management systems to give the overall retrofit experience to the homeowners through a single interface.

Considering the above, an information system with the characteristics of one stop shop model, a socio-technical system and a decision support system is expected to satisfactorily answer the research problem. The capability of the system shall be limited to providing decision support to the homeowners. The proposed system will have to be integrated with a number of other systems to get the required information. For example, the recommendation of retrofit measures for a particular property and the sequencing of these measures.

2.7. Chapter conclusion

The research problem was identified as the limited homeowner interest in housing retrofit. The solution was outlined as an information system artefact. Considering the potential solution, the research aim was designed to encourage homeowners to retrofit their houses through the help of an artefact.

As far as the research problem is concerned, this is generally a practical problem in the UK context. As previously elaborated, due to the limited interest of the homeowners, there is no demand for housing retrofit. Due to the situation, although other requirements can be provided, housing retrofit will not show considerable progress since the homeowners do not show an interest in retrofitting their houses. Achieving UK net zero goals is doubtful due to the poor progress in decarbonising the residential sector. Further, the residential sector shows considerable issues related to their performance such as fuel poverty or poor health and comfort.

The theoretical relevance to the problem can be presented under the demand and supply theories as described in the housing retrofit challenges section in detail. Even if the supply side is strong, there will not be progress in the adoption of housing retrofit due to the poor demand from homeowners. The problem is expected to be addressed through behavioural changes and the COM-B model was selected for this purpose. An information system shall facilitate opportunities to engage with the retrofit for homeowners. Capabilities are to be improved with information and motivation provided through the social system of the housing retrofit.

The research problem of limited homeowner interest in housing retrofit will be answered by providing the answers to what, how and why retrofit questions of the homeowners. A digital one stop shop model information system artefact is proposed for this purpose. The literature review critically evaluated the existing lierature related to the factors affecting poor interest of the homeowners in housing retrofit, together with the relevant background areas to retrofitting houses. The next chapter is assigned for the research methodology.

3. CHAPTER 03: RESEARCH METHODOLOGY

3.1. Introduction to the chapter

This chapter describes the methodology of the research. It also expects to give an overview of the importance of research methodology and how this study has used design science research to achieve the research aim and objectives.

In the first section, the philosophical aspects of research are mainly discussed. Further, different research methods, data collection and data analysis methods are discussed. This is to understand the research in general. Secondly, design science research is studied as this research has used design science research as the methodology. The philosophical aspects and technical aspects of design science research are also discussed. The application of research methodology to this research is discussed next. Studies conducted for this research to achieve research objectives and justification of the methodological aspects are given in this section.

Finally, the research approach section outlines how this research has practically addressed methodological aspects including artefact development process. This has been mainly done with flowcharts, tables, and figures. The purpose of this section is to summarise the overall methodological actions for easy reference.

3.2. Introduction to research methodology

Research is defined as a process of obtaining knowledge systematically with the help of data to answer a problem or to improve the understanding (Hevner & Chatterjee, 2010). Research can be considered as answering knowledge questions and solving design problems. Knowledge questions are answered by empirical research with an empirical cycle. Design problems need to be addressed by design cycle with a validated artefact design (Wieringa, 2014). Traditionally, research was viewed as understanding a phenomenon that leads to creating knowledge, preferably as a theory. In design science, the phenomena can also be created fully or partly (Vaishnavi & Kuechler, 2015).

Research is a systematic study to develop or improve theory. In the case of design science research, this can be developing solutions for problems. Research attempts to bring two realities: theory and practice. Not all the theory in academia is applied in practice. The professionals in the practice seek more problem-solving nature theories (theories with utility). Accordingly, there is a gap between theory and practice where the design science seeks to fill in (Dresch et al., 2015). (Johannesson & Perjons, 2021) describe about two types of research. One is empirical research and the other is design research. Empirical research explains, describes, and predicts the world. Design research can also do the same. Design research tries to change the world or improve it by creating artefacts to solve problems and generate new knowledge.

Considering the above definitions of research, research can be concluded as improving systematic knowledge. General research is aimed at understanding the world. With the understood knowledge about the world, researchers try to change the world with innovation. Accordingly, general research plus creativity equals design research.

3.2.1. Philosophical aspects of research

Research ontology: According to Saunders et al. (2019), the ontology of research is how the researcher sees reality. What are the assumptions about the nature of reality? What is believed as truth by the researcher? There are many ontological views suggested in the literature. Saunders et al. (2019) describe the ontology as the research philosophy and state five ontologies. They are positivism, interpretivism, post-modernism, critical realism, and pragmatism.

Epistemology, axiology and methodology: While ontology is the nature of reality, epistemology is the nature of knowledge. Axiology is the nature of values (Vaishnavi & Kuechler, 2015). With regards to epistemology, one classification describes five knowledge types. They are definitional, descriptive, explanatory, predictive and prescriptive. Another definition classifies knowledge into three groups. Embedded knowledge, embodied knowledge, and explicit knowledge (Johannesson & Perjons, 2021). These are further described in subsequent sections.

When it comes to axiology, different researchers value different characteristics of research. In natural science research, the researcher will value the ability to generalise the theory to a universal level. In medical research, reliability can be more valued. In design science research, the researcher may highly prioritise the utility of the artefact or contribution to the knowledge.

According to Saunders et al. (2019), research design is best viewed from a pluralist point of view. There is no one best way of research design. Research philosophy addresses at least ontology, epistemology, and axiology, which are determined according to the research goal. The researcher decides the research methodology in a way that maximises the potential of achieving the research goal. Johannesson & Perjons (2021) identify the research methodology as a set of procedures and sequence of steps of the research. This includes the method for data collection, data analysis and structuring, research ethics and research process. The research methodology is further elaborated later.

3.2.2. Action research, experimental research and design science research

Action research and experimental research have similarities (Saunders et al., 2019). Further, Action research and design science research also have similarities (Johannesson & Perjons, 2021). It is important to know what the similarities and differences among these research methods are to better understand them. According to Saunders et al. (2019), action research is conducted in a particular context with regard to an existing problem. E.g., Poor efficiency in a company. Action research studies the context and makes changes (taking actions) to test how these actions contribute to solving the problem. According to Kurt Lewin, the pioneer of action research, action research has a four-step iterative process; planning, acting, observing and reflecting (Gogus, 2012). When generalising the knowledge about the taken actions, it is important to state the valid conditions and the tested context too. Generally, action research solves problems by making social, organisational, or psychological changes.

In contrast, design science research considers a practical problem in a broader context. The findings should be able to be generalised to a broader context. E.g., Poor efficiency in government institutes. Further, the problem should be addressed by creating an artefact. By comparing with action research, the design science context is broader and an artefact needs to be created rather than taking action (Johannesson & Perjons, 2021).

Experimental research and action research both take actions (interventions) during the process and the outcome is observed to generalise the knowledge. The basic purpose of action research is to create solutions for existing problems, while the purpose of experimental research is to understand the phenomena. In addition, action research is restricted to a specific context while experimental research tries to generalise the knowledge to a context as broad as possible. Further, in action research, the researcher is inside the context, while in experimental research, the researcher is an outside observer (Saunders et al., 2019).

3.2.3. Why design science?

(Simon, 1996) suggests the world is more artificial than natural. When the world is more artificial, he emphasises the requirement of science to describe these artificial phenomena. According to Dresch et al. (2015), traditional science is used to explain, describe and predict the environment. However, the purpose of science was not always to understand or predict the environment but to change it. The science of changing the world is the science of creativity, the design science. Human creativity is combined with the natural sciences, it is used to create new theories and to create artefacts to solve problems. There are man-made artefacts around the world. Not all of them are created under design science research. The purpose of academic research is to standardise the knowledge creation to make it more rigorous and relevant to the problem context (Hevner & Chatterjee, 2010). When there are problems that need to be answered with artefacts and to create the solutions in a systematic way, design science research is recommended.

The aim of this research is to develop an information system artefact to encourage homeowners to undertake sustainable housing retrofit. It is not just developing the artefact to answer “what” is required. It also required to describe “how” to do that and justify “why” it is done. In general, thorough academic research is required to justify each step of artefact development. According to the literature, design science provides clear guidelines to develop artefacts and contributes to knowledge in a systematic and well-tested manner. Design science is not the only way of developing artefacts and contributing to knowledge. It can be done even without reference to design science. When there is a well-tested and scientifically accepted pathway available, there is no need to develop a strategy from scratch.

3.3. Methodology of the research

3.3.1. Introduction

This section is dedicated to the methodology of the research. According to Johannesson & Perjons (2021), research methodology is considered as the relevant procedures, principles and practices required to conduct research. To identify these activities in the methodology, research onion concept by (Saunders et al., 2019) was used. The following subtopics are used to describe these sections under the research onion for this research.

It is important to highlight that the aim of this research is to encourage homeowners to undertake sustainable housing retrofit through an information system artefact. The research problem is the limited interest of homeowners to retrofit their houses. The problem is a practical problem for all homeowners in the United Kingdom with poor-performing houses. The homeowners do not know what is retrofit, why housing retrofit and how to retrofit their houses. This aim will be achieved by providing retrofit awareness, initial retrofit appraisal and an opportunity to go for a retrofit assessment. Further, homeowner behaviour and housing stock data are important to the government to make better policy decisions. According to Figure 13, the design science approach is helpful in this situation to systematically develop the artefact and to generalise the knowledge.

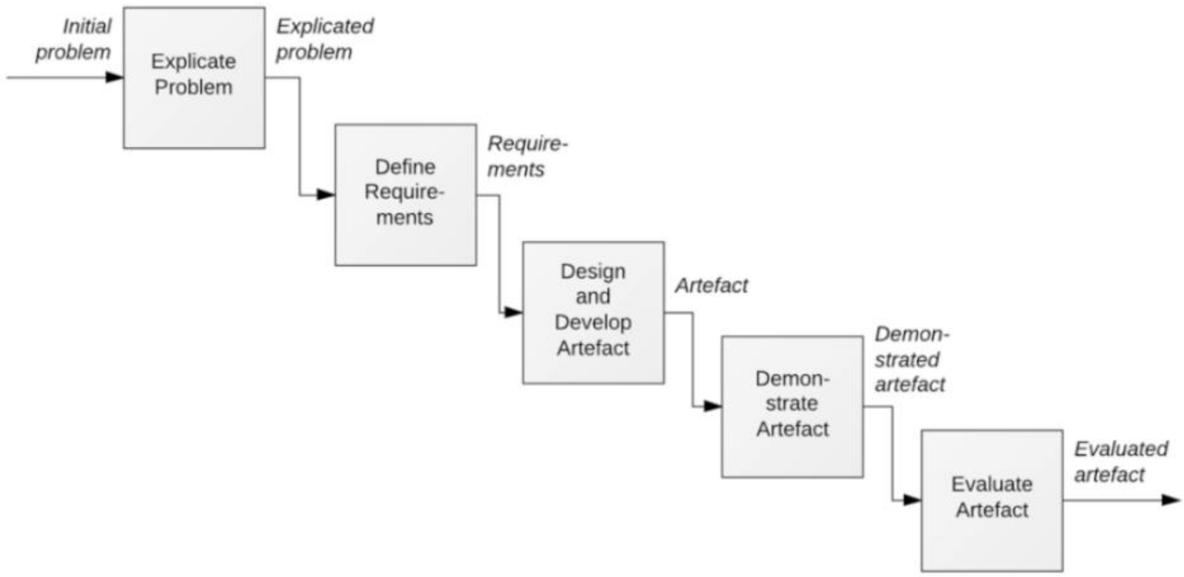

Figure 13: Steps in design science research. (Johannesson & Perjons, 2021).

The philosophical point of view differs from phase to phase of the research process. In this situation, it is important to understand the phases of the research. As the research is conducted under design science, the steps suggested by (Johannesson & Perjons, 2021) are considered for this research.

3.3.2. Adopted research philosophy

The following Table 16 shows how the philosophy of this research has been determined. The ontology, epistemology and axiology were considered in this case. The justification for the selection is given next to the table.

Table 16: Research philosophy summary

<table>
<tr><td rowspan="2">Ontology</td><td>What is truth?</td><td>How do researchers see the problem, artefact, and knowledge?</td></tr>
<tr><td colspan="2">Problem: Positivism and interpretivism

The surface problem is achieving sustainability. This is a general problem applicable to the world and it is viewed from positivism. The research problem is the limited homeowner interest in housing retrofit. This is ideally placed between objectivity and subjectivity, signposting to a typical design science research problem.

Artefact: Pragmatism

The effectiveness of artefact development can be measured according to their utility, which means to what extent the artefact is effective in solving the problem. This is viewed from pragmatism ontology.

Knowledge creation: Critical realism

Knowledge creation by design science uses a retroductive approach, looking at the root causes and designing solutions. This is viewed from the critical realism ontology.</td></tr>
<tr><td rowspan="2">Epistemology</td><td>What is knowledge?</td><td>The knowledge of artefact development</td></tr>
<tr><td colspan="2">The research uses design science knowledge to create an effective information system artefact by understanding the retrofit decision-making challenges of homeowners.</td></tr>
<tr><td rowspan="2">Axiology</td><td>What is value?</td><td>The potential of the artefact for practical use

Contribution to the body of knowledge.</td></tr>
<tr><td colspan="2">Artefact: The value of the artefact depends on the utility level of the artefact. How the artefact can be used practically.

Knowledge: The effectiveness and quality of the knowledge, which can be used for further applications in relevant domains.</td></tr>
</table>

There are a few problems under consideration in the research. The surface problem is sustainability. This is a general problem applicable to the world and it is viewed from positivism. The problem of lack of sustainability can be approached under the triple bottom line. Exploring further, the underlying problem was identified as the limited interest of the homeowners to retrofit their houses. Homeowners do not know what is retrofit, how to retrofit and why they should retrofit their houses. This can be presented as an information deficit and a lack of motivation. Coming back to the philosophical views, sustainability is explained with objectivity and individual homeowner behaviour is with subjectivity. The research problem of limited homeowner interest in housing retrofit comes in between.

According to Vaishnavi & Kuechler (2015), one of the main aspects of the artefact is its utility. Another important aspect of design science research is knowledge creation. Knowledge is created during all five steps in the design science research process as suggested by Johannesson & Perjons (2021). Design science research still can be successful although the artefact did not solve the problem, or it created further problems. While the utility of the artefact is viewed from pragmatism, knowledge creation of the research is viewed from critical realism. For this research, both the utility of the artefact and knowledge creation are important. To make a meaningful contribution to sustainability, the utility of the artefact should be adequately practical. Further, knowledge creation is also important for the generalisation of the findings and using the findings in other contexts and related problems.

According to Saunders et al. (2019), epistemology is the assumptions about knowledge. Dresch et al. (2015) identify design science as an epistemological paradigm. This is agreed by Vaishnavi & Kuechler (2015) as well. This research identifies several knowledge categories and forms. The research worked to collect explicit knowledge from journal articles, published reports, conference papers, books, news articles and websites. It also collected embodied knowledge of the people related to the problem for identifying artefact requirements and homeowner behaviour. The embodied knowledge was then converted to explicit knowledge and synthesised to design and develop the artefact. The artefact consists of embedded knowledge, of how to solve the explicated problem.

According to Saunders et al. (2019), axiology means what are the assumptions of the values of the research. The research values both the knowledge creation and utility of the artefact. Knowledge creation will help both academia and industry to move forward. The artefact will help to develop an information system to address the problem of limited homeowner interest in housing retrofit.

3.3.3. CIFE Horseshoe to present the research methodology

According to Figure 14, the research started with the research problem of the limited interest of the homeowners to retrofit their houses. An information system was proposed using the researcher's intuition. Theoretical point of departure includes many theories under different areas. Mainly, decision-making theories, design theories and other social science theories were used for this purpose. With this literature review, the need for housing retrofit and the potential for an information system was justified. The study was conducted as a design science research project. Accordingly, identifying the problem and the solution, collecting requirements, developing the artefact, artefact validation and contribution to knowledge can be identified as the general phases of the project.

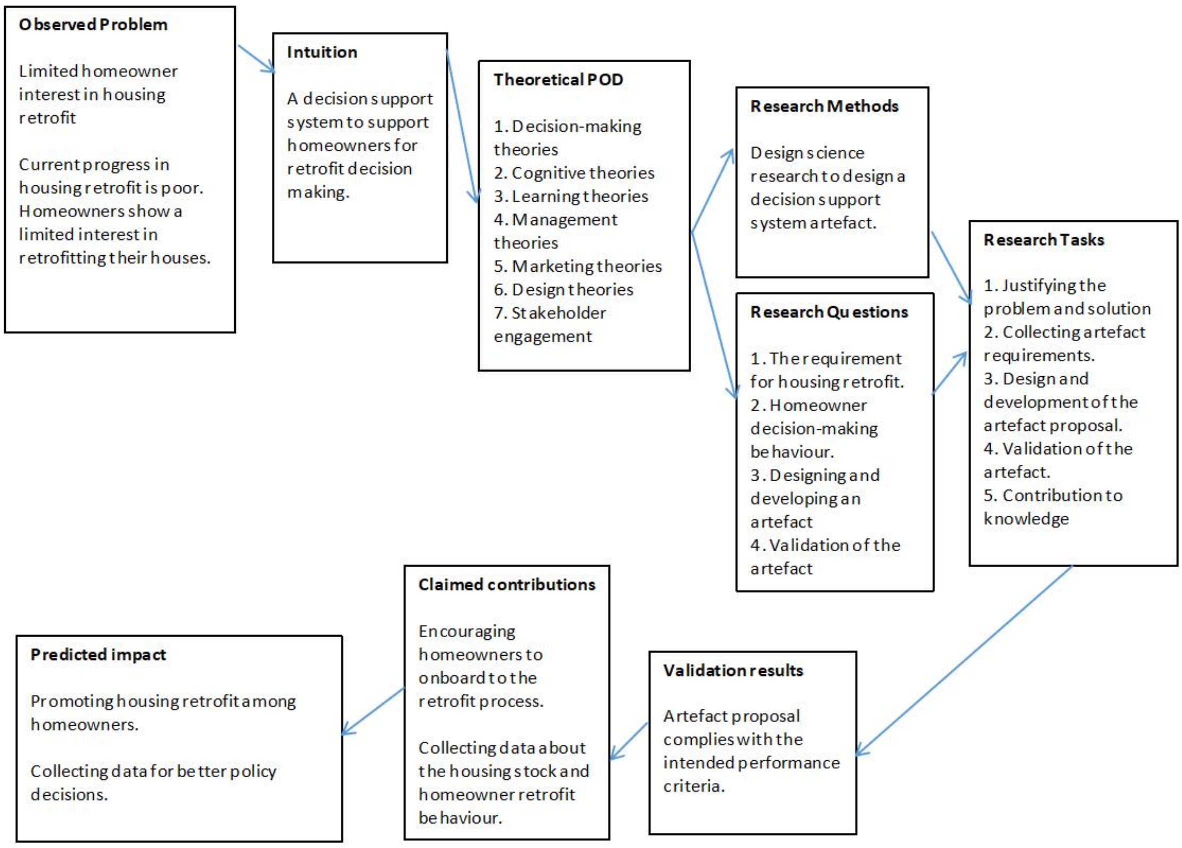

Figure 14: CIFE Horseshoe

The outcome of this research is an artefact for an information system to encourage homeowners to retrofit their houses by addressing the problems of what, how and why housing retrofit. It is expected that this system will promote housing retrofit in the UK. Even if the homeowners decide not to retrofit their houses after using the system, the system will be still beneficial. The government can source information regarding the characteristics of the UK housing stock and homeowner behaviour in housing retrofit. The government will be able to make better policy decisions to suit the situation with the collected information.

Considering the above, the proposed system will either onboard the homeowners to retrofit their houses, or it will collect information about the retrofit industry for better policy decisions. The research will not develop the system, considering financial and technical resource limitations. The research is to develop a high-level artefact for such a system as a framework.

3.3.4. Literature gap

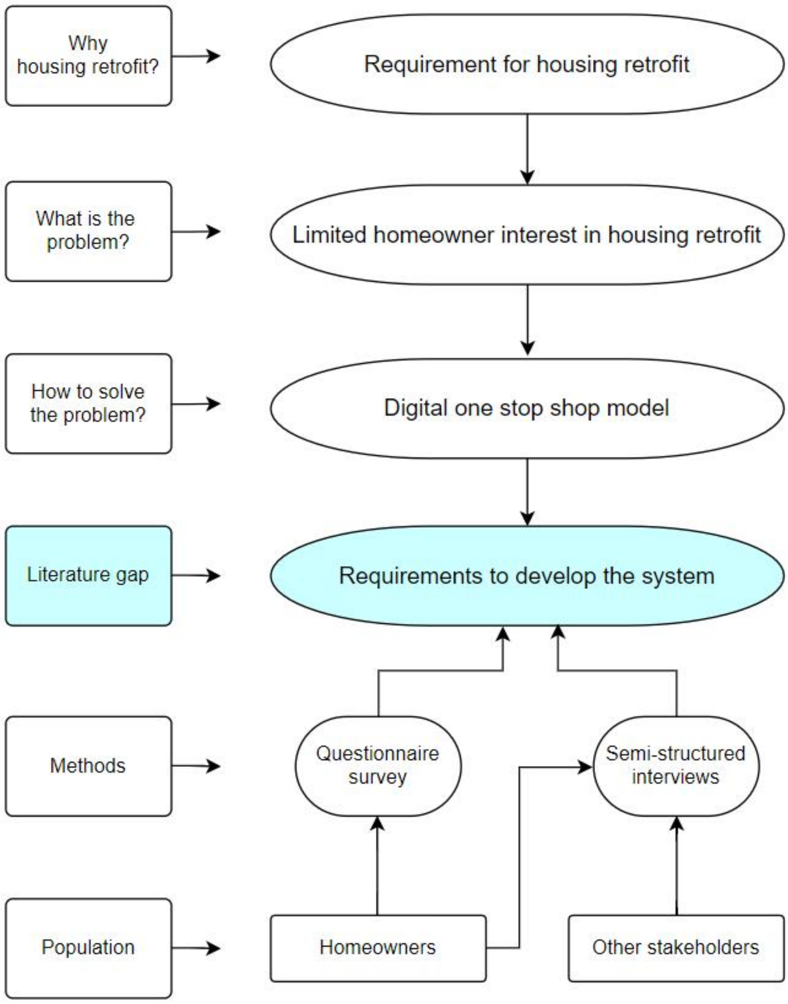

Figure 15: Literature gap

According to Figure 15, the first part of the literature review is to investigate why housing retrofit is important in the first place. Once the justification for housing retrofit arrived, the reason for poor progress in housing retrofit was identified as the limited interest of the homeowners to retrofit their houses. This is the research problem. The solution to this problem is determined as a digital one stop shop model, which was evaluated under the second objective. The research was able to progress up to this point with the available literature. The existing literature was not sufficient to develop the proposed solution. This was identified as the literature gap.

To fill the literature gap, the research focused on empirical studies. A questionnaire survey was conducted to understand the homeowner behaviour according to their demographics. Further, there were semi-structured interviews conducted with the homeowners to know what they would expect from an information system for housing retrofit. Further to this, there were semi-structured interviews conducted with the retrofit industry stakeholders. This was to collect requirements for the proposed system according to the views of different housing retrofit industry stakeholders. Semi-structured interviews were helpful in collecting data from the stakeholders. Further, semi-structured interviews ensured that all the required questions were covered while letting the participants be flexible in their expertise area.

3.3.5. Research approach

Design science uses existing research methods to achieve its purposes. The research onion concept proposed by Saunders et al. (2019) was used to present the methodological aspects, clearly and systematically. The concept is visually presented in the following Figure 16.

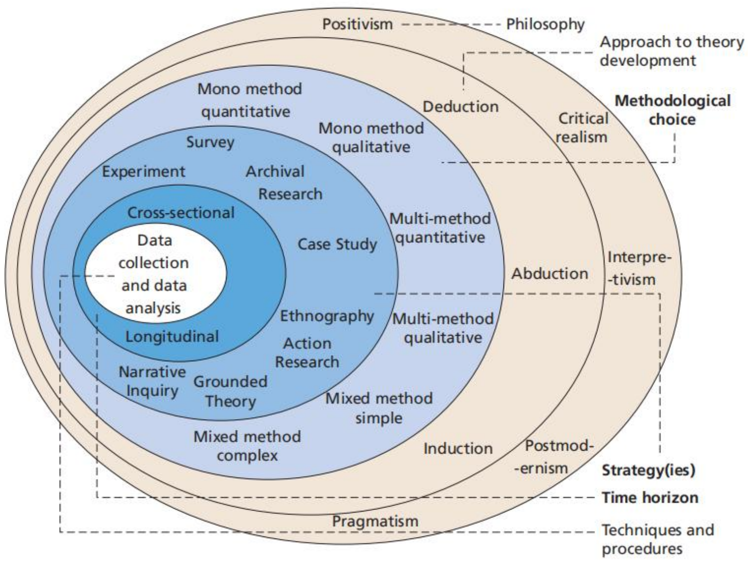

Figure 16: Saunders' research onion concept (Saunders et al., (2019)

The selection of the research philosophy was described in a previous section. According to Saunders et al. (2019), there are three research approaches inductive, deductive and abductive. As discussed previously, design science projects mainly consider the underlying problem and the root causes of the observable problem. The approach of mining for the root causes is considered retroduction. Retroduction is the process of removing what is not to be it is, to determine what it can be. The Five "Why" technique was used for this purpose in the introduction chapter. Retroduction is the technique used in the abduction research approach (Saunders et al., 2019). Literally, explicating the problem and deciding artefact requirements come from the abductive research approach. Artefact development and evaluation are approached under the deductive approach. The theory generalising is done under an inductive approach. A mixed method methodological choice was used as the data collection consists of both quantitative and qualitative studies.

Table 17: Justification of research methodology under the research onion concept

Research aspect	Selected strategy	Justification
Philosophy	Positivism, Interpretivism, Pragmatism, Critical realism	Positivism (Sustainability problem), Interpretivism (Decision-making behaviour), Pragmatism (Utility of the artefact), Critical realism (Contribution to knowledge)
Approach	Induction, Deduction, Abduction	The design science method uses abduction as the theory development approach. However, induction and deduction are also used at different points.
Methodological choice	Mixed methods	There is one quantitative study and further qualitative interviews apart from literature reviews
Strategy	Survey and case study	The strategy is best aligned with the survey and case study.
Time horizon	Cross-sectional	There are not any longitudinal studies in this research
Data collection/ analysis	Literature review, interviews and Questionnaires	Data collection is done through literature reviews, interviews, and surveys. Data is analysed quantitatively and qualitatively through statistical methods and thematic analysis.

The above Table 17 describes the adopted research methodology for this research according to the research onion concept. When it comes to strategy, it is unclear what Saunders et al. (2019) mean by the strategy. For example, a case study may contain a survey. Further, as the research onion is intended for business research, there is doubt to what extent these layers are applicable in design science. In general, this research wishes to define the strategy with case studies and a survey. According to Yin (2018), a case is a contemporary real-life situation where there is an unclear boundary between the case and the context. There is an in-depth analysis required to understand a case study. Further, both qualitative and quantitative data analysis methods are used.

According to the design science approach proposed by Johannesson & Perjons (2021), there are five steps; explicating the problem, artefact requirements, design and development, demonstration and evaluation. This research has followed this approach by aligning the data collection and data analysis parts. The first step is explicating the problem, which was achieved by a critical literature review. This has two sections: justifying the problem and finding a solution. Collecting the requirements was done by way of semi-structured interviews and a questionnaire survey. Table 18 shows how the design science steps are aligned with the conducted studies of the research.

Table 18: Stages of the proposed research and selected research strategy

	Design science step	Selected strategy	Justification
1	Explicate the problem	Literature review	The problem was identified, justified, and presented with an outline of the solution.
2	Define the requirements	40 Semi-structured interviews and a questionnaire survey	Artefact requirements were collected through semi-structured interviews conducted with retrofit industry stakeholders and homeowner behaviour was studied with a questionnaire survey.
3	Design and develop the artefact	Literature and empirical findings	The findings were used to design and develop the artefact.
4	Validation of the artefact	12 Semi-structured interviews and a Benchmark analysis	The artefact was validated by interviews with retrofit industry stakeholders. Compare and contrast the artefact with similar available systems.

Once the artefact requirements were gathered, the artefact was developed by using both the literature findings, questionnaire survey data analysis and semi-structured interview data analysis. Demonstration of the artefact can be identified as validation. The artefact was presented to the retrofit industry stakeholders as a hypothetical case study. The participants were asked to review the artefact against the intended outcomes under determined evaluation criteria. Semi-structured interviews were used for this purpose. The literature had suggested focus group interviews too for validation purposes. Due to the difficulty of gathering different stakeholders (12 numbers) at the same time, the focus group method was not used. This did not affect the rigour of the validation as individuals were presented with the case study separately and allowed them to review the artefact without any in-group bias.

Further critical discussion was done as a benchmark analysis by comparing the artefact with similar available systems in the UK. The evaluation step according to Johannesson & Perjons (2021) was not attended since the system is unable to develop due to the limitations of research scope and availability of resources.

3.4. Research design

3.4.1. Mapping objectives with studies

The four objectives of the research were aligned with the four design science steps of the research according to Johannesson & Perjons (2021). The final step of artefact evaluation was not performed as the artefact was not instantiated to a practical application. The following Table 19 shows the research objectives, aligned design science steps and the acticity related to the step.

The first objective is about the research problem. This was achieved by way of a critical literature review. Considering the scope of the problem and the availability of sufficient literature, the literature review was chosen as the data collection and analysis method to achieve the first two objectives. The second research objective is about the requirements of the proposed artefact. This was achieved with 40 semi-structured interviews and a questionnaire survey. A literature gap was found in this area. Although a certain level of literature was available, they were not conclusive in identifying the requirements to develop the artefact. Considering this literature gap, the requirements were gathered empirically through interviews and a questionnaire survey.

Table 19: Mapping objectives with design science steps

Objective	Design sceince step	Activity
Objective 01: To study the factors influencing homeowners' decision-making.	Design science problem	Critical literature review.
Objective 02: To identify the requirements for an artefact to support homeowner retrofit decision-making.	Requirements of the artefact	40 semi-structured interviews and a questionnaire survey.
Objective 03: To develop an artefact for homeowners to support retrofit decision-making.	Design and develop the artefact	Synthesising the findings.
Objective 04: To validate the artefact for the intended capabilities.	Validation of the artefact	12 semi-structured interviews and a benchmark analysis.

The third objective is to develop an information system artefact to encourage homeowners to retrofit their houses. The findings of the literature, questionnaire survey and semi-structured interviews were used to proceed with this objective. The artefact was developed by synthesising these findings. Finally, the artefact was validated with 12 semi-structured interviews and a benchmark analysis.

As the research data collection involved collecting empirical data from primary sources, ethical consideration was an important part of the research process. The university's ethical approval was obtained on 9th May 2023, for data collection through a questionnaire survey and interviews. The ethical approval decision is given in the annexures.

3.4.2. Gantt chart of the schedule

According to Table 20, the literature review of the research was conducted throughout the study duration. It was noted that the literature regarding the research area is being updated rapidly. There is a high level of research interest in resident engagement in housing retrofit in the UK context.

Table 20: Gantt chart for the research programme

Activity	Duration											
	Ist Year				2nd Year				3rd Year			
	1Qtr	2Qtr	3Qtr	4Qtr	1Qtr	2Qtr	3Qtr	4Qtr	1Qtr	2Qtr	3Qtr	4Qtr
Learning Agreement												
Literature review												
Interim Assessment												
Introduction												
Methodology												
Data collection 1,2												
Internal Evaluation												
Artefact development												
Data collection 3												
Write up thesis												

The introduction to the research was started during the first year. The first year approach to homeowner engagement had only focused on the rational side of homeowner decision-making. The first year academic review examiners pointed out the complexity of human decision-making with reference to behavioural theories. Accordingly, the decision-making scope was broadened to include all the possible scenarios of homeowner decision-making.

The second year period of the research especially focused on the methodology and the data collection. The methodology was designed, and data collection strategies were outlined. One round of semi-structured interviews was conducted. The researcher was unable to recruit experts from the retrofit industry. The interviews were conducted with experts from the construction industry. The questionnaire survey was conducted successfully with 104 responses. During the second-year academic appraisal, the examiners pointed out the importance of conducting interviews with experts in the retrofit industry, but not in the construction industry. Accordingly, the first year interview data collection was discarded.

The first quarter of the third year was dedicated to developing a strategy to recruit retrofit industry experts. It was able to conduct 28 interviews where the saturation of data arrived. The sample consisted of a wide range of participants including a technical author of PAS 2035, book authors of housing retrofit, university professors, researchers, government officials and key industry experts. Apart from the interviews with the above retrofit industry stakeholders, there were further 12 interviews conducted with UK homeowners. Once the data collection was done, the artefact was developed. A set of 12 semi-structured interviews was conducted with retrofit industry stakeholders to validate the artefact. A further benchmark analysis was conducted to compare the artefact with the existing systems. The thesis was written in line with the activities performed from time to time, all over the final year.

3.4.3. Empirical data collection and analysis

3.4.3.1. Introduction

This section is to elaborate on the empirical data collection and analysis of this research. Literature reviews and the benchmark study are not considered here. There are three empirical data collections in this research. The first one is a questionnaire survey to understand the decision-making behaviour of the homeowners in housing retrofit. The second empirical data collection is to collect artefact requirements by way of semi-structured interviews. The third data collection is to validate the developed artefact by way of semi-structured interviews. The characteristics and justifications for these study designs are given below.

3.4.3.2. Study 01 | Homeowner behaviour

Data collection: The theoretical aspects of human decision-making behaviour were studied in the literature review. This questionnaire survey aims to empirically understand how homeowners make housing retrofit decisions in the UK context. In this questionnaire survey, data was collected from a sample of 104 homeowners in the UK. First, the demographic details of the homeowners were collected. Second, different information factors were presented to the homeowners and asked how they would value these information factors when making a retrofit decision. Accordingly, fifty potential information requirements under ten codes were qualitatively selected for the purpose. The summary of the methodology is given below in Table 21.

Table 21: Methodology Summary

Item	Description
Type of data collection	Questionnaire survey
Purpose	To understand the homeowner decision-making behaviour
Type of data	Quantitative primary data
Nature of data	Five-point Likert scale data
Sample	The UK homeowners
Sampling method	Simple random sampling
Sample size	Expected 70, collected 104
Time scale	July & August 2023

Once the original questionnaire was prepared, three pilot studies were conducted with different approaches and levels of detail. The final questionnaire was prepared in a way to minimise respondent fatigue, avoiding jargon and technical words, and reducing responding time to 10-12 minutes while giving an output sufficient to meet the study objectives. The following study objectives and statistical tests were planned in this study.

Table 22: Study objectives and statistical tests

	Objectives	Statistical test
1	Ensuring the datasets for each of the question codes are internally consistent.	Cronbach's Alpha
2	Mean values to identify the most important information requirements.	Frequency analysis
3	To identify how different demographic clusters value different information requirements.	Sectorial analysis of variance (ANOVA)
4	Generalisation of the findings to the whole population	Significance level over 95% ($p<0.05$)

Tests used in this study: Table 22 shows which statistical tests were used to achieve different study objectives. According to Muijs (2022), Cronbach's Alpha can be used to test whether several datasets are measuring the same construct. This is called "internal consistency". This can be identified as the reliability of the datasets (Collins, 2007). Cronbach's alpha is generally used in social sciences when the Likert scales are used (Atweh et al., 2008). For this study, Cronbach's Alpha is used to statistically ensure the information requirements of the homeowners are internally consistent with their relevant codes.

The next purpose is to identify the most important information requirements for the homeowners. Three statistical analyses were pilot tested according to the literature recommendations. First is Item Total Statistics. Item Total Statistics is a test used to find the contribution of one item to the total discriminatory power of the code (Muijs, 2022). Item Total Statistics was not successful in achieving the purpose as it considers the collaborative outcome of the five items, rather than the originally expected outcome of the code. The second method was the Relative Importance Index (RII). It was not incorrect. Using the mean value was found to be simpler and sufficient. The general mean values were used for the purpose. Items with mean values above 3.9 were considered the most important. The scale was from 1 to 5 (1 being not at all important and 5 being extremely important).

Analysis of variance test (ANOVA) is used to check differences among the means of two or more groups (Nesselroade & Grimm, 2019). For this research, several demographic groups can be identified. For example, the respondents of the study were segregated among the generations referring to Strauss & Howe (1991) and Steiner (2016). Further, the respondents are distributed among different income groups. These are some of the different groups of the study. There are ten information requirement codes. ANOVA tests were conducted to see whether there are any differences among these demographic groups when they value the information requirements.

Assumptions and purpose of the study: The main assumption of this study is to treat Likert scale data as interval data. According to Kothari (2004), Likert scale data is ordinal and the distance between two consequent numbers may not be similar. Meanwhile, some authors argue that there is no problem with treating Likert data as interval data (Schindler & Cooper, 2014). Boone & Boone (2012) argue that when several Likert questions are testing the same attitude or trait, the Likert data behaves highly similar to interval data and there is no issue with using statistical tests measuring the central tendency. E.g., Mean, mode, median or standard deviation. This study uses five questions to test one construct (code). Creswell & Creswell (2018) state that when the Likert question has five or more categories of responses, Likert scale data behave similarly to interval data. This study has used five such categories of responses (five-point Likert style).

The overall purpose of this study is to generally understand the homeowner decision-making behaviour in housing retrofit. This was approached by understanding their information requirements for retrofit decision-making. Accordingly, these information requirements need to be ranked and prioritised. The analysis does not need to be 100% precise as the analysis is already constrained by bounded rationality. Considering these factors, the above statistical tests were used despite the limitation of assuming Likert data as interval data. The above statistical tests were decided using a wide range of sources such as existing literature, past PhD thesis and artificial intelligence tools. Subsequently, the suitability of the tests was validated by referring to two statistical experts.

3.4.3.3. Study 02 | Artefact requirements

The study was conducted as semi-structured interviews with the retrofit industry stakeholders. Homeowners, retrofit industry experts, academics and experts in multi-disciplinary subjects were chosen as the population. A sample of 40 interviewees were recruited through personal invitations. The purpose of a diversified sample is to cover the artefact requirements from different aspects. A summary of the interviewees is given in Table 23. A detailed information sheet about the interviewees is given in the annexures (not personal details).

Table 23: Sample of the semi-structured interviews

	Type	Count	Description
1	Retrofit experts	11	People who work in the retrofit industry in senior capacities.
2	Academics	8	Academics who have published retrofit-related articles.
3	Multi-disciplinary	6	Key people who are related to housing retrofit E.g., Supply chain, and health professionals.
4	Retrofit professionals	3	Retrofit professionals who are involved in housing retrofit projects in the bottom line.
5	Homeowners	12	Homeowners from different parts of the United Kingdom.
	Total	40	

The retrofit experts, academics and experts in multi-disciplinary subjects were interviewed using personalised questionnaires. The questionnaires were developed after considering the background and expertise of the interviewees while covering the research questions. In this way, it was able to get the maximum contribution to the data collection from the interviewees. The purpose was to identify the artefact requirements from different housing retrofit stakeholders. There were 12 homeowners from different parts of the United Kingdom. They were interviewed to ask what information they would like to have in a retrofit decision support system. The interviews were conducted with a simplified general questionnaire, not using any technical words to reduce respondent fatigue.

The primary objective of this study was to collect the requirements for the artefact. The proposed system is required to encourage homeowners to make retrofit decisions by exploring retrofit options for their homes and getting to know about housing retrofit. As the interviews were conducted, they were transcribed and thematically analysed until they reached a satisfactory level of saturation.

3.4.3.4. Study 03 | Validation of the artefact

As far as the design science research methods are concerned, validation of the artefact can be recognised as an important step of the artefact development process. Validation of the artefact is identified as ensuring the artefact meets its intended capabilities in an internal test (Wieringa, 2014). As a system prototype will not be developed under the research scope, it will not have a prototyping or external evaluation phase. Artefact validation is an internal validation process where a hypothetical case study of the artefact is shown to a selected audience to get feedback. Table 24 shows the methodology summary of the artefact validation study with semi-structured interviews.

Table 24: Methodology summary of the study 03

Item	Description
Type of data collection	Semi-structured interviews
Purpose	To validate the artefact
Type of data	Qualitative primary data
Nature of data	Text as questions and answers
Sample	Retrofit industry stakeholders
Sampling method	Representative sampling
Sample size	12 participants
Time scale	April 2024

Empirical validation of the artefact was conducted first after developing the artefact. Pries-Heje et al. (2008) have recommended three important questions to focus on when validating design science artefacts (Pries-Heje et al., 2008). The fourth question was added by the researcher. Table 25 shows the key questions in artefact validation.

Table 25: Key questions in artefact validation (Pries-Heje et al., 2008).

Questions	Answers
What is validated?	The artefact for an information system for homeowners to evaluate housing retrofit options.
How is it validated?	By way of a hypothetical case study using semi-structured interviews.
When was it validated?	In April 2024 after developing the artefact.
Who is validating?	12 stakeholders of housing retrofit (Homeowners, professionals, retrofit industry experts, academics, supply chain partners.)

A qualitative data collection method was used for the validation of the artefact by using semi-structured interviews with retrofit industry stakeholders. There were 12 interviews conducted to validate the artefact. The participants were recruited through the personal contacts of the researcher, using the convenient sampling method. The sample consisted of three university academics, a homeowner, two construction industry professionals, a retrofit project manager, two information technology experts, a promoter of a digital retrofit one stop shop platform and two PhD students. The details of the sample demographics are given in the annexures.

The interviewees were presented with the capabilities of the system by way of a hypothetical case study. The presentation explained how a hypothetical user used the system to explore housing retrofit options and finally made a call to contact the retrofit assessor using the system. The interviewees were then allowed to ask questions to clarify anything unclear. They were then invited to comment on the capabilities of the system under five topics.

After validating the artefact with semi-structured interviews, a further validation activity of benchmark analysis was conducted. This is to compare the artefact with the existing similar information systems. The existing information systems for housing retrofit decision help (for homeowners) were identified through a literature review and personal contacts. However, there are only three systems found in the UK context apart from the EPC report. The benchmark analysis method has been recognised by Vaishnavi & Kuechler (2015) as an accepted method of validation. In brief, artefact validation has two parts; empirical validation with semi-structured interviews and benchmark analysis.

3.5. Artefact development

3.5.1. Introduction

Considering the research problem, it can be noted that the problem is of general interest. The limited interest of the homeowners in housing retrofit is a common problem currently applicable to UK homeowners. Due to this problem, the progress of housing retrofit is low and as a result of this the sustainability of the UK is challenged. Further, the problem has a theoretical relevance under the demand and supply theories to justify why limited homeonwer interest leads to the poor adoption of housing retrofit. The solution to this problem has been determined as an information system. This can be identified as an artefact according to Johannesson & Perjons (2021); March & Storey (2008). Design science research is an accepted methodology for developing information system artefacts (Vom Brocke et al., 2020).

Considering the artefact, problem and contribution to the knowledge, design science is recommended as the research methodology. Design science shall create innovative artefacts through a rigorous research process. It will further contribute to the body of knowledge (Johannesson & Perjons, 2021). The theoretical background related to information system design has been given in the next section. Further, the scope and purposes of the artefact are addressed in the next sections.

3.5.2. Scope of the artefact

The artefact of a design science research project is a potentially viable solution to a problem. It can be a construct, model, method, or instantiation (Hevner & Chatterjee, 2010). Wieringa (2014) describes an artefact as something required to solve a problem. An artefact may not solve a problem in full. It can partially solve a problem, fully solve a problem, does not solve a problem at all and even creates more problems. The artefact of this study can be defined as a high-level model for a proposed information system.

According to Offermann et al. (2010), the majority of design science artefacts were used to design information systems, ideally as a structure of a system under a method such as (UML) Unified Modelling Language. Further, there are method artefacts to define activities for a system. Artefact design is a more empirical activity rather than a conceptual model. For this reason, solutions were brainstormed when and where necessary.

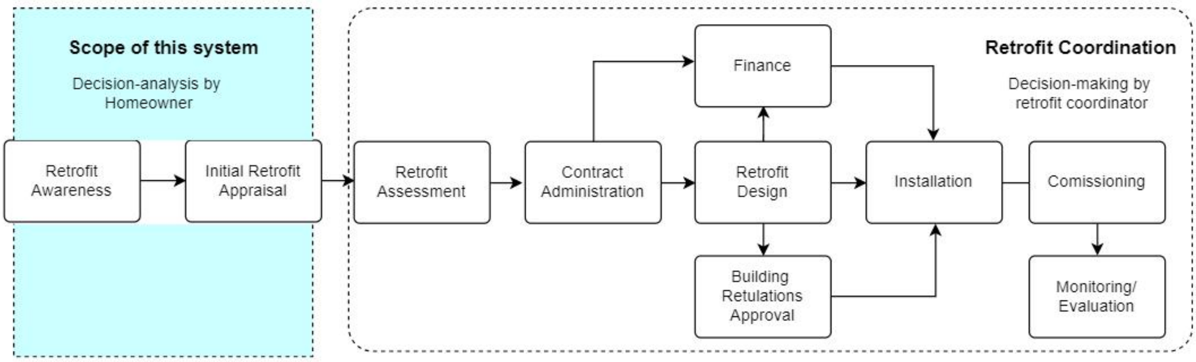

Figure 17: Scope of the system

As far as the artefact development is concerned according to Figure 17, it is important to note that the scope of the artefact is only to manage the first two phases of housing retrofit; making awareness and supporting initial retrofit appraisal. Once the homeowner analysed the retrofit options and demonstrated the interest, the lead shall be passed to the retrofit assessor, and the retrofit coordinator shall take responsibility. Retrofit assessment shall help the retrofit coordinator to present the final retrofit package to the homeowners. The homeowner is still not obliged to retrofit the house. If the homeowner decides to go ahead with the retrofit, the contract is administered and the next steps are to be followed. The proposed system shall create awareness in general and support the homeowner to appraise retrofit options for their own house. Then the lead is passed to the retrofit professionals. Things can change during the process.

The expected outcome of the system is to generate leads by forwarding homeowners for a retrofit assessment. After the retrofit assessment, the homeowners may either decide to retrofit the house or not to retrofit the house. If the homeowner decides to retrofit, that would be the most favourable impact to increase the progress of housing retrofit in the UK. Otherwise, the system shall store the details. If the homeowner decides not to retrofit after the retrofit assessment, the data will be stored at the TrustMark data warehouse (TrustMark, 2024b). The homeowner may come back to proceed with the housing retrofit, ideally motivated by a subsequent trigger. Even if that did not happen, the government and policymakers shall use this data to make better policy decisions regarding promoting housing retrofit.

3.5.3. Purposes of the artefact

Apart from the research aim and objectives, the artefact objectives are given below. These objectives have been determined considering the scope of the artefact and looking at solving the research problem. The artefact development is done by using design science research to achieve the following purposes.

I. To improve the awareness of housing retrofit among homeowners.

II. To support the homeowners for an initial retrofit appraisal.

III. Generating leads by motivating users to go for a retrofit assessment.

IV. Collecting data on user behaviour and housing stock for policy decisions.

Awareness: According to the literature review, the homeowners have poor knowledge and awareness about housing retrofit and its benefits in general (Alabid et al., 2022; Bobrova et al., 2022). In this situation, the initial purpose of the system must be to increase awareness about housing retrofit among homeowners. The awareness-making is about the general characteristics of housing retrofit, but not personalised to the houses of the homeowners.

They can explore the retrofit options for their houses at the next stage. The Homeowners should be able to improve their awareness of what is housing retrofit and how the process of retrofitting a house takes place after using the system. This is to address the problem of information deficit.

Initial retrofit appraisal: Once the homeowners get their awareness about the idea of housing retrofit, ideally they will be looking for personalised recommendations to retrofit their houses. It is important to give them personalised retrofit options for their houses. Apart from the retrofit measures, details about eligibility for loans and government grants will be required. The details about quality assurance and certainty of the benefits should be there to improve their confidence. Further, they will be looking for information related to the retrofit process for their house. This can include details such as project duration, costs of retrofit measures, project schedules, stakeholders in the process. Trust and reliability of the information will be important aspects.

In order to model this information, the system should know the characteristics of the house as well as the homeowner. Obtaining all of these information directly from the homeowner will not be feasible, as the homeowner is a non-technical person. Accordingly, the system shall find ways how this information is sourced, without making the homeowner exhausted. The system will have to coordinate with several other parties to source this information and model it according to the homeowner's requirements. The information may not be required to be 100% correct at this level. The purpose is to support the homeowner to decide whether to retrofit or not, but not to technically design and install the measures. This purpose is also coming under the problem of information deficit.

Lead generation: Once the homeowners become aware of housing retrofit and get to know about available retrofit options for their house, the next step will be forwarding them for a retrofit assessment under PAS 2035. This is called lead generation. At the current level of scope, the system shall only support the homeowner to go for a retrofit assessment through the system. The retrofit assessment is an important milestone of the retrofit process, where the homeowner is onboarded to the formal retrofit process. The homeowner is not obliged to retrofit the house by getting an assessment done or even getting the design done. Retrofit assessment can be considered as providing an opportunity to retrofit their house. As the homeowners are getting onboarded to the process with retrofit assessments, they will be more likely to continue to the next steps subject to capacity and motivation according to the COM-B model (Michie et al., 2011).

Data collection: The ultimate aim is to promote housing retrofit among the homeowners. Once the homeowners are onboarded to the retrofit process with a retrofit assessment, some homeowners may proceed to the next levels and get their houses retrofitted. There is no guarantee that everybody will retrofit their houses. If the retrofit assessments are done, that will create a trigger for the homeowners to re-explore them later sometime. By the time they want to retrofit, the retrofit assessment shall help to expedite the process. Further, even if the homeowners choose not to retrofit, the data collected during the process will be available for further use. This data about the housing stock and the homeowner demographics will help the government to make better policy decisions.

3.6. Chapter conclusion

Research methodology is an important chapter of a thesis. There are a number of research philosophies, data collection strategies and data analysis methods. When it comes to deciding the best research methodology for a study, there were several areas to be considered. Mainly, the research aim and objectives, research problem, output of the research, scope, ethical considerations, and resource limitations were important.

There may be more than one good research methodology for a study. It is important to decide the optimum research methodology and provide justifications for selections. For the purpose of this study, the research method was developed through design science research. The main justification behind this selection is that the output of this research involves designing an artefact and contributing to the scientific body of knowledge. The purpose of the study is in problem solving nature. It was noted that design science is the best methodology to serve these purposes.

In order to conduct the research, there are four steps outlined according to design science research. They are identifying the problem and solution, collecting requirements, artefact development and artefact validation. Both empirical studies and literature reviews were used to achieve these purposes at each stage.

The next chapter is to present the data collection of the research. Empirical data was collected through interviews and questionnaires, which will be presented in the results chapter.

4. CHAPTER 04: RESULTS

4.1. Introduction to the chapter

This chapter focuses on collecting and analysing data for artefact requirements as well as artefact validation. There are three empirical study data collection and analysis reported in this chapter. Table 26 shows a summary of the empirical studies of this research.

Table 26: Summary of the studies for data collection

Study	Type	Purpose	Sample	Sample size
01	Questionnaire survey	Homeowner behaviour	Homeowners	104
02	Semi-structured interviews	Artefact requirements	Retrofit industry stakeholders	40
03	Semi-structured interviews	Artefact validation	Retrofit industry stakeholders	12

The chapter first covers the second step of design science research methodology; collecting artefact requirements. A questionnaire survey was conducted to understand homeowner retrofit decision-making behaviour. Further, the artefact requirements were gathered through 40 semi-structured interviews with retrofit industry stakeholders including homeowners. There are two sets of data analysis separately for retrofit industry stakeholders and homeowners. Further, the chapter also covers the data collection for the artefact validation. This was done by way of 12 semi-structured interviews with retrofit industry stakeholders.

4.2. Study 01 | Questionnaire survey for homeowner behaviour

4.2.1. Introduction

A questionnaire survey was conducted with homeowners in the UK to identify their behaviour in housing retrofit decision-making. The study was able to collect 104 responses from the homeowners. Quantitative data was collected about the demographics of the respondents and their preference for information in housing retrofit decision-making. The questions were prepared in five point Likert style under ten codes and five questions were allocated under each code. The data was quantitatively analysed using descriptive statistics and inferential statistics. The questionnaire is given under the annexures.

4.2.2. Findings

4.2.2.1. Demographics

The survey was responded by 104 homeowners. The minimum required number of responses were 69 to achieve a 90% confidence interval and 10% margin of error. As the purpose was to understand decision-making behaviour, the focus was on the respondent's background, not on the house demographics. Accordingly, how respondents from different demographics value different information (to make a retrofit decision) was studied. Considering the respondent's fatigue as well as the bounded rationality concerns, the following five demographic factors were collected: gender, age group, education, income source and income level.

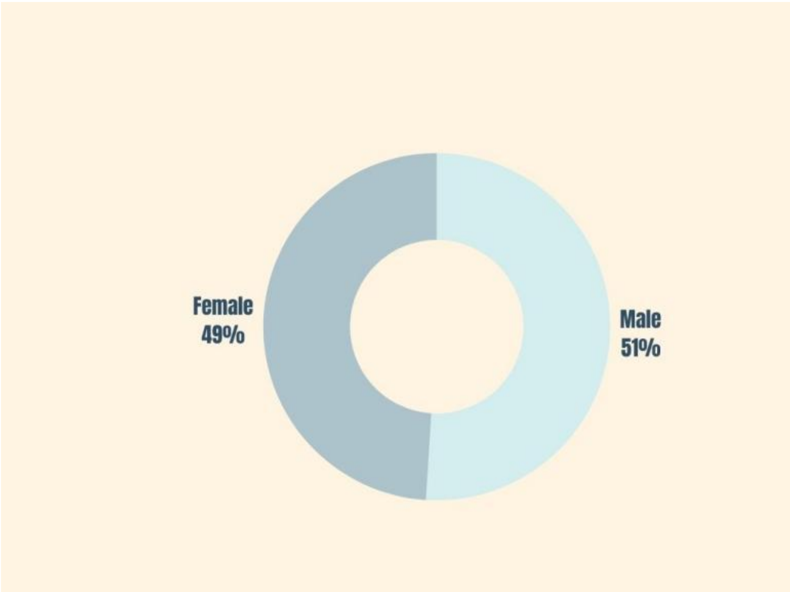

Figure 18: Gender distribution of the sample

According to Figure 18, the sample is observed to be representative of gender. Both male and female respondents have responded to the questionnaire alike.

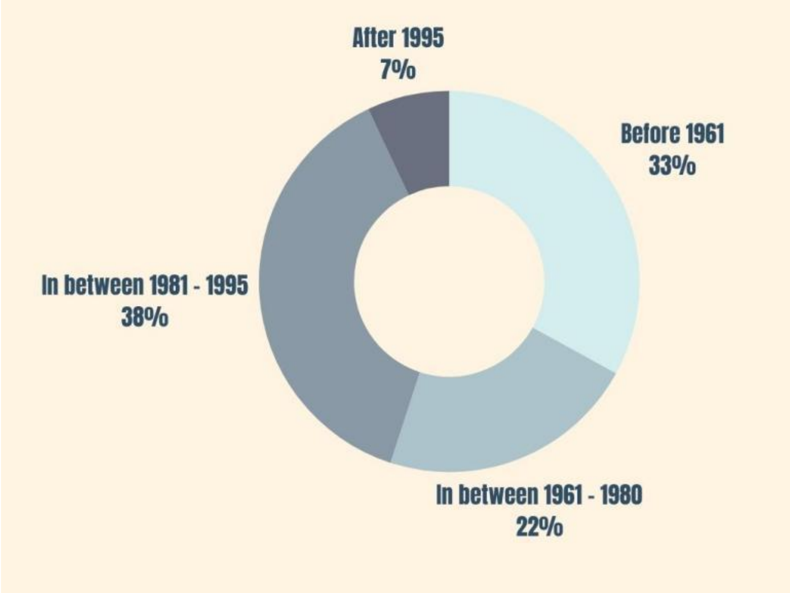

Figure 19: Age group distribution of the sample

According to Figure 19, the age groups of the sample were collected to separate the respondents into different generations according to the generations theory. Respondents born before 1961 belong to the older generations such as baby boomers or silent generation. Accordingly, this study was responded to by people from older generations, generation X, generation Y and generation Alpha. Statistical tests were conducted to see whether there are any differences among these generations in retrofit decision-making information requirements.

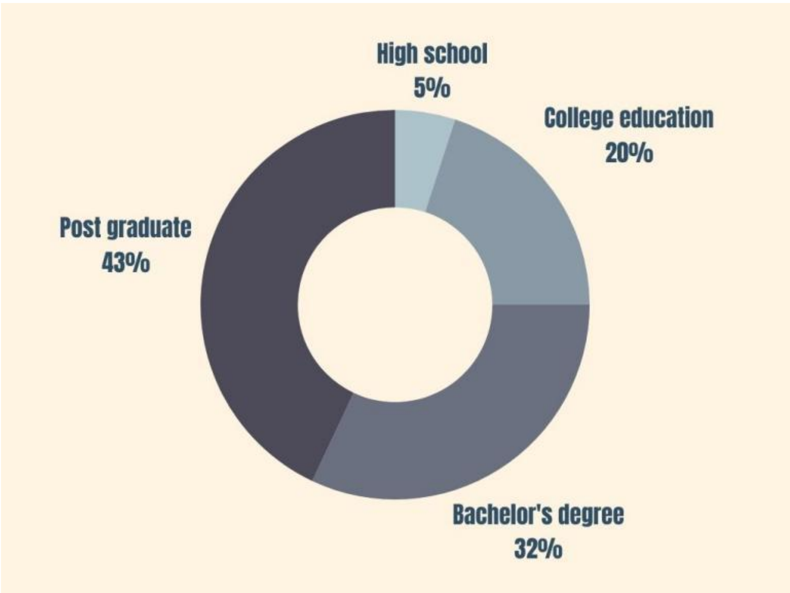

Figure 20: Education distribution of the sample

According to Figure 20, other than the 5% of respondents who only have a high school education, there is 20% of the respondents with a college education and the balance 75%

are degree holders. Considering the above, it can be concluded that the sample is highly educated. There is a concern whether the sample is satisfactorily representating the general homeowner population.

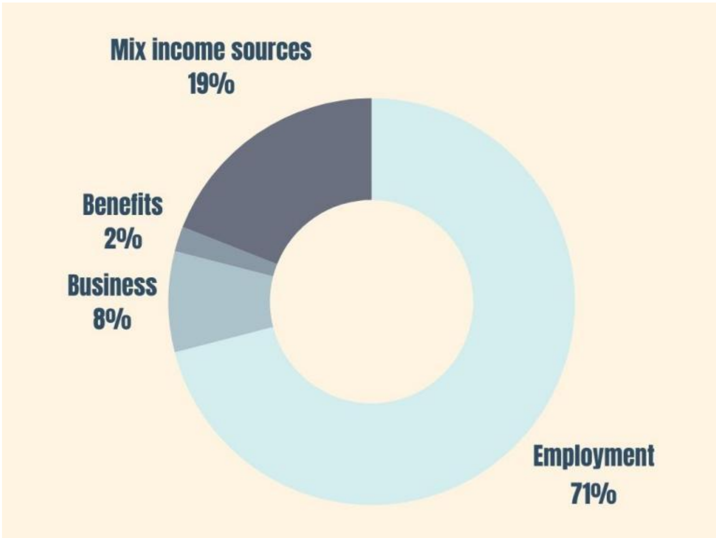

Figure 21: Income source distribution of the sample

According to Figure 21, the majority of the sample (71%) is employed. 8% of the sample is engaged in businesses while 19% of the sample has multiple sources of income. By considering this, it can be expected that the sample mainly represents the view of employed homeowners. This is a limitation of the study.

Figure 22: Income level distribution of the sample

According to Figure 22, income is distributed from £1,000 per household to £5,000. The curve is skewed to the right. There are a few outliers for income levels £7,000, £9,000 and £10,000 per month. Considering the above distribution of income levels, it can be suggested that the statistical test results involving income levels are statistically significant.

4.2.2.2. Internal consistency and mean value ranking

Table 27: Cronbach's Alpha test for Questionnaire codes

	Q1 (Cost)	Q2 (Finance)	Q3 (Grants)	Q4 (Time)	Q5 (Quality)	Q6 (Performance)	Q7 (Disruption)	Q8 (Options)	Q9 (Stakeholders)	Q10 (Risk)
Cronbach's Alpha	0.883	0.932	0.945	0.917	0.886	0.931	0.892	0.919	0.938	0.925
Number of items	5	5	5	5	5	5	5	5	5	5

Table 27 shows the internal consistency measures of the questionnaire codes under Cronbach's Alpha test. According to George & Mallery (2021), the internal consistency is considered acceptable when the value is higher than 0.7. (It is good over 0.8 and excellent over 0.9). It can be noted that all the questionnaire codes have a value above 0.8 according to the above table. It was concluded that all the questions in the questionnaire measured the same construct under their respective code. E.g., All five questions under the code "Cost" measure cost factors and they are internally consistent.

The mean values of the items are used to rank the items in a code. There are ten codes in this study and there are five items per code. The purpose of this analysis is to study the behaviour of the homeowners by looking at how they value information related to housing retrofit. One main limitation of the analysis is treating ordinal Likert-type data as interval data when the frequency analysis was done. In this regard, a deeper evaluation of the frequency analysis is not expected. The objective is to identify the behaviour. According to the questionnaire coding, the value 1 refers to the response "Not at all likely" and the value 5 refers to "Extremely likely". There are three incremental levels in between; 2 – Less likely, 3 - Somewhat likely, 4 – A lot likely. Considering the overall results, over 3.9 ranked responses were considered as more important.

4.2.2.3. Data analysis for ten codes

The data analysis for the questionnaire was done under ten codes. The codes are costs, finance, grants, time, quality, energy performance, disruption, upgrade measures, stakeholders and risk. There are five questions under each code. The following data analysis under frequency analysis shows the findings of the questionnaire survey under these codes.

Table 28: Frequency analysis for the code cost

Cost						
		Total cost	Individual cost	Future costs	Cost comparisons	Included excluded
N	Valid	104	103	103	103	102
	Missing	0	1	1	1	2
Mean		3.9135	3.9709	3.6311	3.9126	3.7059
Median		4.0000	4.0000	4.0000	4.0000	4.0000
Mode		5.00	5.00	4.00	5.00	4.00
Std. Deviation		1.30801	1.13290	1.08456	1.09461	1.08626

According to Table 28 above, total cost, individual costs, and cost comparisons can be noted as highly important according to the respondents. They all have higher mean values, and their mode is 5 (Extremely likely). When making a retrofit decision, the Important information requirements for the homeowners are;

i. Cost of each housing upgrade activity. E.g., Installing a new boiler.

ii. The total upfront cost of the housing upgrade.

iii. Cost comparisons among sources/contractors.

Table 29: Frequency analysis for the code finance

Finance						
		Finance type	Finance conditions	Payback	Eligibility	Support
N	Valid	104	104	104	104	104
	Missing	0	0	0	0	0
Mean		3.9327	3.8558	4.0769	3.7500	3.7981
Median		4.0000	4.0000	5.0000	4.0000	4.0000
Mode		5.00	4.00	5.00	4.00[a]	5.00
Std. Deviation		1.22486	1.08313	1.17161	1.12129	1.20983
a. Multiple modes exist. The smallest value is shown						

According to above Table 29, the type of finances and payback period are observed to be the highly important information requirements for homeowners. Further, the conditions of finance also seem to be important. It is not considered as the mode is 4. Accordingly, important information requirements are;

i. Monthly instalments and payback period.

ii. Types and amounts of finance.

Table 30: Frequency analysis for the code grants

Grants						
		Availability	Conditions	Assistance	Process	Limitations
N	Valid	104	104	102	104	103
	Missing	0	0	2	0	1
Mean		3.8173	3.6923	3.7451	3.5577	3.6408
Median		4.0000	4.0000	4.0000	4.0000	4.0000
Mode		5.00	4.00	5.00	4.00	3.00
Std. Deviation		1.22882	1.08902	1.15772	1.13913	1.07425

The general response for the code "Grants" is not very important to the homeowners according to Table 30. All of the information requirements placed by the respondents are of lesser importance, compared with the other questionnaire codes.

Table 31: Frequency analysis for the code time

Time						
		Overall duration	Individual durations	Combination of durations	Seasonal differences	Milestones
N	Valid	104	104	104	104	104
	Missing	0	0	0	0	0
Mean		4.0481	3.6250	3.5769	3.4808	3.5288
Median		4.0000	4.0000	4.0000	4.0000	3.5000
Mode		5.00	3.00	4.00	4.00	3.00
Std. Deviation		1.04630	1.08106	1.04920	1.05187	1.03302

By evaluating the above Table 31, it can be noted that the homeowners are mainly interested in knowing about the overall duration of the retrofit project. All other suggestions have lower importance according to the analysis.

i. Overall retrofit project duration

Table 32: Frequency analysis for the code quality

Quality						
		Certifications	Certification process	Quality information	Warranties	Minimum quality
N	Valid	103	104	104	102	103
	Missing	1	0	0	2	1
Mean		3.6602	3.3750	3.9135	4.2255	3.9515
Median		4.0000	3.0000	4.0000	5.0000	4.0000
Mode		5.00	3.00[a]	5.00	5.00	5.00
Std. Deviation		1.19273	1.16742	1.13301	1.03318	.99389
a. Multiple modes exist. The smallest value is shown						

According to Table 32, it is observed that homeowners are highly concerned about the warranties for the retrofit measures. It has the highest mean value responses in the direction of “Extremely likely”. Further, quality information and minimum quality aspects are also important.

i. Warranty and guarantee information about home upgrade measures.

ii. Guaranteed minimum quality of upgrade measures.

iii. Quality information about the products and materials.

Table 33: Frequency analysis for the code energy performance

Energy performance						
		Future energy bills	Energy uses	Renewable energy	Comparison of bills	Measures with predictions
N	Valid	104	104	103	104	104
	Missing	0	0	1	0	0
Mean		4.2500	4.2500	3.9320	4.2115	3.8173
Median		5.0000	5.0000	4.0000	5.0000	4.0000
Mode		5.00	5.00	5.00	5.00	4.00
Std. Deviation		1.01206	.97293	1.05032	.98210	.96305

According to Table 33, there is considerable interest in the information requirements by homeowners under the energy performance code. Almost all the suggested information requirements were given a high level of importance by the homeowners. In particular, future energy bills and energy use reductions are highlighted.

i. Estimated future energy bills.

ii. Estimated energy use reductions.

iii. Comparison of future and current energy bill/use reductions.

iv. Potential renewable energy generation by the house.

Table 34: Frequency analysis for the code disruption

Disruption						
		Number of days	Nature of disruption	Alternative accommodation	Cost alternative accommodation	Lower disruption methods
N	Valid	103	104	103	104	103
	Missing	1	0	1	0	1
Mean		3.8835	3.9231	3.8350	3.7596	3.8835
Median		4.0000	4.0000	4.0000	4.0000	4.0000
Mode		5.00	5.00	5.00	4.00	4.00
Std. Deviation		1.14875	1.03053	1.03939	1.05660	1.04131

The above Table 34 shows that the homeowners have mainly focused on the nature of disruptions. The number of days disrupted has been ranked nearly to the nature of the disruptions. Generally, the disruption was considered highly important.

i. Nature of disruption (E.g., Can I use a part of the house while the house is being upgraded?)

Table 35: Frequency analysis for the code upgrade measures

Upgrade measures						
		Recomdd. measures	Justifications	Order of installations	Big picture	Project Breakdown
N	Valid	103	104	103	104	103
	Missing	1	0	1	0	1
Mean		4.0388	3.8077	3.8738	4.0192	4.0097
Median		4.0000	4.0000	4.0000	4.0000	4.0000
Mode		5.00	5.00	5.00	5.00	5.00
Std. Deviation		1.08395	1.07104	1.04487	1.07017	1.08912

According to above Table 35, homeowners prefer to know about the recommendations for housing retrofit measures. Further, they wish to see the big picture of the retrofit and the possibility of breaking down the project into phases.

i. What are the recommended home upgrade measures?

ii. The big picture of home upgrades.

iii. Possibility of breaking down the project into phases and their costs.

Table 36: Frequency analysis for the code stakeholders

Stakeholders						
		Stakeholders	What kind of influence	Level of influence	Time of influence	Quality ratings
N	Valid	104	104	103	104	104
	Missing	0	0	1	0	0
Mean		3.4808	3.4615	3.4466	3.4135	4.1250
Median		4.0000	4.0000	4.0000	4.0000	4.0000
Mode		3.00[a]	4.00	4.00	4.00	5.00
Std. Deviation		1.14044	1.15685	1.07309	1.13728	.98225
a. Multiple modes exist. The smallest value is shown						

According to Table 36, the homeowners have not placed much importance on the information requirements of the stakeholders. The quality ratings of the people involved in the retrofit were given considerable importance.

i. Quality ratings of the suppliers, installers, designers and others.

Table 37: Frequency analysis for the code risk

Risk						
		Potential risk	Risk during upgrades	Design risks	Environmental risks	Health and safety
N	Valid	104	104	102	103	103
	Missing	0	0	2	1	1
Mean		3.9327	3.8365	3.6863	3.6602	4.0388
Median		4.0000	4.0000	4.0000	4.0000	4.0000
Mode		5.00	5.00	3.00	4.00	5.00
Std. Deviation		.95800	1.03446	1.02426	1.00541	.95919

Considering the information requirements under the risk code under Table 37, there are two factors identified. They are the potential risks to the cost, quality, and time as well as the health and safety risks.

i. Health and safety risks.

ii. Potential risk towards cost, time, and quality.

Table 38: ANOVA summary table for homeowner demographics

	Description	D1 Gender	D2 Age group	D3 Education	D4 Income source	D5 Income level
Cost	F-statistic	-	-	7.016	3.967	-
	Significance	-	-	0.010	0.049	-
Finance	F-statistic	-	-	-	-	-
	Significance	-	-	-	-	-
Grant	F-statistic			4.448		
	Significance			0.038		
Time	F-statistic	-	-	4.985	-	-
	Significance	-	-	0.028	-	-
Quality	F-statistic	-	-	-	-	-
	Significance	-	-	-	-	-
Performance	F-statistic	-	-	10.241	-	-
	Significance	-	-	0.002	-	-
Disruptions	F-statistic	-	-	5.471	-	-
	Significance	-	-	0.022	-	-
Options	F-statistic	-	-	9.582	-	-
	Significance	-	-	0.003	-	-
Stakeholders	F-statistic	-	-	7.748	-	-
	Significance	-	-	0.007	-	-
Risk	F-statistic	-	-	6.332	-	-
	Significance	-	-	0.014	-	-

Table 38 shows a summary of the results of the ANOVA test. The purpose of this ANOVA test is to understand decision-making behaviour by looking at how homeowners from different demographic sectors seek information to make a retrofit decision. There are five demographic variables considered in this study: gender, age group, education, income source and income level. In this analysis, the demographic sectors are the independent variables and information requirements are the dependent variables. There were separate

ANOVA conducted for each information requirement code. The results are summarised above. F-statistic shows the comparative value of the influence while the significance shows the possibility of having the result by chance. If the p-value is below 0.05, these results indicate that there is a significant influence from demographic sectors on the particular information requirement. The results do not show a direction of influence, or they cannot be used to measure the level of influence. F-statistics can only be used to compare the influence among different independent variables.

It has been identified that the level of education influences the information requirements in general. Finance and quality are exceptions. Further, Cost information is also influenced by the source of income. Considering the level of comparative influence, information regarding energy performance and retrofit options is highly influenced by the level of education. Cost information and stakeholder information are also fairly influenced by the level of education. As far as the above ANOVA analysis is concerned, the following conclusion can be arrived at; The consideration of information when making a housing retrofit decision differs according to the level of education of the homeowners.

It is unable to conclude whether highly educated homeowners need higher levels of information or vice versa. The above-mentioned results in the table can be generalised to the population according to their significant levels. It is important to bear that the results are subject to the assumption of treating Likert scale data as interval data.

4.3. Study 02 | Semi-structured interviews for artefact requirements

4.3.1. Introduction

An artefact is an artificially created solution to a certain class of problems (Dresch et al., 2015; Hevner & Chatterjee, 2010; Johannesson & Perjons, 2021; Wieringa, 2014). According to Johannesson & Perjons (2021), artefact development is a five-step process, which has been adopted in this research. They are explicating the problem, defining requirements, designing and developing the artefact, demonstrating the artefact and evaluating the artefact. The initial two objectives of the study focused on explicating the problem and justifying the solution. This section focuses on defining requirements according to the conducted interviews with retrofit industry stakeholders.

4.3.2. Findings of the interviews with retrofit stakeholders

4.3.2.1. Retrofit measures, approaches and benefits

A2 says that the retrofit usually never pays back financially. It is not an investment. This was agreed by many participants. The government does not admit that. When it comes to cost, energy prices are kept controlled as they are coming under political pressure. Construction costs are not a political concern. Finally, this worsens the payback of retrofit. Generally, most of the participants highlighted the importance of funding to drive retrofit at a scale. Without a proper funding mechanism, it is unlikely that the housing retrofit will catch up. The reason is that housing retrofit is expensive for most households. A13 says it is best to give three options to the homeowner about the retrofit measures in terms of costs and benefits. One is the lighter one, the second is the medium one and the last is the extreme one. A15 also suggested the same. The cost is a barrier in retrofit assessment as well. According to A15, to properly understand the property, a thorough assessment is required. E.g., Air tightness test, thermal imaging, Co-heating test, condition report. However, not everyone can afford them.

A3 as well as A21 recommend moving away from looking at retrofit benefits in energy savings. They further recommend focusing on health and other benefits. Homeowners will not be motivated when they see the payback numbers. A8 says the main benefits of retrofit are reducing fuel poverty, and better health and comfort. Carbon reduction can be an added advantage. (The reason is people worry about themselves before being concerned about the others). A10 says the health benefits of housing retrofit are now focused by many. For example, the health issues caused by poor housing.

A5 says the earlier focus was to reduce the energy consumption as low as possible since there was no proper heat pump deployment. But now that heat pumps are widely available, the focus is to reduce the demand to a level where the deployment of heat pumps is feasible, not to reduce the heating demand extremely. She sees this as the optimum balance. This is agreed by A21 as well. According to A2, it is always a question of whether to invest in insulation or invest in renewables when the money is tight. From the payback point of view, it is sensible to invest in offshore wind and it is better to do insulation considering the future energy price increases. A17 is doubtful whether trying to achieve extreme performance levels with retrofit is worth it. He says achieving extreme performance criteria seems to be on the law of diminishing returns. That means when the measures are tightened, cost increases more than the increase of returns. A1 focuses on overreliance on technology.

Better insulation, airtightness and ventilation will reduce the demand and eventually overreliance on technologies. In this case, retrofit is something people will not regret in future.

A2 says the initial retrofit measures are ideally loft insulation, floor insulation and wall insulation. Next, the windows can be upgraded. Retrofit measures are going to be expensive afterwards. In this case, it is better to allocate some funds every month to meet the inevitable housing upgrade. According to A15, when it comes to retrofit measures such as mechanical ventilation and heat pumps, the acoustics are often ignored. The retrofit measures are to be installed in a way which minimises "noise". Noise is a part of occupant health and safety. Even if a heat pump with less noise is installed in the wrong place, the sound can multiply and cause excess noise. There can be a potential threat from the sounds of the drones in future unless the houses are not retrofitted to be soundproof.

A13 says some properties have specific challenges when it comes to retrofit. For example, if the area is prone to flood, it is better not to put hemp insulation. When deciding the optimal retrofit measures mix in traditional buildings, A13 says it is mainly the experience that matters as these buildings are different from one to another. A5 points out that every house is different although they look the same. In this case, it needs to take into account these diversities when preparing both individual and collective retrofit projects. A19 highlighted the need for a systematic approach to drive housing retrofit at scale. For this purpose, the focus should be on the newer houses built after the 60s, not the older houses before 1919. Newer houses are easier to retrofit, cheaper to retrofit and easier to count numbers. That will motivate the others to retrofit their houses. A24 also totally agrees with this. One energy company is doing it by focusing on new build, recently built (2013 building regulations) and going backwards. Their ambition is zero energy bill homes. A20 emphasised the importance of using passive measures more. For example, natural lighting. With the invention of artificial lighting, people have ignored natural lighting in building design.

4.3.2.2. Quality, regulations, certifications and standards

A1 finds PAS 2030/2035 specifications are useful and will reduce the problems in the retrofit industry. A3 also points out how PAS specifications prevent homeowners from experiencing unintended consequences. A6 states that the PAS 2030/2035 specifications have added quality to retrofit. "The PAS specification has brought professionalism to the retrofit industry”, A17 says. He further says that the customers need to feel the retrofit was done with them rather than retrofit was done to them.

A7 says the regulatory aspects are almost addressed with the PAS 2030/2035 specifications. Now the priority is to incentivise the homeowners and landlords. She further says there is a poor appetite for retrofit certifications such as Passivhaus or Energiesprong. This was agreed upon by A17 too. A17 is happy that now there are professionals involved in housing retrofit and the homeowners are approached for whole house retrofit rather than single measures.

A3 says the previous policies and retrofit drives were not based on whole-house retrofit, but only for specific measures. Because of bad case studies of damp issues after retrofit, homeowners with traditional homes are reluctant to retrofit. A4 argues the level of accuracy of existing building tests for energy efficiency. He suggests conducting co-heating tests to see the practical levels of energy efficiency of the houses. A12 talks about the current problems with the energy performance certificates. Some of the datasets used in the calculations are outdated and hope these will be addressed with the Home Energy Model, coupled with the future homes standard.

A13 says there should be a discussion between the industry stakeholders such as the designers, planning authorities, insurers and contractors to retrofit old buildings while preserving their historical values. Further, the inefficiencies of the planning process are a clear issue, which could take years. A21’s idea is that following the correct methodology is the main requirement rather than following the standards.

4.3.2.3. Trust, reliability, and accuracy of information

A2 says that homeowners lose confidence in retrofit when the retrofit benefits are misinterpreted by people with a lack of knowledge. Further, he argues that people need to trust science and science needs to be simplified to the people to understand. A12 says the retrofit professionals need to be monitored for compliance with PAS specifications to manage the industry trust. A6 says if the government continuously supports something, the public will think this is the right thing to do. The UK government has not shown consistency in their policies related to climate change, which has caused poor public trust in the UK sustainability policies. According to A8, the government has changed their direction several times in the journey to net zero in the built environment. This has reduced the reliability of the retrofit stakeholders about the consistency of government policy.

People tend to imitate or go beyond their neighbours when it comes to things like homes or cars. This can be used as a point to “Pivot the momentum” by focusing them on retrofit houses, A11 says. She further argues that people go to their trusted opinion leaders to get advice. Accordingly, impartial advice and awareness-making are required in the housing retrofit industry. A15 criticises the tick-box nature of the work of the retrofit assessors and coordinators. She insists that they should talk to the residents and try to understand their requirements. Further, when the assessments are based on assumptions, the results can be less accurate. A17 says the homeowners should be empowered and communicated properly about the retrofit. That will create demand for retrofit. In this manner, retrofit will become something requested by the clients, but not something sold to them.

A10 also points out that most of the government and other sustainability organisations do not have a proper clue what to do. Further, they do not become an example to others. A20 points out the fact that savings from a solar panel can be observed with a smart meter. It is not possible to see the savings from insulation. A solution is required for this. According to A24, there is nothing sexy about insulation or ventilation. A better idea is to couple them with something interesting, such as a new kitchen.

A26 says “Unless we can answer the problem of why I should need a heat pump, we can’t convince it to the others”. She also recommends the neighbourhood approach to driving retrofit. Everybody tries to get something when their neighbour gets it, even if they do not know whether it works or not. A27 says the relational dimensions are the key to understanding why somebody would choose to retrofit their home. He also highlights that the people do not trust that the technology will work, that the disruption will be worth it and that the trades are going to deliver it.

4.3.2.4. Stakeholders and Supply Chain

A1 says the best way to approach retrofit is through a homeowner platform, as they are the key decision-makers in most cases. However, A3 says the focus should not be on the homeowner itself, although they are major actors. The other actors such as supply chain or regulatory bodies should also be considered. A18 and A21 also agree that the local authority is a good channel to approach homeowners and residents for driving housing retrofit at scale. Resource wise, they do not have the time or finance or expertise. She further suggests that the neighbourhood is the key influencer to drive retrofit.

A1 further says that homeowners are best approached by retrofit professionals such as retrofit assessors or coordinators. A1 also talks about the “recognition” of the suppliers and installers. It is important to identify how the industry recognises the expertise and reliability of suppliers, products, professionals and others. A4 says the existing list of gas engineers can be used for the transition to net zero in the housing sector. They know the heating industry well and the residents' behaviour too.

A17 shows that the cases for most bad retrofits are due to unqualified installers having installed measures for the sake of money, without actually looking at the risks. A5 points out that the lack of skilled people in the retrofit industry has caused inefficiencies. People do not know where to start the project even if they want. In this case, a one stop shop will be a clear answer, subject to the collaboration of the project parties. A13 says the industry needs people with good knowledge and enthusiasm about traditional buildings. Currently, there are not many people with this expertise. Further, awareness of the people is also required. People ask for popular measures such as heat pumps or solar panels. But the fabric is the first that makes the house comfortable.

A2 says the heat pump installers are working on an agenda. They try to maximise their cut by installing more than necessary heat pumps. In this case, they do not focus on the fabric-first approach, where the demand could have been further reduced by improving fabric insulation and airtightness. Further, when selecting suppliers, it is good to get three quotations. But it is important to see whether they have made mistakes or manipulations.

A6 says that both the supply side and demand side of the retrofit need to be focused on to drive retrofit. Currently, only the supply side is prominent while the demand side is poor. The government puts too much faith that the market will adapt to policy changes. But that is not the case. A8 says that the retrofit drives need to admit the diversity and fragmentation in the retrofit industry. May be the best thing not to change this fragmentation, but to work with it effectively. However, A9 argues that there are contractors who are moving from single retrofit measures to multiple measures, adapting to the demand.

A10 recommends JCC contracts for retrofit works. A11 highlights the importance of the social element of people in their homes. A14 says the health authorities have a wider context to consider when it comes to public health. This includes better housing as well. The health authorities mainly focus on underprivileged communities. For example, the affordable warmth scheme in 2023 provided funding for low-income households for some retrofit measures.

A22 points out that the purpose of the one stop shop solutions is to reduce transaction costs. With a good database of information, the one stop shop can better facilitate the first steps of the customer's journey. A11's idea is that the current supply chain shortage is a critical issue to promote retrofit. Even the supply chain companies are capable of their work, they are not good at back office works, marketing, soft skills and similar activities. According to A27, a one stop shop shall provide information by collaborating with local groups.

4.3.2.5. Understanding homeowner behaviour

A2 points out that there is a public discourse about having a good bathroom or a good kitchen. It is a nice thing to have, especially when there are guests. People do not expect a payback on these expenses. In this way, the perceived value of a better home should be made a public discourse. A7 says that the problem with retrofit is that, usually it does not add a tangible benefit. For example, if a new kitchen is fitted, people have something to enjoy. But nothing is exciting about loft insulation or draught proofing. A4 points out that people used to have outside toilets half a century ago. Now people value luxury bathrooms and kitchens. A4 suggests a cultural shift is required for moving towards retrofits to have better homes. A8 says the reason for retrofit not being popular is due to the unawareness of the requirement. For example, someone can say they need a new kitchen or bathroom. It is unlikely someone says they need to make the house warmer.

A3 recommends a shift from a financial payback mentality to health, well-being and other benefits such as sustainability. A6 endorses this idea. She signposts to consider both the cognitive and emotional relationship of the homeowner with their house. This is a broader topic covering the place, experience, emotions, and cognition. A15 says the able-to-pay sector is not worried about the payback of retrofit. Simply they need to know what is best for them. The young people, people with kids and less able to pay sector try to find the easiest and cheapest retrofit measures. A16 points out that the retrofit benefits should be framed differently. It should not be some investment where the payback periods are calculated. It is a payment to have a better-quality life. This can be further approached by loss framing and gain framing under prospect theory. A17 also shows that people do not do payback calculations when they are buying a car. Most of the time, people think they are in a comfortable house, which is not the case in technical terms.

A6 further elaborates that people, including the government, believe that innovations will solve every problem. It is the human tendency of belief. But it is too much overconfidence. According to A10, people do not see the justification between the problems associated with houses and the potential benefits of retrofit. In this case, education and awareness are a must. A11 says the homeowner behaviour is diverse, and the retrofit strategies and approaches should be tailor-made to their demographics. A16 says the decision-making behaviour does not fluctuate in different age groups a lot, but their priorities are. For example, an elderly person will not bother to retrofit a house but a newly married person. A9 says the homeowners are going for housing retrofit mainly because they need to have a better house than others which they can be proud of. Further, when somebody has a better house, others also wish to get it even without realising the proper benefits.

A16 further points out that the time of purchasing a house is the best time to talk about retrofit. People often think of how good the kitchen is, how nice the bathroom or what is the heating system when they buy houses. In that case, they may need to retrofit the house. When the time passes, they get used to it and it becomes the new normal. According to A19, there are limitations to changing homeowner behaviour. It is impossible to expect that the homeowner is to be a tech geek. A24 also agrees with this.

A22 recommends a hybrid one stop shop solution (both physical and online) for housing retrofit. Physical presence is needed to build trust in the one stop shop platform. By endorsing this, A28 says human relationships are important to build trust in any case. He further reminds that the different homeowners shall be taken through different personalised processes as the requirements of the people are diverse. This is agreed upon by A26 As well. She further highlights that due to the increasing cost of living, there is a trend of people cutting costs over the past years, which can be unsustainable too. For example, reducing the heating too much. Energy bill savings are not the main aspect which people focus on, people spend a lot of money on unnecessary things. A27 says pitching retrofit as either necessary for an abstract climate change target in 2050 or going to save you a marginal amount on your energy bill per month or per year, completely misses the point in both instances why people choose to retrofit their homes.

4.3.2.6. Case studies, lessons learned and success stories

A1 signposts that everyone is talking about the bad case study in Preston. Nobody is talking about the number of successful case studies in Preston. This is the nature of good and bad news. The normal tendency is to summarise the bad and ignore the good. In this case, it is important to show how the reasons for bad cases are now attended to and how good case studies are outnumbered. The same thing was endorsed by A5 as well.

A2 says the biggest fears of homeowners are damp, not getting money back and unintended consequences of retrofit. In the same sense, A3 says the biggest fear is what will happen to the property after the retrofit, In other words, unintended consequences. This is also agreed upon by A6. A4 says that the people are afraid of being ripped off by the contractors. A5 says the biggest fear of homeowners is the level of disruption. A8 says people have no idea about what retrofit is. Because of the normal tendency to avoid the unknown, people ignore retrofit. A9 says the homeowners are afraid of the uncertainty of the retrofit process and its benefits.

A7 says the evolution of retrofit has shifted from deep retrofit to retrofit at scale. Accordingly, the discussion is what is the level of energy efficiency required to go for mass-scale housing retrofit. A13, who is an expert in traditional building retrofit says the idea of retrofit started in the 70's. People started doing cavity wall insulation and loft insulation. The main reason was the oil crisis at that time. There was not much technical knowledge about retrofit techniques or building physics at that time.

A13 further highlights the challenges of traditional building retrofit. Those houses were not built in a single go. They have been extended, part demolished and upgraded over hundreds of years. In that case, it is difficult to understand the construction details. Further, those buildings usually do not have a plan. A10 says assessing the building is a key priority and it should consider both the house and the occupants. Further, A10 emphasises the importance of doing it right, first approach. For example, cavity wall insulation companies are making more money now by removing them. There is a conflict of interest with installers to retrofit houses to achieve maximum energy efficiency. A9 said earlier the installers installed retrofit measures just by looking at U values. But now there is a holistic approach, and they are responsible for unintended consequences, where this was not the case before.

A1 emphasises that the repair should be included in the retrofit process. Without attending the repairs, the purpose of retrofit will not be properly achieved. A5 says that if the homeowners are aware of the actual situation of their houses compared with the ideal situation, they would be compelled to retrofit their houses. For example, CO2, VOC, relative humidity or temperature sensors can be used to show the desired and actual levels of a house, in terms of air quality. A17 also endorses this. Most people believe they already have a comfortable and well-performing house. According to A8, when it comes to the housing stock in the UK, every house is different, they are too old, and the energy efficiency has been neglected for a long time. This is also agreed upon by A9. A26 says retrofit is not a money problem which can be solved by throwing money. It is a problem about the interests of people. Identifying the trigger points for retrofit in a homeowner’s life is important to hook up retrofit with them.

4.3.2.7. Nature of information

A1 emphasises the fact that the information about housing retrofit should be given in a flow, according to the way the homeowners prioritise. If all the information is given at once, they will find it too difficult to digest. A6 says that the right information from the right sources should be available at the different stages of the innovation curve to promote all segments of the diffusion of innovations theory.

A5 says the government should understand that spending on housing retrofit is an investment in terms of health. There should be a strong focus on the households in fuel poverty which is around 6 million. A9 says the priority should not be decarbonising the housing stock. A house can be decarbonised, but still, the homeowner is in fuel poverty. A7 signposts that it is difficult to justify the benefits of retrofit with numbers. Statistically, it is also complex and not comprehensible to the general public.

According to A8, Each Home Counts report made several recommendations, and the government was able to implement pretty much everything except a national hub for consumer advice. This is the current priority. A11 stresses the need for a better approach to communicating with the homeowners. The right message is to be delivered in the right format. As a recommendation for a one stop shop solution, A6 says it is difficult to build it from scratch to perfection in a single iteration. It needs to be built to the best possible level and feedback is to be expected. How efficiently and effectively those concerns are addressed is the key to the success of the development.

A17 (contractor) says they do not do deep retrofit assessments of the house usually as it will need drilling holes and doing things which increase the disruption to the residents. Further, they do visual assessments and try to understand occupant behaviour and requirements. Not all the properties can be assessed in that way. If there is anything not clear, they proceed with further assessments. Usually, they do further assessments for less than half of their retrofits.

A20 highlights the complexity of government grants and incentives. A23 recommends finding trigger points of the homeowner's behaviour to promote retrofit. When clients ask for one measure, they should be given a free whole-house retrofit plan. Then they know what to do next. A24 suggests that there is no need for technological experts to disseminate the idea of retrofit. Normal men and women who witnessed the benefits of retrofit can talk about why retrofit is good and what good retrofit has done for them. A26 also highlights the importance of focusing on resident requirements when promoting housing retrofit.

4.3.2.8. Way forward and insights for an information system

A7 says now there are two trends in housing retrofit. One is the approach for mass-scale retrofit using technology. The other trend is shifting energy generation and use. Energy generation shifting can be explained as generating energy at one place and transferring energy to another place. Energy use can be shifted during different periods as well. An example of energy use shifting can be considered as shifting peak electricity use to off-peak using smart home systems. This helps to reduce the peak demand for electricity. A9 recommends preventing salespeople from coming in between the homeowner and the retrofit professionals. A14 says the county councils and local authorities are good stakeholders in reaching out to the homeowners and deploying mass-scale retrofit drives. They have community groups and access to local media where two-way communication is efficient. A8 says it is important to empower the people for the process of housing retrofit. This was also agreed by A6, "We should decide what level of agency to give homeowners".

A7 further says that the government is trying to do something. Further, the local authorities and other public stakeholders also strive to deliver retrofit. Due to the complexities of retrofit, they often cannot achieve the targets. A16 points out that government policies are not a lot focused on the human aspect of decision-making. For example, asking the landlords to spend money on retrofitting for future gains is against the prospect theory. Further, when the policies have no consistency (enforcing and suddenly abolishing), that will reduce the stakeholder confidence. A17 says that the mass-scale retrofit was mainly driven by government grant schemes. Now there is a better discussion about driving retrofit than ever before. Being an architect, A17 says now people come asking for "retrofit", rather than asking for remodeling or extending the house, which was the case earlier.

A7 further says the key to a one stop shop is the data. It is important to gather reliable and sufficient data from various sources. If the wrong data is picked, the whole effort can go wrong. A8 recommends onboarding a human retrofit coordinator at some point in the retrofit journey with a digital one stop shop. In terms of a digital one stop shop, A16 says the financial details are important, but the main benefits shall be health and comfort. This information is ideally linked to the homeowners' daily behaviour. Further, she suggests the "Foot in the door" technique to drive homeowners to retrofit houses. It includes getting them for a small commitment first and then pushing for big commitments. She also recommends reciprocity bias (Reciprocity is the impulse to help others for a previous favour that they have already done).

A18 says a one stop solution for retrofit could be highly valuable for social housing clients. One of the structural problems in social housing retrofit is that the stakeholders do not realise the benefits of retrofit and because of this they do not help the retrofit process. Although the residents are recommended to engage with the process months earlier than the project, this is not practical until the funding application is approved. When the project is approved, there is no time to engage the residents and get their consent as the schedules are tight. She said this is a "chicken and egg" situation. A concept like a one stop shop will keep the residents informed and make them aware well early before the project starts. Enlightened residents will positively engage with the retrofit project. According to A16, when it comes to identifying real-time decision-making behaviour, it is important to know whether the person is making decisions by using heuristics or by analysis. Ideally, the person shall be given a question with two alternative answers, one requires some analysis. If the person makes the decision quickly, they may be using heuristics. Different approaches to motivation shall be used according to the way they make decisions.

A6 emphasises that the decarbonisation of the housing stock needs to be addressed with the existing technology. Expecting the future innovation to solve the problem will not be a good idea. A13 sees a positive evolution of housing retrofit as the industry is using the right materials and technology at the right places. Further, the industry has identified the importance of ventilation. There are some concerns when it comes to preservation of old buildings. People choose to construct new buildings to preserve the existing old buildings on the site. It may be good for operational carbon. That is not suitable in terms of embodied carbon.

A16 further says that the focus should be on Planet's health when it comes to retrofit. Planet's health is pivotal around health, but it considers the health of people, flora, fauna and the whole earth. According to A14, the key to healthy living is jobs, homes, and friends. A19 recommends thinking out of the box when brainstorming approaches for housing retrofit. He argues that the problem is not about retrofitting houses, but about mass-scale retrofitting of the houses.

4.3.3. Findings of the interviews with homeowners

4.3.3.1. Costs, finance, and grants

B2 would like to borrow money to retrofit her house if possible. She likes to check the cost breakdown. She prefers simplicity. She does not know how to get information about available government grants. B3 likes to install retrofit measures one by one, and she also needs to know the individual costs. She would like to have a complete financial plan including the total cost, maximum government grant and the amount of finance. B9 also needs to know the total cost of retrofit and the amount of borrowing including the payback period and instalments. That will help him understand whether he can manage the monthly payments for borrowing. B4 says going for a loan for retrofit depends on the financial situation at the time. He does not like to go for loans as he will have to pay interest. B4 has heard of government grants but does not have a good idea.

B1 compares the cost of retrofit with the benefits. However, she does not think only about energy bill savings, but overall health, comfort, and aesthetic improvements. Further, she expects a loan to support the cost if she does not get enough grants. B6 needs the government to reduce the financial burden of retrofit costs as finance is a critical barrier for him. For B7 and B12 too, cost is a critical factor. B7 will not go for retrofit without the help of a grant. B5 needs to know his eligibility for government grants and bank loans to get an idea of whether the retrofit cost can be manageable for him. B12 likes to see all this cost and finance information on a single website if possible.

4.3.3.2. Retrofit measures and benefits

B2 does not need to install all the retrofit measures at once. She prefers to see if they can be installed from time to time according to her availability. B8 also prefers to screen the retrofit options one by one. B5 needs to know the milestones of retrofit, what are the benefits at that time and the cost. That will help her to make a better retrofit decision.

Energy performance is a main aspect of housing retrofit for B3 and B12. B3 likes to see the big picture of housing retrofit so she can digest the idea easily. B4 is worried about energy bills during the winter and ever-increasing energy bills have become a trigger to think about retrofitting the house. Both B4 and B7 like to see the consolidated benefits and costs, rather than individual items. They do not know how to understand a cost breakdown. B1 is concerned about health and safety over anything. She is willing to pay extra to ensure the health and safety of her family. B9 says he needs to know about what to expect during and after the retrofit. That will enable him to make an informed decision. For example, what went wrong in the past and how they are now addressed.

4.3.3.3. Quality, regulations, standards and certifications

When B2 buys something, she mainly relies on reviews. For example, google reviews. In addition, she gets opinions from friends and family. B2 needs to comply with regulations but hesitates to handle them by herself due to the hassle. B9 says he understands quality through the warranties, guarantees and certifications as he is not an expert in housing retrofit. B4 and B10 think a lot about quality as they both have kids. They rely on regulations and quality certifications for this purpose. B1 talks about the sustainability of retrofit. It includes the idea of quality, durability, environmental sustainability, value for money, everything. She also worries about health, safety and comfort a lot.

B3, B8, B2, B10 and B12 look for quality, but they need to weigh it with the cost too. In this way, they try to balance the optimal cost and quality. B7 also values quality a lot. He does not need to compromise on quality as the house is something with sentimental value. One of the main concerns is avoiding unintended consequences.

4.3.3.4. Trust, reliability, and accuracy of information

B2 expects some involvement from the government in the process to improve her confidence about the retrofit process. B10 seeks transparency in costs. She does not like companies approaching her to sell retrofit measures as she does not trust sellers. B6 needs to know whether there are any hidden costs in estimates. B4's fear of retrofit is about the uncertainties of the process and its benefits. He expects accurate and reliable information about them. B6, B8 and B12 all said the same.

B10 also worries about the accuracy and reliability of information. She expects this information from a reliable party who takes responsibility. She also expects the help of a coordinator, and she said it is better if there is a way of getting updates about the overall project and its progress. B7 worries about the cost overrun of the retrofit project. B11 prefers to rely on the energy provider or local authority when dealing with housing retrofit measures. B4 prefers energy providers to come up with retrofit measures whom he trusts the most.

B5 and B12 need to know whether there are any risks to the house, for example to the structure. Further, they prefer to know what went wrong earlier and why it will not happen again. What are the preventive actions taken? B6 also says sharing past case studies and testimonials with prospective retrofit homeowners will influence their decision-making positively.

B6 also thinks the information should be reliable, accurate and tailor-made to the homeowner and their house. B9 highlights the importance of the availability of information when he needs it. He may not be thinking about retrofitting the house all the time. But the need can arise due to a trigger. E.g., Receiving a higher energy bill. He is not ready to pay for the information. Further, he needs full information, as partial information will not convince him.

4.3.3.5. Stakeholders and supply chain

When it comes to the supply chain, B3 does not know about the materials and quality. In this case, she expects someone to describe her options. B10 wants to see other people's reviews about the supply chain and contractors. A rating system will be good. This has been agreed upon by B1 as well. B8 needs to compare the prices between the suppliers before making a decision. B9 also highlights the requirement of having multiple quotations for retrofit measures to make a decision.

B4 trusts his energy supplier and prefers they undertake the responsibility of retrofit. B11 also trusts his energy provider. B7 worries that he will have to go to several people to get the retrofit done. In this case, he prefers if he can get done all the retrofit from one installer. B5 needs to know about the reliability of installer and their availability by the time he is going to retrofit the house.

4.3.3.6. Construction time and disruption

B2 wants to know precisely how much time it will take and what kind of disruption will be there. As she has no idea how to manage the disruption, she would be happy if alternative accommodation options could be included in the retrofit package. B5 finds the idea of supplying a caravan is good during the period of retrofit. B3 also needs to know the project duration and what kind of disruption she can expect during that time. She prefers to go on a holiday during the construction time. This is agreed upon by B7 as well.

According to B4 and B7, proper scheduling of work is important as everyone is busy. The homeowners need to be informed of the correct start and end times and what happens during the retrofit process. Alternative accommodation is a critical problem If somebody has kids. B8 finds it difficult to schedule retrofit due to family priorities. B1 also needs the exact duration and timing of the retrofit so she can make arrangements from her side. This is difficult as she has kids. She has already faced the disruption of part renovation of the house for two weeks. She says it is the worst experience related to her house.

B6 would like it if the project could be broken down into phases. So, he can manage them according to his availability. Further, he suggests giving a clear description of the level of disruption. B6 needs assistance in managing the process as well as the documentation aspects. Project schedule information shall help B12 plan his activities to face the disruption.

4.3.3.7. Aesthetics, health, comfort, and sustainability

B2 especially focuses on safety being a mother, when thinking about housing retrofit. B4 thinks of retrofitting mainly because of the health and comfort of his kids. B3 loves her house due to its appearance, comfort and location. She does not want to change the appearance of her house. B7 is already happy about his house. But he likes improvements. So, if he retrofits, that is because of aesthetics and comfort. If B11 retrofits his house, it may be mainly because of the energy efficiency. B5 wishes to know about the health, comfort, and aesthetic benefits of retrofitting his house apart from the energy bill savings. Further, he prefers if he can see the after-retrofit scenario visualised, before making a decision. B1 says people will consider sustainability only if they know the benefits. She emphasises the requirement to make people aware of the importance of sustainability. B6 says that he is motivated to retrofit by the sustainability benefits of retrofit, although he does not pay much value to sustainability. He is happy to boast that he has a sustainable net zero house. This is agreed upon by B9 as well.

4.3.3.8. Others

B2 hesitates to adopt innovations as she is not comfortable with technical stuff. Her house overheats during the summer, and this can be a trigger for her to retrofit the house. If B3 is afraid of retrofitting, that is because she worries about cost overrun and not receiving the expected benefits. Further, B3 wants to know what other people (who have already retrofitted houses) have to say. B3 has not found any source that convinces her to retrofit the house. B10 values awareness about housing retrofit before making a decision. Her biggest concern about retrofit is how this retrofit works. So, she does not have confidence in the retrofit process or intended benefits. B11 and B10 are happy with their houses. They both do not need to do anything at this moment. B12 has concerns about unintended consequences. He needs to ensure that the retrofit does not have any unintended consequences.

B8 prefers social media and rating systems to get information about the quality and reliability of the stakeholders of housing retrofit as these tools are already close to him. Further, he suggests using technology to overcome existing barriers. For example, an AI chatbot. B5 also needs to know about the post-retrofit monitoring and evaluation. This is to ensure the promised performance benefits are achieved. He further says it will be better if the information is provided in simple words without using technical jargon. B6 thinks it is better if the regulations are handled by the designers and there is no need to give a lot of information about them to the homeowners. The homeowners can be made aware of the approval process under the building regulations.

4.4. Study 03 | Semi-structured interviews for artefact validation

4.4.1. Introduction

The artefact is expected to serve four purposes if it is developed in the real world as a decision support system. These purposes will finally contribute to the research aim and objectives. By referring back to the previous section of artefact development, the purposes of the artefact can be listed as awareness making, initial retrofit appraisal, lead generation and data collection.

The semi-structured interviews are to validate whether the artefact would serve the expected objectives if they were implemented in the real world. Checkland and Scholes (1990), as cited in (Venable et al., 2012) have proposed a simplified method of evaluating artefacts as a 5E framework. The five "E"s are efficacy, efficiency, effectiveness, elegance, and ethicality. According to Venable et al. (2012), there are five goals for evaluating artefacts. They are determining the effectiveness of solving the problem, evaluating the extent of satisfying requirements, understanding the knowledge created, comparing/contrasting the artefact in context, and understanding the side effects as well as opportunities for improvements. The artefact is not practically developed as an information system, but as a concept. Considering the nature of the artefact and the background of the interview participants, the validation criteria were customised as follows: novelty, awareness, option evaluation, lead generation and demand.

Table 39: Synthesizing the validation criteria with literature

	Customised validation criteria	Checkland and Scholes (1990), as cited in (Venable et al., 2012)	(Venable et al., 2012)
1	Novelty	-	Knowledge creation
2	Awareness	Efficacy	Satisfying requirements
3	Option evaluation	Efficacy	Satisfying requirements
4	Lead generation	Effectiveness	Effectiveness
5	Demand	Elegance	-

Table 39 depicts how the customised validation criteria are synthesised with the literature-recommended criteria. Some of the literature recommended validation criteria were not able to be adopted. According to the guidelines by Checkland and Scholes (1990), as cited in

(Venable et al., 2012), efficiency is unable to be validated at this level due to the conceptual nature of the artefact. Ethicality was not specifically validated as the artefact is still at a high level. The ethicality of the artefact needs to be tested and ensured before starting commercial development. Considering the guidelines by Venable et al. (2012), comparing and contrasting the artefact was done. It is presented under the discussion section of the validation interview data analysis. The interviewees were asked to comment on the five topics mentioned below.

4.4.2. Findings

4.4.2.1. Novelty

Other than one participant, all other participants said the idea was satisfactorily innovative. Although the blocks of the concept show no novelty when they are considered separately, putting everything together shows a greater level of innovation. Other than one participant (C10), nobody knew a similar concept currently in practice. C10 is working on the same concept as they have already developed a similar system. C10 agreed the proposed system has key differences on the positive side. Another participant signposted a mass-scale retrofit decision-making support tool “Pathways” developed by Parity Projects. It was intended for large-scale renovation schemes (Parity Projects, 2024b). Although they have a model for homeowners too, the capability is limited. It is better suitable for raising awareness (Parity Projects, 2024a).

C1 said that the need for the retrofit should be highlighted first. Users should feel more confident about why they need to retrofit their houses. In agreement with C1, C2 recommended starting with a problem of the user and showing them how their problem is solved. C3 said although the concept seemed to be innovative, it is still not clear why users should retrofit the house. C4 suggested using artificial intelligence to understand user behaviour better and make the estimates more realistic (Panakaduwa et al., 2024c). C8 recommended improving innovativeness by integrating more parties into the system. For example, C8 recommended integrating the customer profile with DWP (Department for Work and Pensions) and HMRC (HM Revenue and Customs) to see the eligibility for the grants. This needs to be involved with user privacy and confidentiality. Further, it is important to ensure that the users are genuine, not somebody playing around with bogus information.

C9 and C10 both were happy about the innovativeness of the concept. Their concern is how to reach the level of capability in practice. C11 sees this as a homeowner-centric approach rather than a property-centric approach. Retrofit is partly a technical problem and also a social problem. C12 was happy to see how the neighbourhood approach has been creatively used to improve the trust of the homeowner.

4.4.2.2. Awareness

The participants generally agreed that the artefact is helpful to improve the awareness of the homeowners about housing retrofit. Two of them were not happy about the capability as they could not understand the performance with just a specification for an information system without an actual system. Some participants argued that the best tool to improve awareness is not an information system. They believed it was the best way to do this in person. For example, C9 believed the best way of raising awareness is through people. This is a part of the awareness making process, but not the whole of it. The participants who were happy about the system, acknowledged that the presented capability would help to improve retrofit awareness, considering the limitations of an information system.

C1 recommended presenting the resources of the awareness section as blogs. So, it will allow the users to comment and share. This will improve the interaction between the system and the users. C4 also stated a similar idea. If the resources related to retrofit awareness can be shared on social media, it will help to spread the message. Further, if these posts can be commented on and rated, that will improve the interaction between the users and the system. C6 recommended starting awareness from a problem of the user which triggers the need for upgrades and continues to other areas. C8 highlighted the need for a proper strategy to attract traffic to the information system. Collaborating with similar groups, projects and organisations might create win-win situations.

C10 said that the system shall make people aware if they use it. However, C10 is worried about how to drive people to the system. C12 highlighted that the need for information is to be simple and digestible to the homeowners. C12 is happy with the existing level of information available in the system. C12 further said that it is important to show the users what they will achieve with this system. In this case, more KPIs are better to include to clearly show the potential improvement.

4.4.2.3. Option evaluation

The participants recognised the function of option evaluation as a key aspect of the proposed system. It generally received higher ratings from the participants. C1 said presenting retrofit measures all at once is not attractive and it can be too much to digest by the user. In this case, it is better to categorise them for easy digestion. E.g., Insulation category or renewable category. Further, she recommended that benefits be presented as life cycle benefits to make them more meaningful. C6 recommended ensuring that the user is allowed to improve the accuracy by inputting more accurate details of the house. Using real estate websites can be a good way to source more data; especially floor plans.

Without handling the contractor and material prices by this system, outsourcing that part to a comparison site such as Moneysupermarket.co.uk or confused.com was recommended by C6. These comparison sites already have a large user base, and they are already in a particular model of business. So, the proposed system can use their expertise and resources to make the process more efficient and attractive. Further, the system will reach a broader audience. C8 pointed out that the majority of the people coming to this system will not be eligible for government grants. In this case, it is important to let them work out their financing strategy with accurate and reliable information. According to C10, getting real time quotations from the installers using unit rates will not be practical. The first one is the difficulty of understanding the house without an inspection. The second one is that installers will not bother to update their prices and availability, just for the sake of generating quotations.

C9 recommended improving the relational aspect more if possible while C11 recommended improving the technical side of retrofit more, although they did not provide specific instances.

4.4.2.4. Lead generation

One of the main objectives of the system is to generate leads. That means a user escalates their interest in a physical retrofit assessment by making an appointment with a retrofit assessor. This can be called a lead. When the retrofit assessor makes a physical retrofit assessment, data on the house, occupant and risk information become available. This data can be stored in a repository such as the TrustMark data warehouse, which is similar to the concept of a building renovation passport. This was one of the recommendations by the Each Home Counts report in 2016 (TrustMark, 2024b). The most important aspect is that the data will be machine readable and sufficient to make professional retrofit strategies both individual and mass scale. Due to this reason, even if the user decides not to proceed with the retrofit option initially, the data will be highly important for future retrofit drives. As there are already systems available to handle the project management part once the retrofit assessment is done, the scope of this system stops when the user passes the lead to the retrofit assessor. The validation question asked participants how they see the potential of lead generation by this proposed system.

Generally, the participants agreed that the lead turnover would be increased if the assessment was given free. This is agreed by the literature as well. Further, the user should not be obligated to retrofit their house by calling a retrofit assessment. Technically, if there is no obligation to retrofit and if the assessment is free, there is a better chance for a homeowner to proceed with a retrofit assessment.

C4 said that it is better if the user interactions can be given points. For example, the user can be given points to complete retrofit awareness activities, generate the retrofit option evaluation, and input more precise data to improve the accuracy of the system. When the user accumulates a number of points, they will be unlocked for a free retrofit assessment. Otherwise, they will have to pay. This might motivate people to engage with the system more and contact a retrofit assessor. According to C8, there will be a clear demand from a certain breed of people who always look out for energy efficiency, health, comfort, sustainability and similar topics. There is some other segment that will not find much interest in the concept. In this situation, irrespective of the performance of the system, there will be a segment that will not go for an in-person retrofit assessment. This was agreed by C9 and C11. Contrastingly, C10 was highly prospective about the lead generation. A similar system owned by C10’s company is getting one lead generation out of five registrations. In this case, it will work depending on the assessment fees. C12 highlighted an important aspect. She said the hassle involved with the retrofit options needs to be communicated with the user apart from the disruption. This was not thought of earlier in the artefact design.

4.4.2.5. Demand

Although the system is innovative, resourceful and helpful in retrofit decision-making, still there may not be a demand for it from the intended audience. Considering this, the participants were asked how they saw the potential demand for this concept. The general feedback was positive but subject to the attractiveness of the system. As the system is not built in the real world, the participants struggled a bit to brainstorm the model context. It was clear that there is a demand for a potential solution to the problem of retrofit decision-making help to homeowners. The question was how this system is close to the ideal solution.

C1 highlighted the importance of emphasising the benefits more. Presenting a comparison between the existing performance and after-retrofit performance will show a clear justification for the homeowners to proceed with housing retrofit. This will help the homeowners to understand the need for housing retrofit. Some homeowners think they already live in a good performing house, although it is a poor performing house. Further, C2 recommended finding the unique selling proposition of the proposed system. According to Deland (2022), unique selling proposition of a product is the value it has which competitive product does not. C4 also presented a similar idea. He asked to find a “wow” factor in the system which the users will say “wow” over the other products. According to the concept of a unique selling proposition, it can be argued that this system has all the information under a single point of contact. In addition, this system has considered extreme personalisation according to the house and the user.

C3 has recommended improving the attractiveness of the system by adding coloured graphs and tables. C5 said that the idea is clear, nice and simple. In this case, it is important to maintain that level of simplicity without putting too much information. C5 believes the existing level of information is more than enough. This is endorsed by C8 and C12 as well. C7 said it is better if the benefits can be emphasised, especially the financial benefits. The general idea of the interviewees is that it is difficult to give a rating as it depends on the attractiveness of the system. No doubt the concept has a demand. In order to improve the demand, the system needs to be highly attractive.

C9 has no issue with the demand. However, C9 thinks the system will have a demand only from a certain segment of people. According to C10, the demand from the stakeholders is not picked up for their system although the users are highly satisfied with their system. There will be a demand. But the solution needs to come with policy support. C11 warned that the developers will have to do a lot of things outside the system to make the concept a reality. That means the required background is not there yet.

4.5. Chapter conclusion

The purpose of this chapter is to record data collection for the thesis. There are three empirical studies conducted in the research. The first one is a questionnaire survey to identify homeowner behaviour. The second is to collect artefact requirements. The third one is to validate the artefact. As far as the overall research aim is concerned, the purpose of the artefact is to encourage homeowners to undertake housing retrofit. The data collection was highly useful to identify the recommendations for artefact development and to validate the artefact for its intended capabilities.

The next chapter is allocated to discuss the findings of the research. Further, it will develop the artefact and validate it for intended functionalities.

5. CHAPTER 05: DISCUSSION

5.1. Introduction to the chapter

This chapter discusses the data analysis of the previous results chapter. There are two empirical studies to cover the literature gap and another empirical study to cover the artefact validation. The first one is a questionnaire survey and the other two are semi-structured interviews. The population of the questionnaire survey is the UK homeowners and the population of the semi-structured interviews is retrofit industry stakeholders. The following sections discuss the findings of these three studies.

First, the general findings are critically analysed by synthesising the literature. Then the conclusions from the studies are presented as summaries. These summarised factors are considered as recommendations for developing the artefact to encourage homeowners to retrofit their houses. The developed artefact is presented with a description of its characteristics. A final discussion was made with a discussion of the findings of the artefact validation semi-structured interviews and a benchmark analysis to compare the artefact with the existing similar systems in the UK. This chapter focuses on showing how the research achieved the second, third and fourth objectives.

5.2. Study 01 | Homeowner behaviour | Discussion of the findings

Table 40 shows the summary of the findings of the questionnaire survey. A further discussion has been conducted concerning this table. According to Cronbach's Alpha, internal consistency analysis, all the items are satisfactorily contributing to the relevant information requirement code. Generally, the questions measure the construct which they are intended to do. Secondly, the above table summarises the most important information required by the homeowners to make a retrofit decision.

Table 40: Summary table of the important information requirements

Rank	Information requirement	Mean value
1	Estimated energy use reductions.	4.2500
2	Estimated future energy bills.	4.2500
3	Warranty and guarantee information about upgrade measures.	4.2255
4	Potential renewable energy generation by the house.	4.2115
5	Quality ratings of the suppliers, installers, designers and others.	4.1250
6	Monthly loan instalments and payback period.	4.0769
7	Overall upgrade project duration.	4.0481
8	Recommended home upgrade measures.	4.0388
9	Health and safety risks.	4.0388
10	The big picture of home upgrades.	4.0192
11	Possibility of breaking the project into phases and their costs.	4.0097
12	Cost of each housing upgrade activity.	3.9709
13	Guaranteed minimum quality of upgrade measures.	3.9515
14	Potential risk towards cost, time, and quality.	3.9327
15	Types and amounts of finance.	3.9327
16	Comparison of future and current energy bill/use reductions.	3.9320
17	Nature of disruption.	3.9231
18	Quality information about the products and materials.	3.9135
19	The total upfront cost of the housing upgrade.	3.9135
20	Cost comparisons among sources/contractors.	3.9126

As per the conducted sectorial analysis of variance (ANOVA), the study suggests that the homeowners' level of education has a clear impact on the nature of the information they require for retrofit decision-making. Unfortunately, the study does not provide whether highly educated homeowners need more information or vice versa. Further, the study does not provide valid details about the influence of age or other demographic factors on the information they require to make a retrofit decision. The study validates the findings of the previous literature and gives an overall idea of the homeowner decision-making behaviour in housing retrofit.

It can be noted that the estimated energy use reductions and estimated energy bills are the main two information items that the homeowners are highly concerned about. These two items are involved with the payback of the investment and the expected utility of the retrofit. It can be concluded that when homeowners look for information about retrofitting their houses, they look at housing retrofit from an investment point of view, thinking about how to recover the cost of retrofit in due course. This finding contributed to an imortant recommendation of the research.

Further, the homeowners are concerned about the warranty and guarantee information about the housing retrofits. This agrees with the literature findings. According to Wilde (2019), the homeowners are doubtful whether they will receive the promised retrofit benefits. In line with the recommendations of Rickaby (2019), stakeholder confidence regarding the housing retrofit is extremely important. Considering this data analysis, the top three information requirements represent the above-mentioned problem of poor stakeholder confidence from the point of the homeowner. In addition, the quality rating of the suppliers, installers and designers also goes in line with this. In conclusion, homeowners need to ensure that there are no unintended consequences of retrofitting their houses. This leads to the another recommendation of the research, which was originated from the literature and validated in the questionnaire survey.

5.3. Study 02 | Artefact requirements | Discussion of the findings

5.3.1. Introduction

The second empirical study was conducted as semi-structured interviews with retrofit industry stakeholders. The study was conducted in two parts; one with the homeowners and the other with the rest of the retrofit industry stakeholders. The data was collected and analysed separately. However, as the overall purpose is to identify the requirements for the proposed artefact, the discussion was done as a single activity. According to the data collection and analysis of the semi-structured interviews, there are six key recommendations identified to support artefact development.

5.3.2. R1 | Investment focus to consumption focus

According to the literature findings and the conducted questionnaire survey, the homeowners see housing retrofit as an investment. They look for information on how the retrofit cost can be recovered with energy bill savings. This was further endorsed by the interview participants. When it comes to the installation of retrofit measures, homeowners look for the payback period. They do not do payback analysis when they buy a car or install a new bathroom. Conclusively, homeowners see retrofit as an investment, but installing a new bathroom as a consumption.

Retrofit measures have unimpressive payback periods in monetary terms (Liu et al., 2024; Menicou et al., 2016; Murphy, 2014). Further, the energy bill savings are difficult to estimate due to reasons such as unpredictable behavioural patterns of the residents (Booth & Choudhary, 2013) or rebound effect (Castro et al., 2022). This investment mentality has been infused to the homeowners by the industry itself. For example, the PAS 2035 option evaluation justifies retrofit measures according to normal payback analysis and carbon cost-effectiveness analysis (BSI, 2023b). It is recommended to reframe housing retrofit as a consumption where there is no payback analysis present. This recommendation originated from the questionnaire survey and was further validated with the semi-structured interviews with the retrofit industry stakeholders.

As a way of reframing housing retrofit from investment focus to consumption focus, energy bill savings and payback period can be presented without figures. For example, a star rating can be used to present the potential of energy bill savings of a given retrofit measure. That will recommend the homeowner about the energy bill savings potential, but will not push the homeowner to do payback calculations. This idea was referred from the literature from (Ossokina et al., 2021; Seddiki et al., 2022) and brainstormed by the researcher according to the statements of the interview participants.

In line with the above recommendation, the benefit of quality of life from retrofitting houses needs to be highlighted. Quality of life can be defined as the level of physical and mental health, wealth, comfort, necessities, and material goods available to a particular geographic area (World Population Review, 2022). Although the financial benefits may not be attractive, retrofitting houses shall improve the occupant health by avoiding mould growth, condensation, cold and VOC levels (BRETrust, 2020). Further, it can increase the thermal and indoor comfort levels (Hopfe & McLeod, 2015). Due to the potential of reducing energy bills and eliminating fuel poverty, housing retrofit shall give financial comfort and affordability as well (Cpag, 2022; Housing Ombudsman, 2023; National Energy Action, 2024). Considering the national levels, retrofit can save health costs in billions of pounds (Garrett et al., 2021) and remove nearly six million households from fuel poverty (National Energy Action, 2024). By focusing on these reasons, the quality of life benefits of housing retrofit need to be highlighted together with reframing the investment focus.

5.3.3. R2 | A homeowner-centric approach

The literature has suggested that the retrofit drives need to focus on the homeowner rather than the property. The homeowner (this can be the homeowner, landlord, tenant or resident) is the person who is influenced by the performance of the house. The houses are designed for people and people are living in houses. The ultimate objective is to make houses a better place for people. Further, the homeowner is the ultimate decision maker and not the house. If the retrofit is not designed by focusing the homeowner, they will not be interested in retrofitting their houses.

As far as the current government grants are concerned, most of them focus on houses. For example, the Home Upgrade Grant is for houses without central gas heating (Blackpool Council, 2023). As discussed in the literature review, the Home Upgrade Grant is observed to be designed with the perception that people do not have central gas heating because they cannot afford it. In reality, they do not have central gas heating, which may be because of their choice, not because of affordability. The Energy Company Obligation considers only the income criteria of the applicant and nothing more about the homeowner or their decision-making behaviour (Ofgem, 2022). This criticism is not new. Even the 2013 Green Deal is criticised for its overreliance on technical rational models (Booth & Choudhary, 2013). The proposed model focuses on the homeowner and tries to present the idea of retrofit according to their decision-making behaviour.

In line with a homeowner-centric approach to retrofit, the findings recommend not changing the existing socio-economic ecosystems, but promoting stakeholder collaboration in housing retrofit. Poor stakeholder engagement has been identified as a challenge in promoting housing retrofit (McGinley et al., 2020). This challenge has also become a key barrier to the homeowner to source information related to housing retrofit in a user-friendly manner (Brown, 2018; Fylan & Glew, 2021). The whole concept of one stop shop model for housing retrofit is to promote stakeholder engagement and provide homeowners with a single interface to source information (Brown, 2018; McGinley et al., 2020). This was well acknowledged by both the literature as well as the empirical studies. It is expected that the homeowner is motivated to retrofit their house when they can get the required information in a user-friendly and efficient manner.

The complexity of the retrofit process will demotivate homeowners from exploring retrofit options for their houses (Mlecnik, 2010). As far as the existing housing retrofit experience is concerned, the homeowner needs to contact several parties to get information related to housing retrofit (McGinley et al., 2020). It also disrupts their daily routines. Although they can contact a professional such as an architect, that would imply a commitment to retrofit while they have not yet made up their mind. In this situation, it is recommended to simplify the experience of retrofit for the homeowner in a homeowner-centric approach to retrofit.

The questionnaire survey identified that the decision-making of the homeowners has a relationship with their educational background. The interviewees agreed that the complexity of housing retrofit keeps the homeowners away from exploring the topic. The proposed system should reduce the complexity of housing retrofit. It should not make the homeowner obliged to retrofit, but facilitate retrofit awareness, option evaluation and retrofit assessment efficiently and simply. Apart from the simplicity of the retrofit experience, it is better to keep the user interface of the proposed system simple and user-friendly.

The idea of loss framing first emerged through the literature review under the prospect theory. According to the prospect theory, people are sensitive to loss more than gain (Levy, 1992; Mittelstaedt, 2020). Loss framing can be used to convince retrofit benefits more rigorously to the homeowners (Li et al., 2023). For example, without presenting the benefits of housing retrofit, it will be more effective to present losses of not retrofitting houses (Ebrahimigharehbaghi, 2022). People are generally risk-seeking and loss-averse. The idea was taken into the questionnaires for semi-structured interviews and the interviewees also validated the potential of loss framing.

5.3.4. R3 | Perception of already having a better house

One of the challenges to promoting retrofit is that the homeowners believe they already live in a good-performing house (Lewis, 2023). This was identified through the literature review and the interviewees also verified this. The interviews conducted with the homeowners revealed that they do not need to retrofit the house as they think they live in a better performing house and there is no requirement for retrofit. However, the literature reports otherwise. The housing stock in the UK is considered the oldest and worst-performing (BRETrust, 2020; Butt et al., 2020; RICS, 2020). The Health Foundation argues that one in every five houses in England is below the standards of quality of life and it is just a roof over the heads of the residents (The Health foundation, 2017). Citizens Advice has found that one point five million children are living in mouldy, cold or damp private rented houses. This has caused severe illnesses in children (Citizens Advice, 2023). Accordingly, the perception of having a good house needs to be changed. Without making the homeowners realise that their houses are not performing well, they will not think about retrofitting the house. If the house is performing well, there will not be a need for retrofit in the first place.

The existing retrofit programmes focus on the older and hard-to-treat properties. Technically, retrofitting these houses is difficult and the costs can be higher. For example, the Home Upgrade Grant provides 100% funding to retrofit houses without central gas heating (Blackpool Council, 2023). If the homeowners do not believe they live in a poor performing house, the challenge will be higher. It is rational to say that older and worst performing houses need to prioritise considering their impact on the environment as well as the residents. From a social science point of view, it is otherwise.

With reference to theories such as social identity theory or cognitive biases, people try to imitate their neighbours (Hatch & Schultz, 2004; Leaper, 2011; Ramos, 2018). Accordingly, if one house on a street is retrofitted, the others easily follow. Nobody wants to be the guinea pig of the street by retrofitting their house first. When the number of retrofitted houses is counting, the others will try to follow the trend. The hesitation to be the first one to retrofit can be justified with the unintended consequences and uncertainty of the cost and benefits. If the newer houses were given priority to retrofit, that would take less time and require less money. It will be also easier to convince the homeowners since the required retrofit scope is small. Accordingly, the number of retrofitted houses will rise quickly. This message will push others to follow the trend.

5.3.5. R4 | A neighbourhood approach

The intuition for the neighbourhood approach was brainstormed during the literature review. Practice theories (Oerther & Oerther, 2018), social identity theory (Hatch & Schultz, 2004; Leaper, 2011) and place-based approaches (Ingold, 2000; Merrick, 2023) paved the path to the neighbourhood approach to housing retrofit. The idea is to promote retrofit programmes by focusing on a manageable geographic area. This can be a house scheme, road, town or village as it needs to be. The people will know each other in such a small geographic location. If the technical aspects of the retrofit are strong, project delivery is efficient and the risk of unintended consequences is low, there will be a greater chance of spreading the message quickly (Cinderby et al., 2021; Fransman & Timmeren, 2017). As one interviewee said, people will do what their neighbours do, even if they do not know what it is. This led to reduce the focus of the one stop shop to a small geographical area. In this locality, residents may know each other already. The professionals, installers and other stakeholders may be already known by the homeowner. This will encourage the homeowners to engage more in housing retrofit.

Another side of the neighbourhood approach is promoting the social relations within and outside of the system. It is possible to promote online social relations within the system by allowing an opportunity for the users to interact with each other and communicate with the stakeholders. Apart from that, the system shall promote social interactions outside the system wherever possible. For example, the system can list the people in the user's locality who have already retrofitted their houses. They can meet each other in person to witness and discuss the pros and cons of retrofitting houses. Research recommends the importance of social relations to encourage housing retrofit (Cinderby et al., 2021; Galvin & Sunikka-Blank, 2014).

Another consideration of the neighbourhood approach is the use of normal people in the homeowner's neighbourhood to spread the message of housing retrofit. Homeowners will trust their social network comprising of their friends and family than anyone else. There is no need for retrofit experts. People hesitate to believe tradespeople and marketing people. But they do trust people in their neighbourhood. In this situation, if the facts are accurate and reliable, the best way to disseminate it with the help of the most trusted people. The concept is already observed in some contexts. For example, energy ambassadors in the Netherlands (Ebrahimigharehbaghi et al., 2022c). One interviewee clearly said, “We need normal men and women who have witnessed the benefits of housing retrofit to disseminate the message of housing retrofit”.

The proposed information system has a limitation as it can only be used by people with some computer literacy. However, if this type of system is available, any person with computer literacy can easily take others on a retrofit journey with the help of the system. This can be especially helpful for elderly people. The researcher has personally witnessed the potential of such an information system in coffee mornings for elderly people as a retrofit advisor.

The current housing retrofit industry is fragmented and different retrofit measures are installed by different installers. These installers do what they know best. They are not happy to provide integrated measures (McGinley et al., 2020). The housing retrofit industry in the UK has shown unintended consequences in the past due to different installers installing different measures without proper integration of how these measures interact with each other (Rickaby, 2023). The PAS 2035 specification for retrofit project management has been designed to avoid these unintended consequences. The retrofit coordinator should coordinate different installers and other professionals and ensure proper interaction among the retrofit measures (BSI, 2023b).

As the proposed system is complementary to the PAS 2035 specification, it also recommends keeping the industry ecosystems as it is. The proposed system can be designed in a way to reduce the bottlenecks of the existing practices by collaborating information. The idea is to change the promoters how they approach housing retrofit, but not to change the existing socio-economic ecosystems which will be difficult due to the shorter time window before 2050. Some companies are trying to adapt to the marketing need for integrated retrofit services (Blackpool Council, 2023; Furbnow, 2024).

5.3.6. R5 | Actual quotations over estimates

Both the questionnaire survey and the semi-structured interviews highlighted the importance of accurate and reliable information related to retrofit. It is reported that the existing similar systems only provide rough estimates. The EPC report also provides estimated costs of retrofit measures. If there is a way of providing actual quotations of retrofit measures, that could be more convincing. There are challenges according to interview participants. There are issues with the accuracy of building dimensions and other details. Further, installers may not be happy to update their prices on a website just to provide quotations. There can be ways of doing this with the help of comparison sites, that are already in similar types of businesses.

5.3.7. R6 | Best practice

Both the questionnaire survey and the semi-structured interviews have verified that homeowners are highly concerned over the unintended consequences of retrofit. For example, one homeowner expressed her biggest fear of retrofit as “I do not know will this work”. This means she is not sure whether she will get the intended outcomes by retrofitting the house. As per the literature review, the key reason for this issue is the absence of best practice (Rickaby, 2023; Rosenow & Eyre, 2016). People without qualifications are installing single measures where there is no assessment of the risk of interactions among the measures. The risk is now mitigated to a satisfactory level with standards, certifications and best practices (Edwards, 2021; Patterson, 2023). PAS 2030/2035 specifications have addressed the problem to a greater level (Rickaby, 2023). Further, there are proven certifications such as Passivhaus EnerPhit (Traynor, 2019) or Energiesprong (Energiesprong, 2019).

5.4. Artefact requirements | Objective 02

The purpose of the above two empirical studies is to identify the recommendations for artefact requirements under the second research objective. The questionnaire survey contributed to the R1 and R6 recommendations. Interviews contributed to all six recommendations. These recommendations are to be considered in the design of the artefact to encourage homeowners to retrofit their houses. The research aim is to be achieved through a socio-technical systems approach, consisting of the homeowner behaviour, the technical system of housing retrofit and the social system of housing retrofit. The identified recommendations from the previous empirical study discussions are synthesised under these three themes to have a better picture. These recommendations are considered as the key artefact requirements to conclude the achievement of the second objective.

Table 41: Research recommendations

Theme	Recommendation
Homeowner decision-making behaviour	R1. Reframing housing retrofit from investment focus to consumption focus.
	R2. A homeowner-centric approach to retrofit over the existing property-centric approach.
	R3. Change the wrong perception of already having a better performing house.
Social system of the housing retrofit	R4. Neighbourhood approach with laypeople to drive housing retrofit.
Technical system of housing retrofit	R5. Facilitating actual quotations (not estimates) to improve the homeowner's confidence.
	R6. Following PAS 2030/2035 specifications, standards and other industry best practices to reduce unintended consequences.

According to Table 41, the first theme is homeowner decision-making behaviour. There are three recommendations under the theme of homeowner decision-making. The second theme is a social system of housing retrofit. There is only one recommendation under this theme. The third theme is the technical system of housing retrofit. The research did not directly focus on this theme under the scope. However, there are two recommendations were derived from the conducted empirical research on this theme as well.

5.5. Artefact development | Objective 03

5.5.1. Proposed artefact

The third objective of the research is to develop an artefact to encourage homeowners to retrofit their houses. Considering the artefact scope, this artefact will fit in the gap between the homeowner and the retrofit professionals as an information system. It will work as a one stop shop for all the engagement with the retrofit process by the homeowner with a single interface. Considering the academic approach to developing an artefact under the design science methodology, the artefact shows a high-level framework of how the homeowner engaged with the retrofit process with the help of an information system. Figure 23 shows the developed artefact.

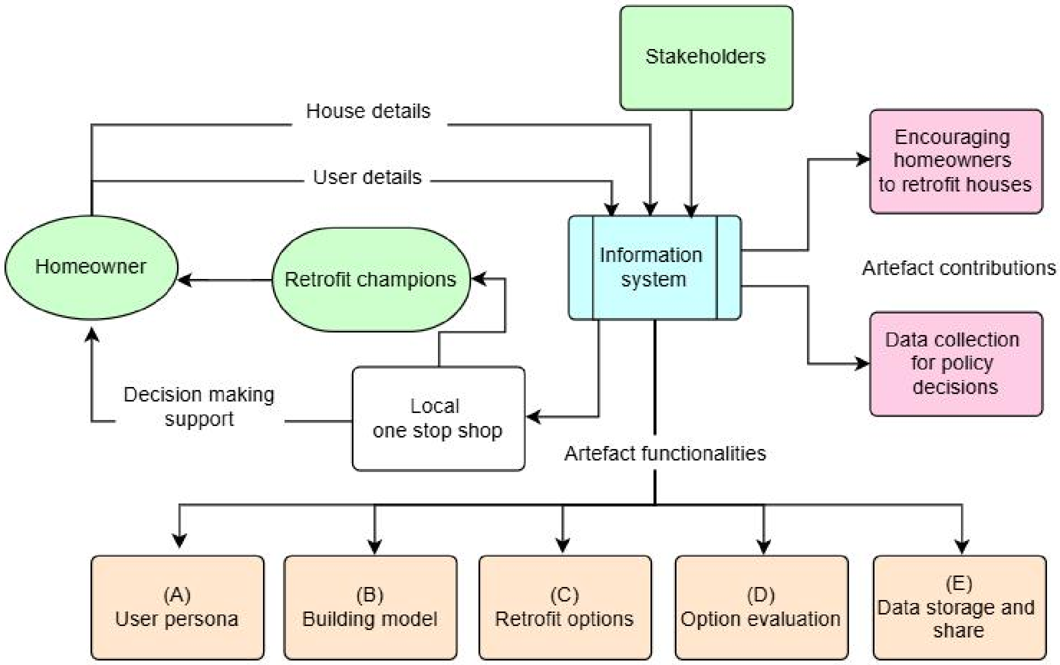

Figure 23: Artefact for the information system

The homeowner is a key stakeholder in the retrofit process in the housing retrofit process. The research recommends a homeowner-centric approach to retrofit under the recommendation "R2" of the research. Homeowner should provide data about the homeowner's circumstances, demographics, preferences and any other relevant information to the information system. Further, the homeowner is supposed to provide data about the houses as well. The interviewees recommended reducing the data input from the homeowner as much as possible to reduce user fatigue and improve user-friendliness. The information system shall seek ways of extracting information from available other sources. This will help to deliver the functional requirements A and B about the user information and house information.

Another important recommendation used for the artefact development is "R4", a neighbourhood approach with laypeople to drive housing retrofit. The information system shall facilitate homeowners to engage with the retrofit process through the system itself as well as through the retrofit champions and people in the neighbourhood. The local one stop shop is the localisation of the homeowner's social network to their neighbourhood. When the homeowner engages with the proposed information system, they will see retrofit professionals, retrofit champions, installers, friends and family in their neighbourhood. This will create a sense of familiarity for the homeowner, where they can engage with this social network through the system as well as outside of the system.

The installers should also list their services, availabilities and unit prices to the system. This will help the system functionality "C", with regard to the retrofit options. According to the research recommendation "R5", it is important to provide real quotations to the homeowners to improve their confidence. If the installers provide their unit rates, the system shall work out real quotations when the homeowner provides the details about their house. The research recommendation "R6" is to use PAS 2035 and other industry best practices to reduce unintended consequences. The system should decide the mix, scope and schedule of the retrofit measures according to the PAS 2035 and other industry best practices.

Now the homeowner can understand and explore the retrofit options available to their house with the system. The functionality "D", option evaluation is to help the homeowner with that. The interviewees recommended giving three default options with high, medium and low energy efficiency levels to the homeowner. The homeowner should also be able to customise these options. According to research recommendation "R3", changing the perception of already having a better-performing house should also be considered in this stage. The homeowner should be shown a comparison of the house's existing performance level with the performance level when the house was retrofitted to EPC "A" or Passivhaus Enerphit level.

The other recommendation "R1" is to reframe the focus of housing retrofit to consumption from investment. This recommendation was discussed in detail in the discussion section. In general, the idea is not to convey the energy bill savings in numbers, but to use a rating system. Further, techniques such as loss framing of retrofit benefits are also to be considered for this purpose.

The system will have to collaborate with several stakeholders to perform its functions. The functionality "E" is related to this requirement. The system shall store and share data with several other stakeholders for smooth functioning. One of the practical contributions of this artefact is to generate data for policy decisions. As the homeowners are engaged with the artefact to explore retrofit options for their houses, the system will generate a substantial amount of data about the homeowners, houses and the housing retrofit options applicable to these circumstances. If the homeowner is not happy to continue with the retrofit process, the government can provide more incentives to encourage the homeowners to retrofit their houses. For example, relaxing the criteria of the grant schemes.

Finally, the main contribution of the artefact is encouraging homeowners to retrofit their houses. The homeowners will be motivated to retrofit houses with the interaction of this system by

I. Enhanced retrofit awareness
II. Understanding the retrofit options and benefits
III. Understanding the retrofit process better
IV. Being reassured by the social network of the homeowner
V. Better policy decisions by the government

5.5.2. Artefact scope and purposes

The artefact design and development were started once the artefact requirements were collected. The following Figure 24 demonstrates the scope of the artefact. This has been designed concerning the artefact's purposes and the research objectives. The methodology section presents the scope of the artefact and its purposes in detail.

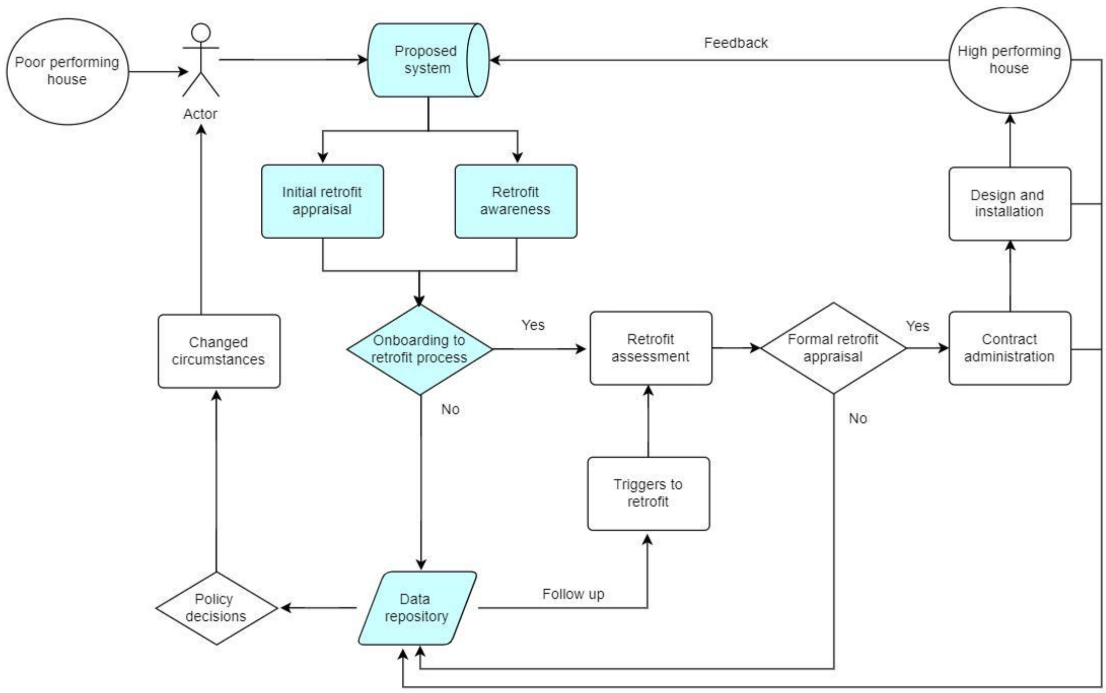

Figure 24: Artefact scope

One of the purposes of the artefact is to improve awareness about housing retrofit. Another purpose is to support homeowners in exploring housing retrofit options for their houses. As per the above figure, the proposed information system shall facilitate the homeowners for the above two purposes. These two purposes shall lead the homeowner to onboard the housing retrofit process. This will lead the homeowner to go for a retrofit assessment. Irrespective of whether the homeowner decides to onboard the retrofit process or not, the data about the homeowner and the property needs to be stored in a data repository.

5.5.3. Functional requirements

There are five functional requirements expected from the proposed system. These functional requirements were determined according to the literature review and the empirical data collection, with reference to the research objectives. The following Table 42 shows the list of the functional requirements.

Table 42: Functional requirements list

Req. ID	Requirement Name	Requirement Description
A	User persona	A persona of the user is to be created to model the homeowner's behaviour.
B	Building model	To have an information model of the house. Ideally a BIM model.
C	Retrofit options	Information about retrofit measures, products, cost, finance, quality, installers, interdependence or scope.
D	Option evaluation	The users shall explore the potential retrofit options for their house and how they can be scheduled, including cost, finance and quality.
E	Data storage and share	Data about users, house models, and retrofit option searches are to be stored in a cloud space including the system itself. The data needs to be shared when and where necessary in different formats and mediums.

Apart from the above-mentioned functional requirements, the non-functional requirements will also be required to decide when the artefact is developed into a prototype as the proposed information system. For example, scalability is an important non-functional requirement. As the UK has more than 30 million households, the system should have the scalability to accommodate 30 million users over time. These non-functional requirements were not considered under the scope of the research.

5.6. Artefact validation | Objective 04

5.6.1. Study 03 | Artefact validation | Discussion

There are several findings from the validation interviews. One is the outsourcing of providing a real quotation function to a comparison site. This was a key recommendation of the research “R5”. Without developing this function from scratch, the process can be outsourced to a company already engaged in a similar type of business. Currently, none of the companies provides real-time quotations for housing retrofit. If the contractors can submit their unit rates and availability (by integrating their resource management systems with the proposed system), that will be possible. There are problems with the level of digitisation of the contractors. The level of adopting digital tools for project delivery among small-scale contractors is doubtful. It is expected that the competition may influence them to go for digital resource planning, management and project delivery.

Another suggestion is to identify the user’s problem and guide them through an attractive user experience to show them how their problem can be solved by retrofitting their home. The requirement of personalisation of the content again comes here. The user experience needs to be highly personalised. As the study found, the unique selling proposition or “wow” factor also plays a role here. There should be a clear business case for the users to engage with the system to make an appointment with the retrofit assessor.

Keeping things nice and simple is another important aspect according to the participants. This can be referred to the 1960’s US Navy design principle “Keep it simple, stupid (KISS)” (Dale, 2017). One participant suggested categorising retrofit measures for easy digestion. Another participant said not to add too many functions as it would make the process exhaustive. Another participant suggested allowing users to input details to the technical user level as some of the users may be capable of that. This needs to be voluntary while keeping the default approach simple.

In general, the participants were satisfied that the artefact shall serve the purpose of its development objectives. As a recap, these objectives can be given as creating housing retrofit awareness, generating leads by user motivation, supporting retrofit option evaluation and collecting user and property data for policy decision-making.

The system will improve retrofit awareness by providing resources. It will generate leads by inviting the users to have a physical retrofit assessment done. The system will show how housing retrofit can help solve their problems with their houses. The system shall also facilitate retrofit option evaluation by integrating with the supply chains and other related parties. Finally, the system collects data about the housing stock as well as the homeowner.

It is important to keep things simple while not compromising the capability. Further, the users are to be given realistic information to make a decision, rather than average results. Lack of trust and confidence have been identified as a critical barrier to promote housing retrofit. If the users were provided with estimated figures, that would not improve the trust and confidence of the users. Although the artefact has been developed through extensive research and the use of theoretical aspects, it is always advisable to review the purposes and up-to-date knowledge if the system is practically developed.

5.6.2. Benchmark analysis

When it comes to artefact validation, there are many methods found in design science research. Design science research identifies validation as ensuring the artefact meets its objectives (Wieringa, 2014). Considering several case studies of artefact validations in the literature, a tailor-made artefact validation criteria was designed by synthesising existing literature. This includes novelty, awareness, option evaluation, lead generation and demand.

For the discussion section of the validation chapter, a final validation method was used according to Vaishnavi & Kuechler (2015). This is considered a benchmarking analysis, where the artefact is compared with three similar systems (Vaishnavi & Kuechler, 2015). The EPC report was taken as the benchmark and three other existing homeowner retrofit engagement systems were compared with the artefact.

The researcher found only three retrofit decision support systems, apart from the EPC report (Dclg, 2017). One is "EcoFurb" developed by Parity Projects. This system uses the RdSAP database, Ordinance survey maps and own cost databases to generate personalised housing retrofit recommendations (Parity Projects, 2024a). The system is observed to be basic in terms of capability. There is another system developed by Energy Savings Trust, which is called the "Home Energy Saving Tool" (HES Tool). This can be accessed through the Halifax Bank website (Halifax, 2024). The third information system is "Snugg" (Snugg, 2022). All the above systems share the same level of capability. On the positive side, the use of these systems is straightforward, nice, and simple but more powerful than the EPC report. It is unclear whether this level of capability can make an impact. Table 43 compares and contrasts these systems, the proposed artefact and the EPC report.

The EPC report is the main document issued under the auspice of the government about the energy performance of residential properties. An EPC report contains details about estimated energy performance, environmental impact assessment and recommendations to improve energy performance. The energy performance is given as a rating from A to G. The report indicates the existing and potential rating with retrofit measures (Dclg, 2017). The EPC report was considered as the benchmark for the above analysis as it is the most basic and the most popular one. Further, the other systems are reported to be based on the EPC database.

A case study of a semi-detached house was used to compare and contrast these systems. As the artefact is not developed to a functional level as a system, the expected functionality was considered as the performance output.

Table 43: Comparison between existing systems and proposed artefact

	Capability	EPC report	EcoFurb	HES Tool	Snugg	Artefact
1	Non-technical audience	Yes	Yes	Yes	Yes	Yes
2	Personalisation (Property)	Yes	Yes	Yes	Yes	Yes
3	Recommendations	Yes	Yes	Yes	Yes	Yes
4	Based on EPC	Yes	Yes	Yes	Yes	Yes
5	Simplicity	V. high	V. high	V. high	V. high	High
6	Update property details	N/A	Medium	Medium	High	V. high
7	Localisation	Low	Low	Low	Low	V. high
8	Personalisation (User)	No	Poor	No	Poor	V. high
9	Real quotations	N/A	No	No	No	Yes
10	Finance & grant eligibility	N/A	No	No	Basic	Yes
11	Quality details	N/A	No	No	No	Yes
12	Networking	N/A	No	No	No	Yes
13	Social science theories	N/A	No	No	No	Yes
14	Human-centred design	N/A	Yes	Yes	Yes	Yes

V. high = Very high

EPC report and all the tools prepared personalised recommendations for energy efficiency according to the property details. All of them addressed a non-technical audience. All of them had recommendations for measures to improve energy efficiency with estimated energy savings and estimated costs. All the other systems were primarily based on the RdSAP database (EPC Report). When it comes to simplicity, apart from the proposed system, all other tools were highly simple. The proposed artefact is required to be simpler. It will be less simple than others due to the level of capability.

Localisation is considered as how the user engagement is coupled with the neighbourhood according to the property address. Due to the local one stop shop concept, the proposed system will be highly localised. The EcoFurb and Snugg tools can be used to contact local contractors. The localisation of those systems is far more limited compared with the proposed system. Further, EcoFurb and Snugg allow it to be personalised according to the user to a certain extent. The proposed system is recommended to be extremely user-centric. For example, it needs to personalise the content dynamically according to the real time behaviour of the user. For example, whether the users make decisions based on rationality or heuristics.

One of the main highlights of the proposed system is actual quotations. None of the other systems provide actual quotations, but estimates. The Snugg tool shows the eligibility for grants at an estimated level. The proposed system should show the actual eligibility for grants and loans. Government databases such as HMRC and DWP as well as credit scores are expected to facilitate this. Quality assurance of the retrofit is not addressed by the existing tools. The proposed system will highlight the quality assurance under PAS 2035: 2023 specifications.

Only the proposed system has addressed the neighbourhood and social interactions. Further, no tools were observed to use social science theories to maximise user interactions as per the analysis, except the proposed artefact. All the existing systems seemed to put a great weight on human-centred design, focusing on easy navigation and unexhaustive user experience.

In general, it can be concluded that the artefact is capable of meeting its purposes. Accordingly, the artefact shall answer the research problem of the limited interest of homeowners in retrofitting their houses. The validation of the artefact also endorsed the key recommendations of the data collection.

5.7. Chapter conclusion

This chapter focused on the discussion of the findings of the research. Along with the discussion, the chapter described how the artefact was developed and validated. The developed artefact is given in the chapter as a model according to design science research. The artefact is a high-level framework for an information system to bridge the gap between the homeowner and the retrofit professional, to encourage the homeowners to retrofit their houses. The artefact was validated satisfactorily to ensure that it will address the intended purposes. There was a further benchmark analysis to compare the proposed system with the existing similar systems.

The next chapter is dedicated to the conclusions of the thesis. It will be the final chapter of the thesis. Research recommendations, limitations, future research and claimed contributions are presented in this chapter.

6. CHAPTER 06: CONCLUSION

6.1. Introduction to the chapter

The first chapter started with an introduction to the research. The limited homeowner interest in housing retrofit was identified as the research problem, which is a challenge to sustainability in the UK. It also described the research aim and objectives. The first chapter sets the background for the research. The second chapter is the literature review to justify the research problem in detail. The chapter discussed housing stock, housing retrofit in the UK and the homeowner behaviour. The third chapter is the methodology chapter. This chapter presented the method followed by this research, which is design science. The fourth chapter presents the data collection and analysis to achieve the second, third and fourth objectives of the research. The fifth chapter discussed the results of empirical studies and synthesised the findings. This chapter presents the requirements for the artefact, develops the artefact and validates the artefact. The validation includes empirical validation and benchmark analysis.

Finally, this sixth chapter aims to articulate the knowledge contribution of this research. The conclusion, recommendation, contribution and limitation sections are included in this chapter.

6.2. Conclusions of the research

6.2.1. Objective 01 | Factors influencing homeowners' Interest in housing retrofit

The first objective of the research is to study the factors influencing homeowners’ interest in housing retrofit. This objective was achieved through a literature review. Retrofitting the housing stock is a timely requirement in the UK. In terms of the climate change goals, the UK will not be able to achieve Net Zero 2050 without achieving housing sector decarbonisation. In addition to the environmental sustainability benefits, housing retrofit has further social and economic benefits. One of the key arguments of the literature as well as the data analysis was the main benefit of housing retrofit is better quality of life. Both the literature and the interviewees of the data collection generally agreed that the benefits of quality of life are less emphasised. While enhancing the quality of life of the residents, housing retrofit is reported to contribute to the protection of cultural heritage. Further, employment opportunities shall be improved considerably due to retrofitting houses at a scale.

There are several economic benefits of housing retrofit according to the study. The number one economic benefit is putting people out of fuel poverty. Although it is not rational to say that every standard retrofit project shall create energy bill savings, retrofit has the potential to reduce fuel poverty (Fernández et al., 2022). The practical energy bill reduction depends on several factors such as the retrofit design, behavioural factors, fuel price fluctuations and government subsidies. The property values are increased with the housing retrofit. Further, retrofit will contribute to economic growth due to increased turnover in the construction industry, employment creation and tax revenue. The sustainability effects of housing retrofit help to complement 11 sustainable development goals (SDG) of a total of 17 (Refer to the conclusion of Chapter 02). There is a critical need to retrofit the existing houses in the UK.

As far as the decision-making process of the homeowners is concerned, the original approach to decision analysis can be identified as rational decisions. There are theories such as expected utility theory which explain the rational decision-making behaviour of people. People look for information to make rational decisions. In this way, people expect to analyse the information and make the decision which gives the maximum value to them. Ideally, the problem that needs to be addressed here is the information deficit. In terms of housing retrofit, it can be concluded that by providing better information, homeowners will get to know what retrofit is and how to retrofit their houses.

Most of the time, people seem not to make purely rational decisions. Rational decisions can be expected in institutional settings. When it comes to individual homeowners or households, the decision-making is not purely rational. It may contain a percentage of rational decision-making. Most of the time there is a major percentage of decision-making which is not rational. According to a study, non-rational decision-making was able to explain homeowner retrofit decision-making 86% of the time. The literature has used different terms for this. For example, relational, irrational or emotional. It is expected to call the counterparts of rational decision-making non-rational decision-making due to the complexity. Unlike rational decision-making, it is highly complex to define a single strategy to address the problems in non-rational decision-making. Sometimes, there may not be any viable answers to address non-rational decision-making problems. According to the COM-B behavioural change model, motivation can be generally used for this. Motivation helps to influence decision-making in general, even if decision-making is not rational. The problem which is addressed here can be considered as a “lack of motivation” or justifying why retrofit to the homeowners.

One of the famous quotes related to this is “People buy with emotions and justify with logic”. This means, that people make decisions for their unknown reasons. Once they make the decision, they try to justify the decision with logic by finding information which supports their decision. According to the literature review, the decisions of the people are based on both rational and non-rational grounds. Although the retrofit decision-making could be better explained from the non-rational point of view, the nature of a decision in a given case study can depend on several factors. The recommendation is to try maximum to understand the decision-making behaviour of the homeowner and make necessary interventions to persuade them to housing retrofit. The demographics of the homeowner can be partly helpful in this regard according to the conducted questionnaire survey.

The literature review also focused on stakeholder engagement; mainly, the one stop shop model for housing retrofit. The model has been proven in the European context to address collaboration in housing retrofit. The interviews with the retrofit industry stakeholders also noted the importance of the one stop shop model in solving fundamental problems of the industry. In this situation, the research recommends a digital one stop shop solution for housing retrofit. This will be a decision support system coming under the scope of information systems. This needs to include the characteristics of socio-technical systems. The solution expects to create a positive engagement of all the retrofit stakeholders, which ultimately encourages homeowners to engage in the housing retrofit process.

6.2.2. Objective 02 | Requirements for an artefact to support homeowner decision-making

The second objective of the research is to develop an artefact to support decision-making in housing retrofit for homeowners. This objective has the most empirical weightage of the total research. There were both qualitative and quantitative data collection in achieving this objective. First, 40 semi-structured interviews were conducted to identify the artefact requirements. These interviews were conducted with stakeholders of the housing retrofit industry including homeowners. Apart from that, there was a questionnaire survey to identify the homeowner's behaviour. There are six recommendations identified with the help of these empirical studies.

The 40 semi-structured interviews were conducted with a sample consisting of academics, retrofit professionals, industry experts, people from the supply chain, people from multi-disciplinary areas and UK homeowners. The idea was to get the requirements sourced from a diversified population. The system shall be functional enough to cater for a range of stakeholders in the retrofit industry. As a part of the interview sample, homeowners from different demographics were recruited for these interviews. They were asked what they would look out for, if they happened to make a decision about retrofitting their houses. Generally, all the homeowners presented highly similar ideas. These interviews were highly important to understand how the homeowners look at housing retrofit. For example, they were asked what their biggest fear of housing retrofit would be. They all pointed out the unintended consequences. “Will this work?” When it comes to data analysis, the interview transcripts were thematically analysed to identify common themes. The findings were qualitatively presented under these themes. The interviews were highly important to form the basis of the artefact development.

There is another questionnaire survey conducted with the homeowners. There were 104 respondents to the questionnaire survey. The purpose of this survey was to identify the homeowner's behaviour in housing retrofit decision-making. In this situation, there was no focus on the property characteristics, but the demographics of the homeowners. It was concluded that the homeowner demographics can only partly explain their behaviour. The behaviour was primarily sensitive to their educational background.

The critical literature review, the 40 semi-structured interviews with retrofit industry stakeholders and the questionnaire survey with 104 UK homeowners made the foundations for the development of the artefact for homeowner retrofit decision-making. The artefact development was addressed under the third objective. The six recommendations for the artefact requirements are stated and described in the recommendations section.

6.2.3. Objective 03 | Development of the artefact to support homeowner decision-making

The literature findings and the findings from the empirical studies were used to develop an artefact to encourage homeowners to retrofit their houses. The developed artefact is given in the discussion section of the research under the third research objective. There are five functionalities expected from this artefact. They are based on the user, house, retrofit options, option evaluation and data management. Further, the artefact was developed based on the six recommendations of the research. They are introduced in the recommendations section of this chapter in detail.

The artefact shall have four purposes. They are providing retrofit awareness, facilitating option evaluation, facilitating the homeowner to contact a retrofit assessor and collecting data for policy decisions. As far as the practical contributions of the artefact are concerned, one is to encourage the homeowners to retrofit their houses. The other is to collect data about the homeowners and houses for policy decisions. Since the artefact is a high-level model for an information system, this needs to be developed into a practical information system first. The desired action of a homeowner after using this system is to contact a retrofit assessor for an in-person retrofit assessment. The success of the system can be measured by looking at the number of conversions to retrofit assessment versus the number of homeowners who evaluated retrofit options through the system.

6.2.4. Objective 04 | Validation of the artefact for intended capabilities

The fourth objective is to validate the artefact for the intended capabilities. This objective was achieved by empirically validating the artefact with the retrofit industry stakeholders. Further, a benchmark analysis was also carried out to see how the artefact would outperform in the context of existing similar systems. The empirical validation of the artefact was done with 12 semi-structured interviews with retrofit industry stakeholders. The sample consisted of homeowners, academics and other stakeholders of the retrofit industry. The interviewees were shown a hypothetical case study of a user exploring their housing retrofit options through the proposed system and onboard to the retrofit process. These interviews were helpful to get better insights to update the artefact. The data was analysed then and there as the interviews were conducted.

Apart from these, another benchmark analysis was conducted by comparing the artefact with three similar homeowner decision support systems available at the time. The energy performance certificate (EPC) was used as the benchmark. Although the EPC report is not an information system, it has some capabilities similar to the proposed system. The validation studies were also complementary to the data collection studies. The studies validated that the artefact can encourage homeowners to retrofit their houses. As the effectiveness of the artefact depends on the user-friendliness of the practical information system to be developed, it is not possible to predict the demand by now. Further, there is no guarantee that every user will be motivated to retrofit their houses after using the artefact. In such a situation, the artefact will be still useful for collecting data for policy decisions.

6.2.5. Research problem and research aim

The problem of this research is “The limited interest of the UK homeowners to retrofit their houses”. According to the problem analysis of the introduction and literature review chapters, the research scope was narrowed down to homeowner engagement with housing retrofit. The problem was further studied by justifying the requirement for housing retrofit with the literature review of the second chapter. The solution to this problem was also articulated in the literature review. According to the study, a digital one stop shop solution was recommended as the solution.

Concerning the research problem, the research aim was determined “To encourage homeowners to undertake sustainable housing retrofit through an information system artefact”. To achieve this research aim systematically, there are four objectives defined under the auspice of the design science research steps. The objectives covered the steps of a design science project: identifying the problem (and outlining the solution), collecting requirements, developing the artefact and validating the artefact.

According to the problem analysis, there are three pillars required to promote housing retrofit among homeowners. They are the homeowner decision-making behaviour, social system and technical system of housing retrofit. The one stop shop model was proposed as an information system. There will be four functions of the system: making awareness, initial retrofit appraisal, lead generation and data collection.

The artefact validation study ensured that the proposed system is capable of making homeowners aware of housing retrofit effectively. This is mainly answering the question of what is retrofit. Further, the system will facilitate homeowners to understand how their houses can be retrofitted through the initial retrofit appraisal. This will help the homeowners to evaluate the decisions of retrofitting their houses. This is mainly answering the question of how to retrofit. The system will not be able to provide direct answers to "Why retrofit?" of all the homeowners. Some homeowners will understand the need for retrofit as they understand the benefits. The justification of why someone should retrofit their houses depends on a range of individual-level justifications, which is beyond the capabilities of an information system artefact. Due to this reason, the artefact will facilitate social interactions with the homeowners to find out justifications for housing retrofit by themselves. The validation interview findings warned that there will be a requirement for a greater level of stakeholder collaboration and work outside the research scope to achieve this deliverable.

If the homeowner is happy to proceed to the next level, the proposed system will facilitate that by providing an opportunity for an in-person retrofit assessment. This is called the lead generation. The scope of the proposed system is limited to lead generation. It was validated that the system should encourage the homeowners to go for a retrofit assessment. The turnover rate is difficult to predict at this level. The other fact is that all the homeowners may not decide to go for a retrofit assessment right away after using the system, but wait for a trigger. Irrespective of the homeowner proceeding to a retrofit assessment, the system shall collect data for policy decisions. The government can amend policy measures to make housing retrofit more attractive with their policy tools.

The study followed the design science methodology as the research is involved with developing an artefact and contributing to knowledge. Apart from the literature reviews, the study used a mixed-method approach to data collection and analysis. The research aim was achieved with the development of the artefact after extensive research. Further, the artefact was validated according to the design science research requirement.

6.3. Recommendations

There are six recommendations made under the findings of this research. These recommendations are basically for determining the artefact requirements. They also can be used to promote housing retrofit in the UK in general. The recommendations are coming under three themes of homeowner decision-making behaviour, the social system of housing retrofit and the technical system of housing retrofit. The discussion section presents these recommendations in detail.

6.3.1. R1. Reframing housing retrofit from investment focus to consumption focus.

The decision-making behaviour of the homeowner is a key theme that needs to be focused on when encouraging to retrofit their houses. The first recommendation is to reframe the investment focus of housing retrofit into a consumption focus. People get demotivated to retrofit their houses when they see the longer payback periods of housing retrofit. Further, the energy bill savings estimations may not be accurate due to various reasons such as resident behaviour or rebound effect. It is better to refrain from quoting estimated energy bill savings when communicating retrofit benefits to the people. Instead, the potential benefits of health and comfort can be highlighted. Further, the message of retrofit can be presented more convincingly by loss framing. For example, presenting the gain of energy bill savings due to retrofit as a loss due to not retrofitting the house. Again, the loss or gain does not have to be in numbers. For example, a star rating. Although industry experts have identified this requirement, there is no significant progress to be observed.

6.3.2. R2. A homeowner-centric approach to retrofit over the existing property-centric approach.

The next recommendation under this theme is a homeowner-centric approach to housing retrofit over the existing property-centric approach. It can be suggested that due to the unintended consequences and the limited knowledge about retrofit technology, the focus of retrofit programmes was on the property, not the homeowner. Now the technology and process related to housing retrofit have become satisfactorily mature. Now the priority should be approaching housing retrofit by focusing on the homeowner (including the residents, landlords or tenants). They are the ultimate decision-makers or people who live in these properties. These two recommendations were mainly identified through empirical data collection.

6.3.3. R3. Change the wrong perception of already having a better-performing house.

Another significant challenge to convince homeowners to retrofit their houses is the perception of already having a better-performing house. This was evident both in the literature review and the interviews conducted with the homeowners. They do not see the requirement of housing retrofit as they think they live in a good-performing house. The house can be a poor-performing one in terms of standard criteria. The literature review has proposed several reasons for the poor performance of the UK housing stock. The homeowner needs to be enlightened about the actual level of performance of their house compared with a good-performing house. E.g., A house with an EPC A rating or Passivhaus EnerPhit certified.

6.3.4. R4. Neighbourhood approach with laypeople to drive housing retrofit.

This recommendation is already established in the literature. The retrofit industry stakeholders also validated the concept in the empirical studies. The digital one stop shop model shall help the mass-scale retrofitting of the UK houses by providing decision support and motivation. It is important to look at the limitations of an information system related to the lack of human interactions. As a response to this limitation, the interviewees and the social practice theorists recommended a neighbourhood approach considering the social interactions of the homeowners. This can also be viewed as a place-based approach. The idea is to narrow the scope of the one stop shop (localise) to the village or town level, where the homeowners are more likely to personally know each other and the other stakeholders of the retrofit process. Importantly, it is recommended to use normal people in the homeowner’s neighbourhood to disseminate the message of retrofit, but not necessarily the technical people. The reason is that the homeowners mainly trust their neighbourhood, friends and family over anyone else. Further, they can practically witness the impact of retrofit in their neighbourhood.

Further, the system shall promote social interaction opportunities both within the system and outside the system. For example, a retrofit champion is a layperson interested in promoting retrofit in their neighbourhood. They can make use of the proposed system to disseminate information related to retrofit among people who do not have access to digital resources.

The proposed digital one stop shop model will not change the existing socio-economic ecosystems. It will be complimentary with the existing retrofit standards and best practices. Considering the time window to retrofit almost all the UK houses before 2050, it is better to go with the existing industry and social system, rather than changing them. The promoters of housing retrofit need to change their strategy, but not the industry.

6.3.5. R5. Facilitating actual quotations (not estimates) to improve the homeowner's confidence.

The study recommends providing actual quotations for time, cost and quality for homeowners. The accuracy and reliability related to actual quotations will better convince homeowners to retrofit their houses. The participants in the artefact validation interviews emphasised that the required technology or the process infrastructure is not readily available for this recommendation. There will be a considerable amount of work required outside of the artefact scope to support this recommendation. This was evident during the benchmark analysis that none of the existing systems provides actual quotations by now. One of the validation interview participants signposted that comparison sites such as moneysupermarket.co.uk or confused.com are already experts in this area of business. In this situation, the work will be able to be outsourced to them as they already have the expertise in a similar trade.

6.3.6. R6. Following PAS 2030/2035 specifications, standards and other industry best practices to reduce unintended consequences.

Both the questionnaire survey and interviews with homeowners highlighted the homeowner’s concern about the unintended consequences of housing retrofit, which is a critical barrier to promoting retrofit among homeowners. It is recommended by the experts to consider the standards and best practices to avoid unintended consequences. As far as the history of housing retrofit in the UK is concerned, poor adoption of the best practices has caused unintended consequences in the past. This has resulted in diminishing the confidence of the homeowners regarding housing retrofit. As the industry best practices such as PAS 2035 or Passivhaus have already proven quality to a certain level, following best practices will reduce unintended consequences and improve stakeholder confidence.

6.4. Limitations and further research

Although the study was conducted with utmost care and attention, there can be limitations. One of the identified limitations is the inability to develop the system within the research scope. Developing this system shall require higher financial resources as well as the collaboration of several external parties. Further research is recommended in the areas of homeowner decision-making behaviour and the potential of a one stop shop model for housing retrofit. Human decision-making behaviour is uncertain. This can be further complicated when homeowners make retrofit decisions. This study has done some research. More studies will be better. The other research priority is stakeholder engagement. This study recommends a one stop shop stakeholder engagement model for housing retrofit with reference to existing literature. No proper empirical case studies were found in the UK for productive data analysis. Due to this reason, the recommendation is based on a literature review. Further empirical research about one stop shop model for housing retrofit shall be more beneficial when such case studies start to emerge.

Another potential limitation of any empirical research can be considered as the sampling bias (Saunders et al., 2019). As it is not practical to collect data from the total population, bias can emerge due to the sample being not representative. As far as the questionnaire survey is concerned, the sample was selected through simple random sampling. The sampling bias is expected to be lower in this case. In the semi-structured interviews, the sampling bias can be present due to the convenient sampling method used. A cluster sampling approach is used by selecting participants in different stakeholder groups to fairly represent each group. A level of sample bias can be there due to the qualitative nature of the study and the convenient sampling process.

Apart from the above limitations, researcher bias can be considered as another common limitation in research. This can be defined as how the researcher's personal beliefs, background and preferences influence the results (Saunders et al., 2019). When there is qualitative data analysis or the researcher's creativity has a stake in the research process, researcher bias can be expected. Being a design science research with qualitative data collection, this research has to be expected with a certain level of researcher bias. For example, the researcher's belief about the success of the artefact to solve the research problem.

In order to minimise any negative impacts due to the research limitations, the research was designed and conducted according to rigorous methodological procedures under the design science methodology, under the close supervision of two supervisors. Further, the research also complied with the university's ethical approval conditions. Considering these factors, it is expected the limitations of the research do not have a detrimental effect on the validity of the findings.

6.5. Claimed contributions

With reference to design science research, the contributions of this research can be outlined from both practical and theoretical perspectives. From a methodological point of view, the practical contribution of the artefact is viewed under pragmatism ontology and the theoretical contribution is viewed under critical realism ontology. Basically, research expects to identify a problem in the context, justify a solution, development of the solution and validate the solution through demonstration.

As far as the practical contribution of the artefact is concerned, there are two main contributions that can be noted. One is encouraging homeowners to retrofit their homes. The artefact shall motivate homeowners to make a positive decision of retrofitting their homes (subjective a supportive delivery infrastructure). In this way, the progress of housing retrofit in the UK can be increased, which is a timely requirement of the UK to achieve sustainability goals.

Another practical contribution of the artefact is data collection. It is not rational to assume that every user will be encouraged to retrofit their houses after using the proposed artefact. Even if they are happy to retrofit their houses, it may not happen due to a plethora of reasons. The use of the system shall generate new data about the homeowner and the characteristics of the house. For example for homeowner related data, the demographics of the homeowners, the reasons why they are looking to retrofit houses or what reasons prevent them from retrofitting their houses can be considered. Examples of house related data can be given as spatial information, location information, energy efficiency levels, photographic evidence or immediate retrofit requirements. This information will help the policymakers to identify the housing stock and the resident requirements to make better policy decisions. For example, deciding the amount of grant to retrofit a house or which homeowner segment is to prioritise for these grants.

When it comes to the contribution to knowledge, the research shall contribute to the development of information systems for non-technical audiences. The methodology and the findings followed by this study will be favourable for similar studies to develop systems for non-technical audiences. The second contribution is the understanding of homeowner behaviour through extensive research. Anybody engaged in promoting housing retrofit among homeowners can make use of the findings to better align their promotion strategies with homeowner behaviour.

As far as the novelty of the contributions is concerned, the artefact is estimated to become obsolete within three to five years (2027 - 2029). There are already similar systems in the UK context, although their capabilities are basic. Due to the advancement of technology, better systems will be developed within the next couple of years to the level of capability suggested by this research. This research will be still valuable after decades as a reference point for developing decision support systems for non-technical audiences. It is possible that artificial intelligence can be helpful to improve capability and performance.

6.6. Chapter conclusion

This is the sixth and final chapter of the thesis. This chapter concluded the overall research. It further made recommendations, identified limitations, signposted future research and presented the contributions. Accordingly, this chapter summarises the overall research. An opportunity was sought to look at how the research problem, research aim and objectives were achieved during the progress of the research steps.

The next section is allocated to references and annexures. Further, it consists of related documents such as questionnaires and ethical approval.

REFERENCES

Aguilar-Santana, J. L., Jarimi, H., Velasco-Carrasco, M., & Riffat, S. (2020). Review on window-glazing technologies and future prospects. *International Journal of Low-Carbon Technologies*, *15*(1), 112-120.

Akhatova, A., & Kranzl, L. (2022). Neighbourhood-level energy retrofits driven by intermediary actors: what are the prospects? Eceee Summer Study Proceedings,

Alabid, J., Bennadji, A., & Seddiki, M. (2022). A review on the energy retrofit policies and improvements of the UK existing buildings, challenges and benefits. *Renewable & Sustainable Energy Reviews*, *159*, Article 112161. https://doi.org/10.1016/j.rser.2022.112161

APM. (2012). *APM body of knowledge* (6 ed.). Association For Project Management.

Appelbaum, S. H. (1997). Socio-technical systems theory: an intervention strategy for organizational development. *Management Decision*, *35*(6), 452-463. https://doi.org/10.1108/00251749710173823

Ares, E. (2016). *Zero Carbon Homes*. https://researchbriefings.files.parliament.uk/documents/SN06678/SN06678.pdf

Armstrong, M. (2006). *A Handbook of Human Resource Management Practice* (10 ed.). Kogan Page Limited.

Atweh, B., Barton, A. C., Borba, M. C., Gough, N., Keitel-Kreidt, C., Vistro-Yu, C., & Vithal, R. (2008). *Internationalisation and Globalisation in Mathematics and Science Education*. Springer Science & Business Media.

Avanzini, M., Pinheiro, M. D., Gomes, R., & Rolim, C. (2022). Energy retrofit as an answer to public health costs of fuel poverty in Lisbon social housing. *Energy Policy*, *160*, Article 112658. https://doi.org/10.1016/j.enpol.2021.112658

Awwal, S., Tzortzopoulos, P., Gulzar, M. R., Mishra, R., Fleming, L., & Conor, S. (2024, 2024/07/01). Smart Homes and Waste Reduction. Proceedings of the 32nd Annual Conference of the International Group for Lean Construction (IGLC 32), Auckland, New Zealand.

Baeli, M. (2013). *Residential Retrofit: Residential Retrofit*. Riba Publishing.

Baker, H., Moncaster, A., Remøy, H., & Wilkinson, S. (2021). Retention not demolition: how heritage thinking can inform carbon reduction. *Journal of Architectural Conservation*, 1-19. https://doi.org/10.1080/13556207.2021.1948239

Banks, N. (2024). Fabric fifth: rethinking the hierarchy of retrofit, with Nigel Banks (Octopus Energy). *Listen Notes*. https://www.listennotes.com/podcasts/zero-ambitions/fabric-fifth-rethinking-the-6UgFdQKRTPw/

Barrett, L. F. (2020). *Seven And A Half Lessons About The Brain*. Picador.

Bartiaux, F., Gram-Hanssen, K., Fonseca, P., Ozoliņa, L., & Christensen, T. H. (2014). A practice–theory approach to homeowners' energy retrofits in four European areas. *Building Research & Information*, *42*(4), 525-538.

Bell, S., Chaytor, S., Crawford, K., Davies, M., Johnson, C., Joojoo, S., Jones, M., & Rose, M. (2014). *Making Decisions on the Demolition or Refurbishment of Social Housing UCL POLICY BRIEFING*. https://www.ucl.ac.uk/engineering-exchange/sites/engineering-exchange/files/policy_brief_refurbishment_and_demolition_of_social_housing.pdf

Bergman, N., & Foxon, T. J. (2020). Reframing policy for the energy efficiency challenge: Insights from housing retrofits in the United Kingdom. *Energy Research & Social Science*, *63*, 101386. https://doi.org/10.1016/j.erss.2019.101386

Bertoldi, P., Boza-Kiss, B., Della Valle, N., & Economidou, M. (2021). The role of one-stop shops in energy renovation - a comparative analysis of OSSs cases in Europe. *Energy and Buildings*, *250*, 111273. https://doi.org/10.1016/j.enbuild.2021.111273

Blackpool Council. (2023). Home Upgrade Grant | Cosy Homes in Lancashire. *Cosy Homes in Lancashire*. https://www.chil.uk.com/home-upgrade-grant

Boardman, B. (2010). *Fixing fuel poverty : challenges and solutions*. Earthscan.

Bobrova, Y., Papachristos, G., & Chiu, L. F. (2021). Homeowner low carbon retrofits: Implications for future UK policy. *Energy Policy*, *155*(1), 112344. https://doi.org/10.1016/j.enpol.2021.112344

Bobrova, Y., Papachristos, G., & Cooper, A. (2022). Process perspective on homeowner energy retrofits: A qualitative metasynthesis. *Energy Policy*, *160*, 112669. https://doi.org/https://doi.org/10.1016/j.enpol.2021.112669

Bolton, E., Bookbinder, R., Middlemiss, L., Hall, S., Davis, M., & Owen, A. (2023). The relational dimensions of renovation: Implications for retrofit policy. *Energy Research & Social Science*, *96*, Article 102916. https://doi.org/10.1016/j.erss.2022.102916

Bolton, P. (2024). Energy efficiency of UK homes. *House of Commons Library*. https://researchbriefings.files.parliament.uk/documents/CBP-9889/CBP-9889.pdf

Bolton, P., & Stewart, I. (2023). Domestic energy prices. *commonslibrary.parliament.uk*. https://commonslibrary.parliament.uk/research-briefings/cbp-9491/

Bonfield, P. (2016). *Each Home Counts*.

Boone, H., & Boone, D. (2012). Analyzing Likert Data. *The Journal of Extension*, *50*(2). https://tigerprints.clemson.edu/joe/vol50/iss2/48

Booth, A. T., & Choudhary, R. (2013). Decision making under uncertainty in the retrofit analysis of the UK housing stock: Implications for the Green Deal. *Energy and Buildings*, *64*, 292-308. https://doi.org/https://doi.org/10.1016/j.enbuild.2013.05.014

Bourke, J. (2023). Blog: What's in store for landlords after EPC U-turn? *Mortgage Finance Gazette*. https://www.mortgagefinancegazette.com/lending-news/buy-to-let/blog-whats-in-store-for-landlords-after-epc-u-turn-17-11-2023/

BPIE. (2021). Underpinning the role of One-Stop Shops in the EU Renovation Wave > BPIE - Buildings Performance Institute Europe. *BPIE - Buildings Performance Institute Europe*. https://www.bpie.eu/publication/underpinning-the-role-of-one-stop-shops-in-the-eu-renovation-wave/

Branson, A. (2021). To retrofit or rebuild? That is the question. *Property Week*. https://www.propertyweek.com/insight/to-retrofit-or-rebuild-that-is-the-question/5117070.article

BRE. (2013). *Prepared by BRE on behalf of the Department of Energy and Climate Change Report 4: Main heating systems*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/274772/4_Main_heating_systems.pdf

Bre. (2014). *SAP 2012 The Government s Standard Assessment Procedure for Energy Rating of Dwellings*. https://files.bregroup.com/SAP/SAP-2012_9-92.pdf

BRETrust. (2020). *The Housing Stock of The United Kingdom*. www.bretrust.org.uk

Brook, M. (2004). *ESTIMATING AND TENDERING FOR CONSTRUCTION WORK* (3 ed.). Elsivier.

Brown, D. (2018). Business models for residential retrofit in the UK: a critical assessment of five key archetypes. *Energy Efficiency*, *11*(6), 1497-1517. https://doi.org/10.1007/s12053-018-9629-5

Brown, D., & Bailey, T. (2022). Cheaper Bills Warmer Homes. *Cheaper Bills Warmer Homes*. https://www.cheaperbillswarmerhomes.org/downloads

Brown, D., Sorrell, S., & Kivimaa, P. (2019). Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit. *Energy Policy*, *128*, 418-430. https://doi.org/10.1016/j.enpol.2018.12.033

BSI. (2019). *PAS 2035:2019 Retrofi tting dwellings for improved energy effi ciency – Specifi cation and guidance*. The British Standards Institution.

Bsi. (2022). BS 40101:2022. In *Building performance evaluation of occupied and operational buildings (using data gathered from tests, measurements, observation and user experience). Specification*: British Standards Institution.

BSI. (2023a). PAS 2030:2023 Energy efficiency in existing dwellings. In. United Kingdom: British Standards Institution.

BSI. (2023b). PAS 2035:2023 Retrofitting dwellings for improved energy efficiency. Specification and guidance. In. United Kingdom: British Standards Institution.

Buck, D., & Gregory, S. (2018). Housing and health. *The King's Fund: London, UK*. https://www.kingsfund.org.uk/insight-and-analysis/reports/housing-and-health

Butt, B., Jones, R. V., & Fuertes, A. (2020). Opportunities and barriers to business engagement in the UK domestic retrofit sector: An industry perspective. *Building Services Engineering Research and Technology*, 014362442097564. https://doi.org/10.1177/0143624420975640

Carey, J. (2023). What are the upcoming changes to MEES and EPC requirements? *Freeths*. https://www.freeths.co.uk/2023/01/18/minimum-energy-efficiency-standards-mees-requirements-and-energy-performance-certificates-epc-rules/

Carratt, A., Kokogiannakis, G., & Daly, D. (2020). A critical review of methods for the performance evaluation of passive thermal retrofits in residential buildings. *Journal of Cleaner Production*, *263*, 121408.

Castro, C. G., Trevisan, A. H., Pigosso, D. C. A., & Mascarenhas, J. (2022). The rebound effect of circular economy: Definitions, mechanisms and a research agenda. *Journal of Cleaner Production*, *345*, 131136.

CCC. (2017). *About the Committee on Climate Change - Committee on Climate Change*. https://www.theccc.org.uk/about/

CCC. (2019). *UK housing: Fit for the future?* https://www.theccc.org.uk/publication/uk-housing-fit-for-the-future/

CCC. (2023a). CCC assessment of recent announcements and developments on Net Zero. *Climate Change Committee*. https://www.theccc.org.uk/2023/10/12/ccc-assessment-of-recent-announcements-and-developments-on-net-zero/

CCC. (2023b). *Progress in reducing emissions 2023 Report to Parliament*. C. C. Committee.

CCC. (2024). UK off track for Net Zero, say country's climate advisors - Climate Change Committee. *Climate Change Committee*. https://www.theccc.org.uk/2024/07/18/uk-off-track-for-net-zero-say-countrys-climate-advisors/

Chatterjee, I., Kunwar, J., & den Hond, F. (2019). Anthony Giddens and structuration theory. *Management, Organizations and Contemporary Social Theory*, 60-79. https://doi.org/10.4324/9780429279591-4

Chen, R. K., Fan, R. G., Yao, Q. Y., & Qian, R. R. (2023). Evolutionary dynamics of homeowners? energy-efficiency retrofit decision-making in complex network. *Journal of Environmental Management*, *326*, Article 116849. https://doi.org/10.1016/j.jenvman.2022.116849

Chen, X., Qu, K., Calautit, J., Ekambaram, A., Lu, W., Fox, C., Gan, G., & Riffat, S. (2020). Multi-criteria assessment approach for a residential building retrofit in Norway. *Energy and Buildings*, *215*, 109668.

Chinyio, E., & Olomolaiye, P. (2010). *Construction Stakeholder Management*. Oxford, Uk Wiley-Blackwell.

Ciardiello, A., Dell'Olmo, J., Ferrero, M., Pastore, L. M., Rosso, F., & Salata, F. (2023). Energy Retrofit Optimization by Means of Genetic Algorithms as an Answer to Fuel Poverty Mitigation in Social Housing Buildings. *Atmosphere*, *14*(1).

Ciat. (2023). Considering Passivhaus influence – too ambitious or now the norm? *architecturaltechnology.com*. https://architecturaltechnology.com/resource/considering-passivhaus-influence-too-ambitious-or-now-the-norm.html

CIBSE. (2022). *https://www.cibse.org/media/ci1ltbaf/2022-10-10_part-l-2021_cibse-building-simulation-group_to-publish.pdf*. https://www.cibse.org/media/ci1ltbaf/2022-10-10_part-l-2021_cibse-building-simulation-group_to-publish.pdf

Cinderby, S., Archer, D., Mehta, V. K., Neale, C., Opiyo, R., Pateman, R. M., Muhoza, C., Adelina, C., & Tuhkanen, H. (2021). Assessing Inequalities in Wellbeing at a Neighbourhood Scale in Low-Middle-Income-Country Secondary Cities and Their Implications for Long-Term Livability [Original Research]. *Frontiers in Sociology*, *6*. https://www.frontiersin.org/journals/sociology/articles/10.3389/fsoc.2021.729453

CITB. (2021). *Building Skills for Net Zero Industry insights and analysis Report prepared by Eunomia for CITB* (www.citb.co.uk, Issue. https://www.citb.co.uk/media/kkpkwc42/building_skills_net_zero_full_report.pdf

Citizens Advice. (2023). More than one and a half million children in England live in cold, damp or mouldy private rented homes, Citizens Advice reveals. *www.citizensadvice.org.uk*. https://www.citizensadvice.org.uk/about-us/about-us1/media/press-releases/more-than-one-and-a-half-million-children-in-england-live-in-cold-damp-or-mouldy-private-rented-homes-citizens-advice-reveals2/

CLC. (2021). *Greening Our Existing Homes National retrofit strategy A consultative document*. https://www.constructionleadershipcouncil.co.uk/wp-content/uploads/2021/05/Construction-Leadership-Council-National-Retrofit-Strategy-Version-2.pdf

Clemen, R. T. (1996). *Making hard decisions : an introduction to decision analysis*. Duxbury Press.

Collins, L. M. (2007). Research Design and Methods. *Encyclopedia of Gerontology*, 433-442. https://doi.org/10.1016/b0-12-370870-2/00162-1

Cotswold District, C. (2021). *Net Zero Carbon Toolkit*. https://www.cotswold.gov.uk/media/05couqdd/net-zero-carbon-toolkit.pdf

Coulentianos, M. J., Abbey, D., So, C. T., & Ward, W. O. C. (2024). An Expert View on Data and Modelling for Planning Domestic Retrofit. *Buildings*, *14*(4).

Cpag. (2022). Fuel poverty: updated estimates for the UK | CPAG. *cpag.org.uk*. https://cpag.org.uk/news/fuel-poverty-updated-estimates-uk

Creswell, J. W., & Creswell, J. D. (2018). *Research design : qualitative, quantitative, and mixed methods approaches* (5 ed.). Sage Publications, Inc.

Dale, J. (2017). *Applying the KISS principle*. Association for Project Management. https://www.apm.org.uk/blog/applying-the-kiss-principle/

Day, C. (2015). *The Eco-Home Design Guide: Principles and practice for new-build and retrofit*. Bloomsbury Publishing.

DBEIS. (2021a). Heat and buildings strategy. *GOV.UK*. https://www.gov.uk/government/publications/heat-and-buildings-strategy

DBEIS. (2021b). *International review of domestic retrofit supply chains* (www.assets.publishing.service.gov.uk, Issue. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/987411/international-review-domestic-retrofit-supply-chains.pdf

Dbeis. (2021c). Sustainable warmth: protecting vulnerable households in England. *GOV.UK*. https://www.gov.uk/government/publications/sustainable-warmth-protecting-vulnerable-households-in-england

DBEIS. (2022). British energy security strategy. *GOV.UK*. https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

Dclg. (2017). *A guide to energy performance certificates for the marketing, sale and let of dwellings Improving the energy efficiency of our buildings*.

Deben, L. (2022). Reducing energy demand in buildings in response to the energy price crisis. *The climate change committee*. https://www.theccc.org.uk/wp-content/uploads/2022/11/221108-LD-JH-Letter-to-Rt-Hon-Jeremy-Hunt-MP-Energy-Efficiency.pdf

Deland, A. (2022). Council Post: Unique Selling Propositions: What It Is, Why You Need One And How To Write Your Own. *Forbes*. https://www.forbes.com/sites/forbesbusinesscouncil/2022/07/21/unique-selling-propositions-what-it-is-why-you-need-one-and-how-to-write-your-own/?sh=300efa2e77d0

DellaValle, N., Bisello, A., & Balest, J. (2018). In search of behavioural and social levers for effective social housing retrofit programs. *Energy and Buildings*, *172*, 517-524. https://doi.org/10.1016/j.enbuild.2018.05.002

Desnz. (2013). Fuel poverty statistics. *GOV.UK*. https://www.gov.uk/government/collections/fuel-poverty-statistics

DESNZ. (2022). *Final UK greenhouse gas emissions national statistics: 1990 to 2022*. https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2022

DESNZ. (2023a). About us. *GOV.UK*. https://www.gov.uk/government/organisations/department-for-energy-security-and-net-zero/about

Desnz. (2023b). Heat pump net zero investment roadmap. *GOV.UK*. https://www.gov.uk/government/publications/heat-pump-net-zero-investment-roadmap

Desnz. (2024). Annual fuel poverty statistics report: 2024. *GOV.UK*. https://www.gov.uk/government/statistics/annual-fuel-poverty-statistics-report-2024

DLUHC. (2021a). Energy Performance of Buildings Certificates Statistical Release July to September 2021 England and Wales. *Energy Performance of Buildings Certificates Statistical Release July to September 2021 England and Wales*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1028741/EPB_Cert_Statistics_Release_Q3_2021.pdf

DLUHC. (2021b). *English Housing Survey Headline Report, 2020-21*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1123670/2020-21_EHS_Headline_Report_revised_v2.pdf

Dluhc. (2023). *English Housing Survey 2021 to 2022: energy*. https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-energy/english-housing-survey-2021-to-2022-energy

Dresch, A., Lacerda, D. P., & Antunes, J. A. V. A. (2015). *Design Science Research* (1 ed.). Springer International Publishing.

Duah, D., & Syal, M. (2016). Intelligent decision support system for home energy retrofit adoption. *International Journal of Sustainable Built Environment*, *5*(2), 620-634. https://doi.org/https://doi.org/10.1016/j.ijsbe.2016.05.003

Duran, Ö., & Lomas, K. J. (2021). Retrofitting post-war office buildings: Interventions for energy efficiency, improved comfort, productivity and cost reduction. *Journal of Building Engineering*, *42*, 102746. https://doi.org/https://doi.org/10.1016/j.jobe.2021.102746

Ebrahimigharehbaghi, S. (2022). *Understanding the decision-making process in homeowner energy retrofits* [PhD Thesis, https://doi.org/10.7480/abe.2022.06

Ebrahimigharehbaghi, S., Qian, Q. K., de Vries, G., & Visscher, H. J. (2022a). Application of cumulative prospect theory in understanding energy retrofit decision: A study of homeowners in the Netherlands. *Energy and Buildings*, *261*, Article 111958. https://doi.org/10.1016/j.enbuild.2022.111958

Ebrahimigharehbaghi, S., Qian, Q. K., de Vries, G., & Visscher, H. J. (2022b). Identification of the behavioural factors in the decision-making processes of the energy efficiency renovations: Dutch homeowners. *Building Research and Information*, *50*(4), 369-393. https://doi.org/10.1080/09613218.2021.1929808

Ebrahimigharehbaghi, S., Qian, Q. K., de Vries, G., & Visscher, H. J. (2022c). Municipal governance and energy retrofitting of owner-occupied homes in the Netherlands. *Energy and Buildings*, *274*, Article 112423. https://doi.org/10.1016/j.enbuild.2022.112423

EcoMerchant. (2022). RETROFITTING TO REGULATIONS. *www.ecomerchant.co.uk*. https://www.ecomerchant.co.uk/news/retrofitting-to-regulations/#:~:text=The%20regulations%20apply%20to%20any,energy%20efficiency%20improvements%20including%20the

Edwards, J. (2021). Retrofitting traditional buildings for improved energy performance in the context of BSI PAS 2035. *Journal of Building Survey, Appraisal & Valuation*, *9*(4), 294-304.

Elaine, M., Daniel, S., & Chris, P. (2014, 2014/08). Beyond Behavior Change: Household Retrofitting and ICT. Proceedings of the 2014 conference ICT for Sustainability,

Ellis, G. (2018). *Cognitive Biases in Visualizations*. Springer.

Ellis, T., Manidaki, M., & Pantelidou, H. (2021). Good Progress But Not Fast Enough: Decarbonising Infrastructure » Construction Leadership Council. *www.constructionleadershipcouncil.co.uk*. https://www.constructionleadershipcouncil.co.uk/news/good-progress-but-not-fast-enough-decarbonising-infrastructure/

Energiesprong. (2019). Energiesprong explained – Energiesprong. *Energiesprong.org*. https://energiesprong.org/about/

Energiesprong, U. K. (2023). Energiesprong UK. *www.energiesprong.uk*. https://www.energiesprong.uk/newspage/energiesprong-2023-highlights

Environmental Audit, C. (2021). *Energy Efficiency of Existing Homes Fourth Report of Session 2019-21 HC 346*. https://committees.parliament.uk/publications/5171/documents/52521/default/

Environmental Audit, C. (2022a). Building to net zero: costing carbon in construction. *House of Commons*. https://committees.parliament.uk/publications/22427/documents/165446/default/

Environmental Audit, C. (2022b). Decarbonising heat in homes. *House of Commons*. https://committees.parliament.uk/publications/8742/documents/88647/default/

Eyre, N., Fawcett, T., Topouzi, M., Killip, G., Oreszczyn, T., Jenkinson, K., & Rosenow, J. (2023). Fabric first: is it still the right approach? *Buildings & cities*, *4*(1), 965-972. https://doi.org/10.5334/bc.388

Fathi, M. (2024). Sustainability and Energy Efficiency in Buildings: A Review. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *16*(2). https://doi.org/10.1061/jladah.ladr-1110

Fernández, A., Haffner, M., & Elsinga, M. (2022). Comparing the financial impact of housing retrofit policies on Dutch homeowners. *IOP Conference Series: Earth and Environmental Science*, *1085*(1), 012044. https://doi.org/10.1088/1755-1315/1085/1/012044

Ferreira, J., Duarte Pinheiro, M., & de Brito, J. (2015). Economic and environmental savings of structural buildings refurbishment with demolition and reconstruction - A Portuguese benchmarking. *Journal of Building Engineering*, *3*, 114-126. https://doi.org/10.1016/j.jobe.2015.07.001

Fitton, R., & Swan, W. (2023). Retrofit assessment: Getting it right from the start. *Journal of Building Survey, Appraisal & Valuation*, *12*(3), 208-217. https://doi.org/10.1136/bmj.p2155

Fitton, R., Swan, W., Hughes, T., & Benjaber, M. (2017). The thermal performance of window coverings in a whole house test facility with single-glazed sash windows. *Energy Efficiency*, *10*, 1419-1431.

Fogg, B. J. (2009). A behavior model for persuasive design. *Proceedings of the 4th International Conference on Persuasive Technology - Persuasive '09*(40), 1-7. https://doi.org/10.1145/1541948.1541999

Fransman, R., & Timmeren, A. v. (2017). Psychological and social factors underlying pro-environmental behaviour of residents after building retrofits in the City-zen project. *Energy Procedia*, *122*, 1051-1056. https://doi.org/https://doi.org/10.1016/j.egypro.2017.07.477

Friedman, C., Becker, N., & Erell, E. (2017). Retrofitting residential building envelopes for energy efficiency: motivations of individual homeowners in Israel. *Journal of Environmental Planning and Management*, *61*(10), 1805-1827. https://doi.org/10.1080/09640568.2017.1372278

Frost, G. (2024). What is the difference between the energy price guarantee and Ofgem's energy price cap? *The Times*. https://www.thetimes.co.uk/money-mentor/energy/what-is-the-difference-between-the-energy-price-guarantee-and-ofgems-energy-price-cap#:~:text=The%20government%20has%20said%20that,13%20billion%20in%202023%2D24.

Furbnow. (2024). Furbnow | Furbnow - Your companion for home improvements for the future. *Furbnow*. https://furbnow.com/

Fyhn, H., & Baron, N. (2016). The Nature of Decision Making in the Practice of Dwelling: A Practice Theoretical Approach to Understanding Maintenance and Retrofitting of Homes in the Context of Climate Change. *Society & Natural Resources*, *30*(5), 555-568. https://doi.org/10.1080/08941920.2016.1239149

Fyhn, H., & Baron, N. (2017). The nature of decision making in the practice of dwelling: A practice theoretical approach to understanding maintenance and retrofitting of homes in the context of climate change. *Society & Natural Resources*, *30*(5), 555-568.

Fylan, F., & Glew, D. (2021). Barriers to domestic retrofit quality: Are failures in retrofit standards a failure of retrofit standards? *Indoor and Built Environment*, 1420326X2110271. https://doi.org/10.1177/1420326x211027197

Galvin, R., & Sunikka-Blank, M. (2014). The UK homeowner-retrofitter as an innovator in a socio-technical system. *Energy Policy*, *74*, 655-662. https://doi.org/10.1016/j.enpol.2014.08.013

Galvin, R., & Sunikka-Blank, M. (2017). Ten questions concerning sustainable domestic thermal retrofit policy research. *Building and Environment*, *118*, 377-388. https://doi.org/10.1016/j.buildenv.2017.03.007

Garrett, H., Mackay, M., Nicol, S., Piddington, J., & Roys, M. (2021). *The cost of poor housing in England 2021 Briefing paper* (www.bregroup.com, Issue. https://files.bregroup.com/research/BRE_Report_the_cost_of_poor_housing_2021.pdf

George, D., & Mallery, P. (2021). *IBM SPSS Statistics 27 Step by Step* (17 ed.). Routledge.

Gledhill, T., Swan, W., & Fitton, R. (2023). A practitioner study into the variability of UK domestic energy assessments. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/ijbpa-10-2022-0167

Glew, D., Parker, J., Fletcher, M., Thomas, F., Miles-Shenton, D., Brooke-Peat, M., Johnston, D., & Gorse, C. (2021). *February 2021 DEMONSTRATION OF ENERGY EFFICIENCY POTENTIAL Literature review of benefits and risks in domestic retrofit practice and modelling*. https://assets.publishing.service.gov.uk/media/6059b5e0d3bf7f2f0e7d04ec/deep-literature-review.pdf

Gogus, A. (2012). Action Research on Learning. In N. M. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 69-72). Springer US. https://doi.org/10.1007/978-1-4419-1428-6_488

Gouveia, J. P., & Palma, P. (2019). Harvesting big data from residential building energy performance certificates: retrofitting and climate change mitigation insights at a regional scale. *Environmental Research Letters*, *14*(9), 095007. https://doi.org/10.1088/1748-9326/ab3781

Gov.uk. (2017). Domestic private rented property: minimum energy efficiency standard - landlord guidance. *GOV.UK*. https://www.gov.uk/guidance/domestic-private-rented-property-minimum-energy-efficiency-standard-landlord-guidance

Gov.uk. (2019). UK Becomes First Major Economy to Pass Net Zero Emissions Law. *GOV.UK*. https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

Government, H. M. (2021). *UK Hydrogen Strategy*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

Government, U. K. (2021). *Net Zero Strategy: Build Back Greener*. Controller of Her Majesty's Stationery Office.

Gram-Hanssen, K. (2014). Retrofitting owner-occupied housing: remember the people. *Building Research & Information*, *42*(4), 393-397. https://doi.org/10.1080/09613218.2014.911572

Greater Manchester CA. (2021). *Pathways to Healthy and Net Zero Housing in Greater Manchester*. https://democracy.greatermanchester-ca.gov.uk/documents/s13523/07%20Pathways%20to%20Healthy%20Net%20Zero%20Housing%20GM_Report.pdf

Green Finance Institute. (2019). About Us. *www.greenfinanceinstitute.co.uk*. https://www.greenfinanceinstitute.co.uk/about-us/
Guo, L., Li, X., Hu, X., & Ye, K. (2024). Evolution of housing energy-efficient retrofitting game: A perspective of heterogeneous expectations on retrofit effects. *Journal of Building Engineering*, *82*, 108293-108293. https://doi.org/10.1016/j.jobe.2023.108293
Häckel, B., Pfosser, S., & Tränkler, T. (2017). Explaining the energy efficiency gap - Expected Utility Theory versus Cumulative Prospect Theory. *Energy Policy*, *111*, 414-426. https://doi.org/https://doi.org/10.1016/j.enpol.2017.09.026
Hackett, P. (2019). *The hidden costs of poor quality housing in the North*. https://www.northern-consortium.org.uk/wp-content/uploads/2018/10/The-Hidden-Costs-of-Poor-Quality-Housing-in-the-North.pdf
Hadnagy, C. (2018). *Social Engineering*. John Wiley & Sons.
Halifax. (2024). Halifax Home Energy Saving Tool | Where do you live? *home-energy-saving-tool.halifax.co.uk*. https://home-energy-saving-tool.halifax.co.uk/WhereDoYouLive/
Han, Q.-x., Zheng, B., Abakoumkin, G., Leander, N. P., & Stroebe, W. (2022). Why some people do not get vaccinated against COVID-19: Social-cognitive determinants of vaccination behavior. *Applied Psychology. Health and Well-Being*.
Hardy, A., & Glew, D. (2019). An analysis of errors in the Energy Performance certificate database. *Energy Policy*, *129*, 1168-1178. https://doi.org/https://doi.org/10.1016/j.enpol.2019.03.022
Hatch, M. J., & Schultz, M. (2004). *Organizational identity : a reader*. Oxford University Press.
He, S., & Qian, Q. K. (2023). Planning home energy retrofit in a social environment: The role of perceived descriptive and injunctive social norms. *Sustainable Cities and Society*, *99*, 104954. https://doi.org/https://doi.org/10.1016/j.scs.2023.104954
Heath, L. (2022). Social Housing Decarbonisation Fund: majority of councils failed to retrofit single home by deadline. *Inside Housing*. https://www.insidehousing.co.uk/news/social-housing-decarbonisation-fund-majority-of-councils-failed-to-retrofit-single-home-by-deadline-75180
Hevner, A. R., & Chatterjee, S. (2010). *Design research in information systems : theory and practice*. Springer.
Heyn, J. (2023). Energy efficiency: EPC reforms are on the horizon : Clyde & Co. *www.clydeco.com*. https://www.clydeco.com/en/insights/2023/03/energy-efficiency-epc-reforms-are-on-the-horizon#:~:text=The%20recent%20independent%20review%20of
Higney, A., & Gibb, K. (2024). Net zero retrofit of older tenement housing – The contribution of cost benefit analysis to wider evaluation of a demonstration project. *Energy Policy*, *191*, 114181. https://doi.org/https://doi.org/10.1016/j.enpol.2024.114181
Hilber, C. (2015). UK Housing and Planning Policies: the evidence from economic research. *CEP | Publications*. http://cep.lse.ac.uk/pubs/
Historic, E. (2016). Listed Buildings | Historic England. *Historicengland.org.uk*. https://historicengland.org.uk/advice/hpg/has/listed-buildings/
HistoricEngland. (2014). Decisions: Legal Requirements for Listed Building and Other Consents | Historic England. *Historicengland.org.uk*. https://historicengland.org.uk/advice/hpg/decisionmaking/legalrequirements/
HM Government. (2021a). *Conservation of fuel and power | Approved document L*.
HM Government. (2021b). *UK Hydrogen Strategy*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

HM Revenue & Customs. (2016). SDLTM20700 - Zero carbon homes relief - HMRC internal manual - GOV.UK. *www.gov.uk*. https://www.gov.uk/hmrc-internal-manuals/stamp-duty-land-tax-manual/sdltm20700

HM Revenue & Customs. (2023). *Energy-saving materials and heating equipment (VAT Notice 708/6)*. https://www.gov.uk/guidance/vat-on-energy-saving-materials-and-heating-equipment-notice-7086

Ho, A. M. Y., Lai, J. H. K., & Chiu, B. W. Y. (2021). Key performance indicators for holistic evaluation of building retrofits: Systematic literature review and focus group study. *Journal of Building Engineering*, *43*, 102926.

Hoffeld, D. (2016). *The science of selling : proven strategies to make your pitch, influence decisions, and close the deal*. Tarcherperigee.

Holms, C. (2023). *Demand: Net Zero Tackling the barriers to increased homeowner demand for retrofit measures*. https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Demand_%20Net%20Zero.pdf

Hopfe, C., & McLeod, R. (2015). *The Passivhaus Designer's Manual: A technical guide to low and zero energy buildings*. Routledge.

Hossain, M. U., Wu, Z., & Poon, C. S. (2017). Comparative environmental evaluation of construction waste management through different waste sorting systems in Hong Kong. *Waste Management*, *69*, 325-335. https://doi.org/10.1016/j.wasman.2017.07.043

Housing Ombudsman. (2023). *Housing Ombudsman Special Report on Rochdale Boroughwide Housing*. https://www.housing-ombudsman.org.uk/wp-content/uploads/2023/03/P49-RBH-FINAL-200323.pdf

Howard, R. A., & Abbas, A. E. (2016). *Foundations of decision analysis*. Pearson.

Howe, N., & Strauss, W. (2000). *Millennials Rising : the next Great Generation*. Vintage Books.

Howell, B. (2019). Solar Panel Statistics 2023: Everything You Need To Know. *The Eco Experts*. https://www.theecoexperts.co.uk/solar-panels/solar-statistics#:~:text=What%20percentage%20of%20the%20UK

HSE. (2015). Construction - Construction Design and Management Regulations 2015. *Hse.gov.uk*. https://www.hse.gov.uk/construction/cdm/2015/index.htm

Huang, C., Ma, J., & Song, K. (2021). Homeowners' Willingness to Make Investment in Energy Efficiency Retrofit of Residential Buildings in China and Its Influencing Factors. *Energies*, *14*(5).

Huculak, M., Jarczewski, W., & Dej, M. (2015). Economic aspects of the use of deep geothermal heat in district heating in Poland. *Renewable and Sustainable Energy Reviews*, *49*, 29-40.

Hudson, N. (2015). Size matters. *www.savills.co.uk*. https://www.savills.co.uk/research_articles/229130/188035-0

Ibaseta, D., García, A., Álvarez, M., Garzón, B., Díez, F., Coca, P., Del Pero, C., & Molleda, J. (2021). Monitoring and control of energy consumption in buildings using WoT: A novel approach for smart retrofit. *Sustainable Cities and Society*, *65*, 102637.

IEA. (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector* (www.iea.org, Issue. https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

Industrial Strategy Council. (2019). UK Skills Mismatch in 2030. *industrialstrategycouncil.org*. https://industrialstrategycouncil.org/sites/default/files/UK%20Skills%20Mismatch%2020030%20-%20Research%20Paper.pdf

Ingold, T. (2000). *The perception of environment : essays in livelihood, dwelling and skill*. Routledge.

Innovate. (2020). *HOW TO SET UP A ONE-STOP-SHOP FOR INTEGRATED HOME ENERGY RENOVATION?* (Energy Cities, Issue. https://energy-cities.eu/wp-content/uploads/2020/07/INNOVATE_one-stop-shop_guide_2020.pdf

International Standards Organisation. (2020). ISO 6707-1:2020 Buildings and civil engineering works — Vocabulary. In.

Iso. (2018). ISO/IEC/IEEE 29148:2018. *International Standards Organisation*. https://www.iso.org/standard/72089.html

Jafari, A., & Valentin, V. (2017). An optimization framework for building energy retrofits decision-making. *Building and Environment*, *115*(1), 118-129. https://doi.org/10.1016/j.buildenv.2017.01.020

James, B., Mondol, J., Hyde, T., & Houlihan Wiberg, A. (2024). How far can low emission retrofit of terraced housing in Northern Ireland go? *Environmental Research: Infrastructure and Sustainability*, *4*(1), 015010. https://doi.org/10.1088/2634-4505/ad2c97

James, P. (2015). *Urban sustainability in theory and practice : circles of sustainability*. Routledge.

Joanna Hale, C. J. P. C. (2022). Decarbonising existing homes in Wales: a participatory behavioural systems mapping approach. *UCL Open Environment*, *4*(1). https://journals.uclpress.co.uk/ucloe/article/id/783/

Johannesson, P., & Perjons, E. (2021). *An Introduction To Design Science* (2 ed.). Springer International.

Johnson, G., Scholes, K., & Whittington, R. (2008). *Exploring corporate strategy* (8 ed.). Financial Times Prentice Hall.

Judson, E. P., & Maller, C. (2014). Housing renovations and energy efficiency: insights from homeowners' practices. *Building Research & Information*, *42*(4), 501-511.

Kahneman, D. (2011). *Thinking, Fast and Slow*. Farrar, Straus and Giroux.

Karvonen, A. (2013). Towards systemic domestic retrofit: a social practices approach. *Building Research & Information*, *41*(5), 563-574. https://doi.org/10.1080/09613218.2013.805298

Kerr, N. J. (2018). The rationale for retrofit: A multi-level, interdisciplinary perspective on the energy efficient retrofit of existing residential buildings. *etheses.whiterose.ac.uk*. https://etheses.whiterose.ac.uk/22049/

Kerstens, A., & Greco, A. (2023). From Buildings to Communities: Exploring the Role of Financial Schemes for Sustainable Plus Energy Neighborhoods. *Energies*, *16*(14).

Khaled Mohammad, A., & Ghosh, A. (2023). Exploring energy consumption for less energy-hungry building in UK using advanced aerogel window. *Solar Energy*, *253*, 389-400. https://doi.org/10.1016/j.solener.2023.02.049

Korol, E., & Shushunova, N. (2022). Analysis and Valuation of the Energy-Efficient Residential Building with Innovative Modular Green Wall Systems. *Sustainability*, *14*(11), Article 6891. https://doi.org/10.3390/su14116891

Kothari, C. R. (2004). *Research methodology : methods and techniques* (2 ed.). New Age International (P) Limited, Publishers.

Kotler, P., & Armstrong, G. (2018). *Principles of Marketing* (17 ed.). Pearson Education Limited.

Kuylenstierna, J. C. I., Heaps, C. G., Ahmed, T., Vallack, H. W., Hicks, W. K., Ashmore, M. R., Malley, C. S., Wang, G., Lefèvre, E. N., Anenberg, S. C., Lacey, F., Shindell, D. T., Bhattacharjee, U., & Henze, D. K. (2020). Development of the Low Emissions Analysis

Platform – Integrated Benefits Calculator (LEAP-IBC) tool to assess air quality and climate co-benefits: Application for Bangladesh. *Environment International*, *145*, 106155. https://doi.org/https://doi.org/10.1016/j.envint.2020.106155

Leaper, C. (2011). More Similarities than Differences in contemporary Theories of social development? *Advances in Child Development and Behavior*, *40*, 337-378. https://doi.org/10.1016/b978-0-12-386491-8.00009-8

Leeds University Business, S. (2023). Socio-technical systems theory. *business.leeds.ac.uk*. https://business.leeds.ac.uk/research-stc/doc/socio-technical-systems-theory

Housing Act 2004, (2004).

Social Housing (Regulation) Act 2023, (2023).

LETI. (2020). *LETI Embodied Carbon Primer*. London Energy Transformation Initiative.

LETI. (2021). *LETI Climate Emergency Retrofit Guide*. https://www.leti.uk/_files/ugd/252d09_c71428bafc3d42fbac34f9ad0cd6262b.pdf

Levy, J. S. (1992). An introduction to prospect theory. *Political psychology*, 171-186.

Lewis, O. (2023). Millions of homeowners wrongly believe their property is energy efficient. *The Independent*. https://www.independent.co.uk/property/energy-bills-heating-home-cost-of-living-b2263185.html

Li, Q., Qian, T., Zhang, X., Long, R., Chen, H., Huang, H., Liu, L., Zhu, L., Jiang, H., & Zhu, H. (2023). How does stakeholder loss aversion affect the promotion of green housing? *Economic Analysis and Policy*, *80*, 647-668. https://doi.org/https://doi.org/10.1016/j.eap.2023.09.015

Li, X., Arbabi, H., Bennett, G., Oreszczyn, T., & Densley Tingley, D. (2022). Net zero by 2050: Investigating carbon-budget compliant retrofit measures for the English housing stock. *Renewable and Sustainable Energy Reviews*, *161*, 112384. https://doi.org/10.1016/j.rser.2022.112384

Lingard, J. (2020). Residential retrofit in the UK: The optimum retrofit measures necessary for effective heat pump use. *Building Services Engineering Research and Technology*, 014362442097570. https://doi.org/10.1177/0143624420975707

Liu, G., Tan, Y. T., & Huang, Z. J. (2021). Knowledge Mapping of Homeowners' Retrofit Behaviors: An Integrative Exploration. *Buildings*, *11*(7), Article 273. https://doi.org/10.3390/buildings11070273

Liu, G., Xie, Q., Li, X., & Tan, Y. (2024). Modeling heterogeneous and adaptive homeowners’ decision-making for green retrofit. *Energy and Buildings*, *312*, 114212. https://doi.org/https://doi.org/10.1016/j.enbuild.2024.114212

Liu, G., Ye, K. H., Tan, Y. T., Huang, Z. J., & Li, X. H. (2022). Factors influencing homeowners housing renovation decision-making: Towards a holistic understanding. *Energy and Buildings*, *254*, Article 111568. https://doi.org/10.1016/j.enbuild.2021.111568

Liyanage, D. R., Hewage, K., Hussain, S. A., Razi, F., & Sadiq, R. (2024). Climate adaptation of existing buildings: A critical review on planning energy retrofit strategies for future climate. *Renewable and Sustainable Energy Reviews*, *199*, 114476. https://doi.org/https://doi.org/10.1016/j.rser.2024.114476

Local Partnerships LLP. (2021). *LOCAL AUTHORITY DOMESTIC RETROFIT HANDBOOK*. https://localpartnerships.org.uk/wp-content/uploads/2023/04/Local-Partnerships-LA-Domestic-Retrofit-Handbook-July2021.pdf

Lomas, K. J., Li, M., & Drury, P. (2024). How do energy efficiency measures affect the risk of summertime overheating and cold discomfort? Evidence from English homes. *Energy Policy*, *188*, 114108. https://doi.org/https://doi.org/10.1016/j.enpol.2024.114108

Loscher, G., Splitter, V., & Seidl, D. (2019). Theodore Schatzki's practice theory and its implications for organization studies. *Management, Organizations and Contemporary Social Theory*, 115-134. https://doi.org/10.4324/9780429279591-7

LPOC. (2021). What is a Listed Building? *Listed Property*. https://www.lpoc.co.uk/help-advice/what-is-a-listed-property/

Lutzenhiser, L. (2014). Through the energy efficiency looking glass. *Energy Research & Social Science*, *1*, 141-151. https://doi.org/10.1016/j.erss.2014.03.011

Ma, J., Qian, Q. K., Visscher, H., & Song, K. (2022). Barriers for Homeowners in Decisions to Undertake Government-Led Energy Efficiency Renovation Projects in Northern China. *Sustainability*, *14*(12), 7298. https://doi.org/10.3390/su14127298

March, S. T., & Storey, V. C. (2008). Design Science in the Information Systems Discipline: An Introduction to the Special Issue on Design Science Research. *MIS Quarterly*, *32*(4), 725. https://doi.org/10.2307/25148869

Matulka, R., & Wood, D. (2013). The History of the Light Bulb. *Energy.gov*. https://www.energy.gov/articles/history-light-bulb

May, N., McGilligan, C., & Ucci, M. (2019). *Health and Moisture in Buildings*. UK Centre for Moisture in Buildings.

Mayer, Z., Heuer, J., Volk, R., & Schultmann, F. (2021). Aerial thermographic image-based assessment of thermal bridges using representative classifications and calculations. *Energies*, *14*(21), 7360.

McCrindle, M., & Wolfinger, E. (2014). *The ABC of XYZ : understanding the global generations*. Mccrindle Research Pty Ltd.

McGinley, O., Moran, P., & Goggins, J. (2020). Key Considerations In The Design Of A One-Stop-Shop Retrofit Model. *Civil Engineering Research in Ireland 2020*.

MCS. (2024). *Record number of heat pumps installed in UK homes in 2023*. Microgeneration Certification Scheme. https://mcsfoundation.org.uk/news/record-number-of-heat-pumps-installed-in-uk-homes-in-2023/

Melvin, J. (2018). The split incentives energy efficiency problem: Evidence of underinvestment by landlords. *Energy Policy*, *115*, 342-352. https://doi.org/10.1016/j.enpol.2017.11.069

Menconi, M., Painting, N., & Piroozfar, P. (2024). Modelling and simulation of low-risk energy retrofit measures for Traditional Listed Dwellings in the UK. *Journal of Building Engineering*, *82*, 108346. https://doi.org/https://doi.org/10.1016/j.jobe.2023.108346

Menicou, M., Exizidou, N., Vassiliou, V., Christou, P., Assimakopoulou, M., & Tsairidi, E. (2016). Economic Evaluation of Financial Incentive Schemes for Energy Retrofit Projects in Residential Buildings. *Journal of Sustainable Architecture and Civil Engineering*, *16*(3). https://doi.org/10.5755/j01.sace.16.3.16200

Merrick, N. (2023). What does a place-based, citizen-led approach to retrofit look like? *Carbon Co-op*. https://carbon.coop/2023/12/what-does-a-place-based-citizen-led-approach-to-retrofit-look-like/#:~:text=Area%20based%20retrofit%20involves%20undertaking

MHCLG. (2019). The Future Homes Standard: changes to Part L and Part F of the Building Regulations for new dwellings. *GOV.UK*. https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings

Miao, C., Teng, K., Wang, Y., & Jiang, L. (2020). Technoeconomic Analysis on a Hybrid Power System for the UK Household Using Renewable Energy: A Case Study. *Energies*.

Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, *6*(1), 42. https://doi.org/10.1186/1748-5908-6-42

Mittelstaedt, M. (2020). *Consumer Psychology and Consumer Behavior*. scientific-economics.

Mlecnik, E. (2010). Challenges and opportunities of the passive house concept for retrofit. *University of Salford Institutional Repository*. http://usir.salford.ac.uk/10001/1/17_Barrett_PS_CIB_proceedings_2010.pdf#page=181

Mlecnik, E., Kondratenko, I., Cré, J., Vrijders, J., Degraeve, P., Have, J. A. v. d., Haavik, T., Aabrekk, S. A., Grøn, M., Hansen, S., Svendsen, S., Stenlund, O., & Paiho, S. (2012). Collaboration Opportunities in Advanced Housing Renovation. *Energy Procedia*, *30*(1), 1380-1389. https://doi.org/10.1016/j.egypro.2012.11.152

Mohammadpourkarbasi, H., Riddle, B., Liu, C., & Sharples, S. (2023). Life cycle carbon assessment of decarbonising UK's hard-to-treat homes: A comparative study of conventional retrofit vs EnerPHit, heat pump first vs fabric first and ecological vs petrochemical retrofit approaches. *Energy and Buildings*, *296*, 113353. https://doi.org/10.1016/j.enbuild.2023.113353

Morgan, C. (2018). *Sustainable renovation : improving homes for energy, health and environment*. The Pebble Trust.

Morgan, D. J., Maddock, C. A., & Musselwhite, C. B. A. (2024). These are tenants not guinea pigs: Barriers and facilitators of retrofit in Wales, United Kingdom. *Energy Research & Social Science*, *111*, 103462. https://doi.org/https://doi.org/10.1016/j.erss.2024.103462

Morgan, J., Chu, C. M., & Haines-Doran, T. (2023). Competent retrofitting policy and inflation resilience: The cheapest energy is that which you don't use. *Energy Economics*, *121*, 106648. https://doi.org/10.1016/j.eneco.2023.106648

Morgan, J. M., & Liker, J. K. (2006). *The Toyota product development system : integrating people, process, and technology*. Productivity Press.

Muijs, D. (2022). *Doing Quantitative Research in Education with IBM SPSS Statistics* (3 ed.). SAGE.

Murphy, L. (2014). The influence of energy audits on the energy efficiency investments of private owner-occupied households in the Netherlands. *Energy Policy*, *65*(1), 398-407. https://doi.org/10.1016/j.enpol.2013.10.016

Nanda, A., Gibbs, L., Wong, C., Baker, M., Longlands, S., Bentley, R., & Jennings, A. (2022). *Retrofitting housing: Translating net-zero commitments into actions and impacts*. University of Manchester. https://research.manchester.ac.uk/en/publications/retrofitting-housing-translating-net-zero-commitments-into-action

National Energy Action. (2024). Energy crisis. *National Energy Action (NEA)*. https://www.nea.org.uk/energy-crisis/

National, G. (2022). How much of the UK's energy is renewable? | National Grid Group. *www.nationalgrid.com*. https://www.nationalgrid.com/stories/energy-explained/how-much-uks-energy-renewable

Nesselroade, K. P., & Grimm, L. G. (2019). *Statistical applications for the behavioral and social sciences* (2 ed.). Hoboken, Nj Wiley.

Nicol, S., Roys, M., Ormandy, D., & Ezratty, V. (2016). *The cost of poor housing in the European Union* (www.bre.co.uk, Issue. https://www.bre.co.uk/filelibrary/Briefing%20papers/92993_BRE_Poor-Housing_in_-Europe.pdf

Obr. (2024). A history of natural gas in the UK. *Office for Budget Responsibility*. https://obr.uk/box/a-history-of-natural-gas-in-the-uk/#:~:text=In%20the%201970s%2C%20following%20the

Oerther, S., & Oerther, D. B. (2018). Pierre Bourdieu's Theory of Practice offers nurses a framework to uncover embodied knowledge of patients living with disabilities or illnesses: A discussion paper. *Journal of Advanced Nursing*, *74*(4), 818-826. https://doi.org/10.1111/jan.13486

Offermann, P., Blom, S., Schönherr, M., & Bub, U. (2010, 2010). Artifact types in information systems design science–a literature review.

Ofgem. (2022). ECO4 Guidance: Local Authority Administration. *Ofgem*. https://www.ofgem.gov.uk/publications/eco4-guidance-local-authority-administration

ONS. (2022). *Dwelling stock: by tenure, United Kingdom, as at 31 March*. United Kingdom: Office for National Statistics

Ossokina, I. V., Kerperien, S., & Arentze, T. A. (2021). Does information encourage or discourage tenants to accept energy retrofitting of homes? *Energy Economics*, *103*, 105534. https://doi.org/10.1016/j.eneco.2021.105534

Oyedele, L. O., Ajayi, S. O., & Kadiri, K. O. (2014). Use of recycled products in UK construction industry: An empirical investigation into critical impediments and strategies for improvement. *Resources, Conservation and Recycling*, *93*, 23-31. https://doi.org/10.1016/j.resconrec.2014.09.011

Palmer, J., & Terry, N. (2017). *Solid Wall Insulation: Best Practice and Innovation Report for the Department of Business, Energy and Industrial Strategy* (www.gov.uk, Issue. https://assets.publishing.service.gov.uk/media/5a82bd26e5274a2e8ab59197/BEIS_-_SWI_Innovation_Final_Report_-_FINAL_Approved.pdf

Panakaduwa, C., Coates, P., & Munir, M. (2023). *What demotivates homeowners to retrofit their Houses: A systematic review* The 14th International Conference on Sustainable Built Environment (ICSBE 2023), Sri Lanka. https://www.kandyconference.org/wp-content/uploads/2024/07/ICSBE-vol-2-New.pdf

Panakaduwa, C., Coates, P., & Munir, M. (2024a). *Considering Human-Centred System Design in Relation to Cognitive and Educational Theories* Smart Digital Futures 2024, Portugal.

Panakaduwa, C., Coates, P., & Munir, M. (2024b). *Evaluation of Government Actions Discouraging Housing Energy Retrofit in the UK: A Critical Review* European Energy Markets 2024, Istanbul, Turkey.

Panakaduwa, C., Coates, P., & Munir, M. (2024c). *How artificial intelligence will change the housing retrofit process* The 10th International Congress on Architectural Technology [ICAT 2024], Galway, Ireland. https://drive.google.com/file/d/1rQLNKyX1MvVy6uFaz92YrYxDRxTbI_lw/view

Panakaduwa, C., Coates, P., & Munir, M. (2024d). Identifying sustainable retrofit challenges of historical Buildings: A systematic review. *Energy and Buildings*, *313*, 114226. https://doi.org/https://doi.org/10.1016/j.enbuild.2024.114226

Pardalis, G., Mahapatra, K., Mainali, B., & Bravo, G. (2021). Future energy-related house renovations in Sweden: one-stop-shop as a shortcut to the decision-making journey. *Emerging Research in Sustainable Energy and Buildings for a Low-Carbon Future*, 37-52.

Pardalis, G., Talmar, M., & Keskin, D. (2021). To be or not to be: The organizational conditions for launching one-stop-shops for energy related renovations. *Energy Policy*, *159*(1), 112629. https://doi.org/10.1016/j.enpol.2021.112629

Parity Projects. (2024a). Home. *Ecofurb - the Low Carbon Home Service*. https://www.ecofurb.com/

Parity Projects. (2024b). Pathways. *Parity Projects*. https://parityprojects.com/platform/pathways/

Passivhaus, T. (2023). *How to build a Passivhaus GOOD PRACTICE GUIDE* (2 ed.). Passivhaus Trust. https://www.passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/How%20to%20Build%202023/How%20to%20Build%20v2.1.pdf

Passivhaus Trust. (2021). *Passivhaus retrofit in the UK*.

Patterson, J. (2023). *Developing a practical retrofit early-stage survey tool to inform the decision-making process for existing homes*. https://orca.cardiff.ac.uk/id/eprint/161139/1/PRESS-1EarlyRetrofittool_FINAL_202307.pdf

Pease, A., & Pease, B. (2001). *Why Men Don't Listen and Women Can't Read Maps*. MIRA.

Pender, R. (2021). Making good decisions: avoiding alignment problems and maladaptation in retrofit and construction. *Journal of Architectural Conservation*, *27*(3), 151-175. https://doi.org/10.1080/13556207.2021.1965759

Pernetti, R., Pinotti, R., & Lollini, R. (2021). Repository of Deep Renovation Packages Based on Industrialized Solutions: Definition and Application. *Sustainability*, *13*(11), Article 6412. https://doi.org/10.3390/su13116412

Petsou, A., Medina, H. A., Pender, R., & Hong, S. M. (2023). Understanding current retrofit practices to prevent the unintended consequences affecting IEQ and health. *E3S web of conferences*, *396*, 01087-01087. https://doi.org/10.1051/e3sconf/202339601087

Pickles, D. (2016). *Energy Efficiency and Historic Buildings:*
Draught-proofing Windows and Doors. https://historicengland.org.uk/images-books/publications/eehb-draught-proofing-windows-doors/heag084-draughtproofing/

Pinkasovitch, A. (2023). Introduction to Supply and Demand. *Investopedia*. https://www.investopedia.com/articles/economics/11/intro-supply-demand.asp

PMI. (2017). *A Guide to the Project Management Body of Knowledge : (PMBOK guide)* (6 ed.). Project Management Institute.

Price, S., Elena, A., Tim, W., Konstantinos, M., & Nuria, L. (2021). *Retrofit Internal Wall Insulation: Guide to Best Practice*. Department for Business Energy and Industrial Strategy.

Pries-Heje, J., Baskerville, R., & Venable, J. R. (2008). Strategies for design science research evaluation.

Ramos, V. J. (2018). *Analyzing the Role of Cognitive Biases in the Decision-Making Process*. IGI Global.

RBKC. (2020). Prevent heat loss in your home | Royal Borough of Kensington and Chelsea. *www.rbkc.gov.uk*. https://www.rbkc.gov.uk/environment/climate-change/prevent-heat-loss-your-home

RIBA. (2020). Greener Homes - decarbonising the housing stock. *www.architecture.com*. https://www.architecture.com/knowledge-and-resources/resources-landing-page/greener-homes-decarbonising-our-housing-stock

RIBA. (2021). The Future Homes Standard explained. *www.architecture.com*. https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/the-future-homes-standard-explained

RIBA. (2022). Passivhaus Overlay to the RIBA Plan of Work. *www.architecture.com*. https://www.architecture.com/knowledge-and-resources/resources-landing-page/passivhaus-overlay-to-the-riba-plan-of-work

Rickaby, P. (2019). PAS2035, Each Home Counts and a career in energy efficiency - an interview with Dr Peter Rickaby. *www.youtube.com*. https://www.youtube.com/watch?v=HpV_-SF4GW8

Rickaby, P. (2023). *The importance of standards for safe energy retrofit | A BSI white paper*. https://www.bsigroup.com/siteassets/pdf/en/insights-and-media/insights/white-papers/retrofit_standards_executive_briefing.pdf

RICS. (2020). *Retrofitting to decarbonise UK existing housing stock RICS net zero policy position paper*. https://www.rics.org/news-insights/rics-policy-report-retrofitting-to-decarbonise-uk-existing-housing-stock

RICS. (2024). Residential retrofit standard. *www.rics.org*. https://www.rics.org/content/dam/ricsglobal/documents/standards/residential-retrofit-standard_march-2024-1.pdf

Rodrigues, L., Gillott, M., Waldron, J., Cameron, L., Tubelo, R., Shipman, R., Ebbs, N., & Bradshaw-Smith, C. (2020). User engagement in community energy schemes: A case study at the Trent Basin in Nottingham, UK. *Sustainable Cities and Society*, *61*, 102187. https://doi.org/https://doi.org/10.1016/j.scs.2020.102187

Rogers, E. M. (1983). *Diffusion of innovations* (3 ed.). Free Press.

Rosenow, J., & Eyre, N. (2016). A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. *Energy Research & Social Science*, *21*, 141-144. https://doi.org/10.1016/j.erss.2016.07.005

Rosenow, J., Lowes, R., Broad, O., Hawker, G., Wu, J., Qadrdan, M., & Gross, R. (2020). *The pathway to net zero heating in the UK A UKERC policy brief Key findings*. https://strathprints.strath.ac.uk/76380/1/Rosenow_etal_UKERC_2020_The_pathway_to_net_zero_heating_in_the_UK.pdf

Royapoor, M., Allahham, A., Hosseini, S. H., Rufa'I, N. A., & Walker, S. (2023). Towards 2050 net zero carbon infrastructure: a critical review of key decarbonization challenges in the domestic heating sector in the UK. *Energy Sources, Part B: Economics, Planning, and Policy*, *18*(1). https://doi.org/10.1080/15567249.2023.2272264

Saffari, M., & Beagon, P. (2022). Home energy retrofit: Reviewing its depth, scale of delivery, and sustainability. *Energy and Buildings*, *269*, 112253. https://doi.org/10.1016/j.enbuild.2022.112253

Santander. (2022). *Buying into the Green Homes Revolution*. https://www.santander.co.uk/assets/s3fs-public/documents/buying_into_the_green_homes_revolution_report.pdf

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2019). *Research methods for business students* (8 ed.). Pearson.

Schindler, P. S., & Cooper, D. R. (2014). *Business research methods* (12 ed.). Mcgraw-Hill Education.

Schoenefeldt, H. (2014). Interrogating the technical, economic and cultural challenges of delivering the PassivHaus standard in the UK. *www.kent.ac.uk*. https://kar.kent.ac.uk/44559/

SEAI. (2022). One Stop Shop Service. *Sustainable Energy Authority Of Ireland | SEAI*. https://www.seai.ie/grants/home-energy-grants/one-stop-shop/

Seddiki, M., Bennadji, A., Alabid, J., Gray, D., & Deveci, G. (2022). Development and Pilot Evaluation of an Online Retrofit Decision-Making Tool for Homeowners. *Buildings*, *12*(10), 1513. https://www.mdpi.com/2075-5309/12/10/1513

Seddiki, M., Bennadji, A., Laing, R., Gray, D., & Alabid, J. M. (2021). Review of Existing Energy Retrofit Decision Tools for Homeowners. *Sustainability*, *13*(18), 10189. https://doi.org/10.3390/su131810189

Serin, B. (2023). *Reviewing Residential Retrofitting Literature An Explorative Mapping Study*. https://thinkhouse.org.uk/site/assets/files/2820/cache0523b.pdf

Shelter. (2021). Health of one in five renters harmed by their home. *Shelter England*. https://england.shelter.org.uk/media/press_release/health_of_one_in_five_renters_harmed_by_their_home

Shwashreh, L., Taki, A., & Kagioglou, M. (2024). Retrofit Strategies for Alleviating Fuel Poverty and Improving Subjective Well-Being in the UK's Social Housing. *Buildings*, *14*(2).

Simcock, N., & Bouzarovski, S. (2023). A cure-all for energy poverty? Thinking critically about energy advice. *Critical Social Policy*, 02610183231219185. https://doi.org/10.1177/02610183231219185

Simcock, N., Walker, G., & Day, R. (2016). Fuel poverty in the UK: beyond heating? *People Place and Policy Online*, *10*(1), 25-41. https://doi.org/10.3351/ppp.0010.0001.0003

Simon, H. A. (1993). Decision Making: Rational, Nonrational, and Irrational. *Educational Administration Quarterly*, *29*(3), 392-411. https://doi.org/10.1177/0013161x93029003009

Simon, H. A. (1996). *The sciences of the artificial* (3 ed.). MIT Press.

Simpson, S., Banfill, P., Haines, V., Mallaband, B., & Mitchell, V. (2015). Energy-led domestic retrofit: impact of the intervention sequence. *Building Research & Information*, *44*(1), 97-115. https://doi.org/10.1080/09613218.2014.996360

Sinek, S. (2011). *Start with why: How great leaders inspire everyone to take action*. Portfolio/Penguin.

Sinek, S. (2020). How to Make a Cultural Transformation | Simon Sinek. *www.youtube.com*. https://youtu.be/N9d0NqSztWA

Skidmore, C. (2023). *MISSION ZERO Independent Review of Net Zero*. https://assets.publishing.service.gov.uk/media/63c0299ee90e0771c128965b/mission-zero-independent-review.pdf

Skidmore, C., & McWhirter, S. (2023). *Mission Retrofit* (UKGBC, Issue. https://missionzerocoalition.com/wp-content/uploads/2023/09/MZC-Mission-Retrofit-Report_FINAL.pdf

Snowden, D., & Boone, M. (2007). A Leader's Framework for Decision Making. *Harvard Business Review*. https://hbr.org/2007/11/a-leaders-framework-for-decision-making

Snugg. (2022). *The simple and affordable way to make your home energy efficient*. Arniston Ltd. https://www.snugg.com/

Spetzler, C., Winter, H., & Meyer, J. (2016). *Decision Quality*. John Wiley & Sons.

Steen, S. (2015). Amazed by Grace: Simplicity in life is enough. *The Daily News Journal*. https://eu.dnj.com/story/life/2015/07/18/steen-keep-life-simple/30345955/

Steiner, S. (2016). Generation Y in the workplace. *Talentor*. https://talentor.com/blog/generation-y-in-workplace

Stevenson, F., & Leaman, A. (2010). Evaluating housing performance in relation to human behaviour: new challenges. *Building Research & Information*, *38*(5), 437-441. https://doi.org/10.1080/09613218.2010.497282

Strauss, W., & Howe, N. (1991). *Generations : the history of America's future, 1584 to 2069*. William Morrow.

Suhr, M., & Hunt, R. (2019). *Old house eco handbook : a practical guide to retrofitting for energy efficiency and sustainability*. Frances Lincoln.

Sunak, R. (2023). PM speech on Net Zero: 20 September 2023. *GOV.UK*. https://www.gov.uk/government/speeches/pm-speech-on-net-zero-20-september-2023

Sunikka-Blank, M., & Galvin, R. (2012). Introducing the prebound effect: the gap between performance and actual energy consumption. *Building Research & Information*, *40*(3), 260-273.

Swan, W. (2013). Retrofit innovation in the UK social housing sector. In *Retrofitting the Built Environment* (pp. 36-52). https://doi.org/https://doi.org/10.1002/9781118273463.ch4

Tan, L. M., Arbabi, H., Ward, W., Li, X., Tingley, D. D., Khan, A., & Mayfield, M. (2023). Towards an automated workflow for large-scale housing retrofit. *Environmental Research Letters*, *18*(6), 061006. https://doi.org/10.1088/1748-9326/acd797

Tayeh, B. A., Abu Aisheh, Y. I., & Abuzuhri, I. O. (2020). Factors Affecting Sustainability Performance during the Construction Stage in Building Projects-Consultants' Perspective. *The Open Construction and Building Technology Journal*, *14*(1), 17-26. https://doi.org/10.2174/1874836802014010017

The Health foundation. (2017). How does housing influence our health? | The Health Foundation. *The Health Foundation*. https://www.health.org.uk/infographic/how-does-housing-influence-our-health

The Retrofit Academy. (2021). *PAS 2035 What is it and what does it mean for you?* https://www.retrofitacademy.org/wp-content/uploads/2019/10/PAS-2035.pdf

TheIET. (2020). *Scaling up retrofit 2050* (www.theiet.org, Issue. https://www.theiet.org/media/8758/retrofit.pdf

Thornley, L., & Waa, A. (2009). *Increasing public engagement with historic heritage A social marketing approach*. https://www.doc.govt.nz/documents/science-and-technical/sfc294entire.pdf

Todd, P. M., & Gigerenzer, G. (2000). Précis of Simple heuristics that make us smart. *Behavioral and Brain Sciences*, *23*(5), 727-741. https://doi.org/10.1017/s0140525x00003447

Torgal, F. P., Granqvist, C.-G., Jelle, B. P., Vanoli, G. P., Bianco, N., & Kurnitski, J. (2017). *Cost-Effective Energy Efficient Building Retrofitting : Materials, Technologies, Optimization and Case Studies*. Elsevier Science & Technology.

Tozer, L., MacRae, H., & Smit, E. (2023). Achieving deep-energy retrofits for households in energy poverty. *Buildings and Cities*. https://doi.org/10.5334/bc.304

Traynor, J. (2019). *EnerPHit: A Step by Step Guide to Low Energy Retrofit*. Routledge.

TrustMark. (2022). TrustMark - About Us. *www.trustmark.org.uk*. https://www.trustmark.org.uk/aboutus

TrustMark. (2024a). A guide to Retrofitting your home. *www.trustmark.org.uk*. https://www.trustmark.org.uk/homeowner/information-guidance/retrofit-your-home

TrustMark. (2024b). TrustMark Data Warehouse. *www.trustmark.org.uk*. https://www.trustmark.org.uk/business/data-warehouse

Tsang, C., Parker, J., & Glew, D. (2024). A Heat Loss Sensitivity Index to Inform Housing Retrofit Policy in the UK. *Buildings*, *14*(3).

UK Government. (2020). The ten point plan for a green industrial revolution. *GOV.UK*. https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

UK Government. (2021). *Net Zero Strategy: Build Back Greener*. Controller of Her Majesty's Stationery Office.

UK Parliament. (2021). Energy Efficiency of Existing Homes - Environmental Audit Committee - House of Commons. *publications.parliament.uk*. https://publications.parliament.uk/pa/cm5801/cmselect/cmenvaud/346/34605.htm

UKEA. (2021). PAS 2035. *www.uk-energy-assessors.co.uk*. https://www.uk-energy-assessors.co.uk/services/pas-2035

UKGBC. (2021). *The Retrofit Playbook Driving retrofit of existing homes – a resource for local and combined authorities* (www.ukgbc.org, Issue. https://www.ukgbc.org/wp-content/uploads/2021/02/Retrofit-Playbook.pdf

Ukgbc. (2022). *Five key tests for a net zero and climate resilient Future Homes Standard UKGBC briefing paper for policymakers*. https://ukgbc.s3.eu-west-2.amazonaws.com/wp-content/uploads/2022/11/08092138/UKGBC-5-Key-Tests-for-Future-Homes-Standard-Oct-2022.pdf

Unfcc. (2023). COP28 Agreement Signals "Beginning of the End" of the Fossil Fuel Era. *Unfccc.int*. https://unfccc.int/news/cop28-agreement-signals-beginning-of-the-end-of-the-fossil-fuel-era

United Nations. (2015). THE 17 GOALS | Sustainable Development. *sdgs.un.org*. https://sdgs.un.org/goals#icons

Vaishnavi, V. K., & Kuechler, W. (2015). *Design science research methods and patterns innovating information and communication technology*. Crc Press.

Venable, J., Pries-Heje, J., & Baskerville, R. (2012). A Comprehensive Framework for Evaluation in Design Science Research. *Lecture Notes in Computer Science*, 423-438. https://doi.org/10.1007/978-3-642-29863-9_31

Vergragt, P. J., & Brown, H. S. (2012). The challenge of energy retrofitting the residential housing stock: grassroots innovations and socio-technical system change in Worcester, MA. *Technology Analysis & Strategic Management*, *24*(4), 407-420. https://doi.org/10.1080/09537325.2012.663964

Vom Brocke, J., Hevner, A. R., & Mädche, A. (2020). *Design Science Research. Cases*. Springer Nature.

WCED. (1987). *Our Common Future*. Oxford University Press. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

Welch, S., Obonyo, E., & Memari, A. M. (2023). A review of the previous and current challenges of passive house retrofits. *Building and Environment*, *245*, 110938. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.110938

Wieringa, R. J. (2014). *Design Science Methodology for Information Systems and Software Engineering* (1 ed.). Springer.

Wilde, M. D. (2019). The sustainable housing question: On the role of interpersonal, impersonal and professional trust in low-carbon retrofit decisions by homeowners. *Energy Research & Social Science*, *51*, 138-147. https://doi.org/10.1016/j.erss.2019.01.004

Wood, G., Ong, R., & McMurray, C. (2012). Housing Tenure, Energy Consumption and the Split-Incentive Issue in Australia. *International Journal of Housing Policy*, *12*(4), 439-469. https://doi.org/10.1080/14616718.2012.730218

World Population Review. (2022). Standard Of Living By Country 2020. *worldpopulationreview.com*. https://worldpopulationreview.com/country-rankings/standard-of-living-by-country

Worthing, D., Dann, N., & Heath, R. (2021). *Marshall and worthing's the construction of houses*. Routledge.

Xu, Z., Hu, X., & Liu, G. (2023, 2023//). Optimization of Housing Retrofit Policies: A Perspective of Homeowners' Motivations. Proceedings of the 27th International Symposium on Advancement of Construction Management and Real Estate, Singapore.

Yin, R. K. (2018). *Case study research : design and methods* (6 ed.). Sage.

Zahiri, S., & Gupta, R. (2023). Examining the Risk of Summertime Overheating in UK Social Housing Dwellings Retrofitted with Heat Pumps. *Atmosphere*, *14*(11), 1617-1617. https://doi.org/10.3390/atmos14111617

Zaunbrecher, B. S., Arning, K., Halbey, J., & Ziefle, M. (2021). Intermediaries as gatekeepers and their role in retrofit decisions of house owners. *Energy Research & Social Science*, *74*(1). https://doi.org/https://doi.org/10.1016/j.erss.2021.101939

Zhang, X., Jung, G.-J., & Rhee, K.-N. (2022). Performance evaluation of thermal bridge reduction method for balcony in apartment buildings. *Buildings*, *12*(1), 63.

Zuhaib, S., Manton, R., Hajdukiewicz, M., Keane, M. M., & Goggins, J. (2017). Attitudes and approaches of Irish retrofit industry professionals towards achieving nearly zero-energy buildings. *International Journal of Building Pathology and Adaptation*, *35*(1), 16-40. https://doi.org/10.1108/ijbpa-07-2016-0015

APPENDICES

Appendix A: Ethics approval

Ethics Application: Panel Decision

ethics <ethics@salford.ac.uk>
Tue 5/9/2023 10:40 PM
To: Chamara Panakaduwa Gamage <C.S.PanakaduwaGamage@edu.salford.ac.uk>
Cc: Paul Coates <S.P.Coates@salford.ac.uk>

The Ethics Panel has reviewed your application: A Proposal for An Interface To Support Homeowner Business Case Justification for Sustainable Housing Retrofit
Application ID: 10162

The decision is: Application Approved.

If the Chair has provided comments, these are as follows:

It will be useful for applicant to provide justifications for the methodologies, population, sample techniques and sizes etc adopted.

You will no longer be able to edit your application in the system.

Link to the Ethics Application Tool: https://apps.powerapps.com/play/de0240e7-3d59-4974-849e-ba87d2541856?tenantId=65b52940-f4b6-41bd-833d-3033ecbcf6e1

Appendix B: Questionnaire of the survey

COLLECTING INFORMATION REQUIREMENTS FOR HOME UPGRADE DECISION-MAKING

01.07.2023

Dear respondent,

Invitation to Respond to a Questionnaire Survey

I am Chamara Panakaduwa, a post-graduate research student at the University of Salford, United Kingdom. I am conducting research to help homeowners with their decision-making in housing retrofits. (Housing retrofits are basically defined as any of the upgrades to the house. However, energy-related improvements are highlighted). If you are a homeowner (or willing to buy a house) in the UK, I warmly invite you to take part in this questionnaire survey.

One of the ultimate objectives of this study is to reduce energy bills of our houses.

Your personal details are not collected and there is no way for us to trace back who are the respondents and which respondent provided what information. Responding to this survey is totally voluntary. By submitting a completed response, you are giving us informed consent to collect, store and process your submitted data. Details with regard to this questionnaire survey are further elaborated in the participant information sheet. Click the below link.

https://drive.google.com/file/d/1LehpZ2cPUy_Oob99LHMT4lrpLhSIXk2q/view?usp=sharing

There are 10 question sections and one demographic question section. The questionnaire will take approximately 10 minutes to complete. The deadline for this activity is 31st July 2023.

Thanks in advance,
Yours truly,

Chamara Panakaduwa

1.0 Eligibility criteria check

In order to be eligible for taking part in the questionnaire survey, you must be a UK resident. You (or your family) may already own a house in the UK. Alternatively, you may be willing to buy a house in the future.

We are going to talk about upgrading the house (already owned or to be purchased).

Please choose the best answer

- ○ I/we already own a house in the UK. (A UK homeowner)
- ○ I/we expect to buy a house in the UK (Potential UK homeowner)
- ○ This is not for me. I quit

1 - Not at all likely
2 - Less likely
3 - Somewhat likely
4 - A lot likely
5 - Extremely likely

Imagine you are thinking about upgrading your home. How likely are you to use the following information for decision-making?

2 Cost information					
Total upfront cost of the housing upgrade	1	2	3	4	5
Cost of each upgrade activity Eg. Installing a new boiler					
Future maintenance and refurbishment costs					
Cost comparisons among sources					
Included costs and excluded costs in the total cost					

3 Financial information					
Types and amounts of finance	1	2	3	4	5
Cost and conditions of the finance					
Monthly loan instalment and payback period					
Eligibility checking for finance					
Support available to obtain finance					

4 Grant information					
Types and amounts of available grants	1	2	3	4	5
Conditions of the grants					
Assistance available to obtain grants					
Process and documentation of obtaining grants					
Limitations of grants					

5 Time information					
Overall upgrade project duration	1	2	3	4	5
Individual durations of home upgrade measures					
Durations of different combinations of home upgrade measures					
Seasonal differences in scheduling					
Milestones of the project and key deliverables					

6 Quality information					
Certifications possible after the home upgrade (Eg. EnerPhit)	1	2	3	4	5
Certification process (How these certifications are obtained)					
Quality information about the products and materials					
Warranty and guarantee information of home upgrade measures					
Guaranteed minimum quality or upgrade measures					

7 Energy performance					
Estimated future energy bills	1	2	3	4	5
Estimated energy use reduction					
Potential renewable energy generation by the house					
Comparison of current and future energy use/bills					
Linking retrofit measures with energy performance predictions					

8 Disruptions to daily routines					
Number of days affected by the home upgrade	1	2	3	4	5
Nature of disruption (Eg. Can I use a part of the house during upgrade?)					
What are the alternative accommodation options available?					
What will be the cost and availability of alternative accommodation?					
Upgrade works and methods which have lower disruption					

9 Home upgrade options					
What are the recommended home upgrade options?	1	2	3	4	5
On what basis these options are recommended?					
Order of installation of upgrade measures					
The big picture of home upgrade					
Possibility of breaking the project into phases and their costs					

10 Stakeholders					
Who are the stakeholders of home upgrades	1	2	3	4	5
What kind of influence they make					
What is their level of influence Eg. High or low					
When these stakeholders will influence the upgrade					
Quality rating of the suppliers, installers, designers and others.					

11 Risk information					
Potential risk towards cost, time quality	1	2	3	4	5
Risks during home upgrades					
Potential design risks					
Potential environmental risks					
Health and safety risks					

Demographic information

It is important to highlight that the questionnaire does not collect your email address, name or anything that helps someone to identify the respondents.

12 I am a ☐ Male ☐ Female ☐ Prefer not to say

13 I was born
☐ Before 1961 ☐ In between 1961 - 1980 ☐ In between 1981 - 1995
☐ After 1995

14 My maximum educational qualification is
☐ Below high school ☐ High school ☐ College ☐ Bachelors ☐ Post graduate

15 My source of income is from
☐ Employment ☐ Business ☐ Public benefits ☐ Other

16 My net household income is
☐ £1000 ☐ £2000 ☐ £3000 ☐ £4000 ☐ £5000
☐ £6000 ☐ £7000 ☐ £8000 ☐ £9000 ☐ £10000

17 Number of people in my/our house is
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

18 I/we live in a house

☐ Mid-terrace ☐ End of Terrace ☐ Flat ☐ fully Detached/Bungalow
☐ Semi-detached ☐ I don't know

19 This house was built

☐ Pre 1919 ☐ 1919-1944 ☐ 1945-1964 ☐ 1965-1980
☐ 1981-1990 ☐ After 1990 ☐ I Don't know

20 The heating of my/our house is

☐ Gas ☐ Electricity ☐ Heat pump ☐ LPG ☐ Firewood ☐ Coal ☐ Other

21 I/we have mortgaged my house

☐ Yes ☐ No ☐ Not applicable as I am renting

Thank you!

Declaration of the respondent

I have duly read and understood the information on the participant information sheet. By submitting the responses to the questionnaire survey, I consent voluntarily to be a respondent in this study. I understand that I can refuse to answer any question and I can withdraw from the survey at any time before submitting the responses, without having to give a reason.

Submit

Appendix C: Demographics of the interview participants

Artefact development - Academics

		Position	University	Expertise
1	A16	Professor	Leeds Beckett	Psychology
2	A3	Research fellow	Robert Gorden	Housing retrofit systems
3	A1	Asst. Professor	Bradford	Housing retrofit systems
4	A6	Research fellow	Oxford	Stakeholder engagement in retrofit
5	A2	Research associate	Cambridge	Driving housing retrofit
6	A22	Senior Lecturer	Lund (Sweden)	One stop shop
7	A28	Professor	Sussex	One stop shop
8	A27	Professor	Leeds	Stakeholder engagement in retrofit

Artefact development - Retrofit experts

		Position	Organisation	Expertise	Education
1	A5	Partner/Author	Architect firm	Retrofit design and project delivery	Architect
2	A11	Sustainability Consultant	Construction consultant	Sustainability, social housing retrofit	PhD student in retrofit
3	A10	Educator	Retrofit training institute	Housing retrofit and zero carbon new built	Architect
4	A7	Director of sustainability	Construction consultant	Social housing retrofit	Environmental engineering
5	A9	Retrofit Surveyor	County council	Social housing retrofit	Building surveyor
6	A12	Director of retrofit	Surveying firm	Energy assessment	Building Surveyor
7	A8	Director/PAS Author	Retrofit consultancy firm	Policy regulations and building physics	PhD in Physics
8	A17	Architect	Own firm	Retrofit contractor	Architect
9	A21	Architect/Author	Architect firm	Passivhaus and sustainable construction	Architect
10	A18	Senior Consultant	Energy company	Fomer retrofit project manager of a county council	PhD in energy
11	A25	Supply chain development lead	Leveling up consulation firm	Levelling up retrofit supply chains	BA in Geography

Artefact development - Retrofit professionals

		Position	Organisation	Expertise	Education
1	A15	Retrofit assessor	Freelancing	Retrofit assessment	PhD in Acoustics
2	A13	Designer	Freelancing	Historical housing retrofit	BA in Design
3	A20	Renewable energy consultant	Freelancing	Renewable energy	Unknown

Artefact development - Multidisciplinary stakeholders

		Position	Organisation	Expertise	Education
1	A4	Freelancer	NA	Promoting housing retrofit	Bachelors
2	A14	Public Health Director	County Council	Public health	Medical practitioner
3	A24	Low carbon home director	Energy company	Running ECO4 schemes	Building surveyor
4	A23	Entrepreneur	Own company sustainable homes	Promoting energy efficiency among people	Masters
5	A19	Architect	Retired	Enthusiast of energy efficient homes	Architect
6	A26	Director	National level Independent organisation	Homeower engagement	Masters

Artefact validation - Details of the interviewees

		Position	Organisation	Expertise	Education
1	C1	PhD Student	University of Salford	Sustainable construction and smart building	Masters
2	C2	Software developer/ Academic	College	Software development and business management	Masters
3	C3	Data scientist	GIS company	Data science and GIS	Masters
4	C4	Engineering assistant	Department of agriculture	Civil and building construction	Masters
5	C5	Homeowner	Business	Banking and finance	Diploma
6	C6	Researcher	University of Salford	Design science research	PhD
7	C7	PhD Student	University of Salford	Sustainable construction and project management	Masters
8	C8	Project Manager	Local authority	Retrofit project delivery	Bachelors
9	C9	Lecturer	University of Salford	Sustainable housing	PhD
10	C10	Business development lead	Software development company	Sales and marketing	Unknown
11	C11	Professor	University of Salford	Energy efficiency	PhD
12	C12	Policy expert	Institute for European climate and energy	Homeowner engagement with housing retrofit	PhD

Appendix D: References of the publications

Panakaduwa, C, Coates, P. and Munir, M. (2023, December), **What Demotivates Homeowners to Retrofit Their Houses: A Systematic Review.** *14th International Conference on Sustainable Built Environment. 2023*, December 15-17, University of Peradeniya, Sri Lanka. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2023, December), **Transforming Housing Retrofit: The Potential Impact Of Artificial Intelligence**. *14th International Conference on Sustainable Built Environment.* 2023, December 15-17, University of Peradeniya, Sri Lanka. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2024, January), **How Artificial Intelligence Will Change the Housing Retrofit Process.** *The 10th International Congress on Architectural Technology*, 2024 January 19, Atlantic Technological University, Galway, Ireland. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2024), **Identifying Sustainable Retrofit Challenges of Historical Buildings: A Systematic Review.** *Energy & Buildings*, Volume 313, 114226. Q1 Journal article.

Panakaduwa, C, Coates, P. and Munir, M. (2024), **Comparative analysis of homeowner decision-support systems for housing retrofit in the UK**. IPGRC 2024, 28th May 2024, University of Salford, UK. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2024), **Considering Human-Centred System Design in Relation to Cognitive and Educational Theories**. KES HCIS 2024, 18 - 22 June 2024, Madeira, Portugal. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2024), **Evaluation of Government Actions Discouraging Housing Energy Retrofit in the UK**: A Critical Review. EEM 24, 10 - 12 June 2024, Istanbul, Turkey. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2023, June), **Analysis of Homeowners' practices triggering housing retrofits: A practice theory approach**. *International Research Symposium - Climate Change Adaptation in the Coastal Built Environment*, 2023, June 19-20, Santander, Spain. (Accepted, Pending Book Chapter Publication)

Panakaduwa, C, Coates, P, Munir, M and De Silva, O. (2024), **Designing Visual User Interfaces To Reduce User Cognitive Fatigue For Better Mental Health**. IIMA 2024, 2nd - 4th September 2024. Manchester, UK. Conference paper.

Panakaduwa, C, Coates, P. and Munir, M. (2024), **Greening the Brown: Sustainable Retrofitting of UK Houses through Green Walls and Green Roofs**. ISHS Green Cities 2024, 25 - 28 Sept 2024, RHS Garden Wisely, Surrey, UK. Conference Paper.