Process perspective on homeowner energy retrofits: a qualitative metasynthesis

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Abstract

EU policy recognises the importance of encouraging low-carbon retrofit among homeowners to reduce operational energy use in dwellings and mitigate climate change. Building research and policy has traditionally focused on the identification of retrofit drivers and barriers, to strengthen the former and reduce the later. However valuable the static juxtaposition of drivers and barriers may be, it cannot capture their temporal dynamics during a retrofit process. Recent research emphasises repeatedly that retrofits should be understood as dynamic processes that unfold over extended periods of time. This paper presents a metasynthesis of qualitative case studies on energy retrofit in single-family owner-occupied dwellings. A process perspective is used to capture the dynamics between socio-technical aspects of the built environment that shape retrofit depth and energy use post-retrofit. Metasynthesis results show that: (i) pre-existing homeowner knowledge about energy retrofit plays a significant role on the depth of a technological solution achieved during the retrofit; (ii) the actual energy use post-retrofit depends on the extent of owners' involvement in the development of their retrofit design solutions. These findings have important implications for EU energy policy uptake to support household transition to low-carbon living.

Keywords: domestic retrofit, energy, process, socio-technical, qualitative metasynthesis, systematic review

Highlights

- Retrofit depth depends on alignment of actor goals and beliefs
- The alignment is contingent on existing socio-technical realities

- Such realities include homeowner expectations and maturity of the market
- Homeowner expectations can be shaped by proactive actions prior to retrofit
- Homeowner involvement in design development may reduce energy use post-retrofit

1. INTRODUCTION

Energy efficiency retrofit in the owner-occupied sector is an important part of European policy strategies that aim to reduce operational energy use in dwellings, and meet the global sustainability goals set out in Paris Agreement (UN, 2015), and mitigate climate change (IEA/IRENA, 2017). The use of energy services in European buildings accounts for 41% of the final energy consumption, of which two-thirds are for residential buildings (Rousselot, 2018). Seventy per cent of the residential stock in the EU is owner-occupied (Eurostat, 2020). For these reasons, low-carbon retrofit in the owner-occupied housing sector is an important part of the effort to address climate change challenge. The building sector is considered a major reservoir of energy efficiency potential (IEA, 2018). For instance, the maximum energy technical reduction potential has been estimated to be 53% in Sweden (Mata et al., 2013), 53% in Italy (Ballarini et al., 2014) and 50% in the UK (Rosenow et al., 2018).

A number of policies have been implemented in Europe to improve energy efficiency in the domestic sector (Economidou et al., 2020; IEA/IRENA, 2017; Kern et al., 2017; Rosenow et al., 2016). Current energy transitions scenarios to achieve global sustainability goals indicate that most of the current building stock would need to undergo deep retrofits by 2050 (IEA, 2018). However, the energy renovation rate in European Union results in 0.4–1.2% annual reduction of the total building stock's primary energy consumption, which is insufficient to meet the targets set (EC, 2019). The rate of energy efficiency improvements dropped even further due to the Covid-19 pandemic, which is expected to have long-term adverse effects on energy-efficiency investments in the building sector (IEA, 2020). This suggests that a complementary approach to the current policy focus is necessary to maintain and accelerate the rate of energy renovations.

Building research and policy has traditionally focused on the identification of drivers and barriers of various retrofit options, and numerous lists of such influences have been produced over time (Kastner and Stern, 2015; Kaveh et al., 2018; Martiskainen and Kivimaa, 2019; Organ et al., 2013; Wilson et al., 2015). The logic is that when homeowners weigh the benefits and costs of particular options, information provision and various incentives may influence their decisions in favour of or against more sustainable solutions. Thus, the identification of various drivers and barriers to retrofit can help make desired options seem more beneficial than alternatives and raise the rate of domestic energy renovations (Fyhn and Baron, 2017; Wilson et al., 2015).

A list of drivers and barriers to retrofit, however useful, does not reveal anything about the temporal sequence of various influences that operate between different stages of the process. Research on domestic retrofit suggests that such retrofits are often associated with a lengthy time period, over which renovation decisions unfold and strengthen, and therefore, should be conceptualised as processes with a series of stages (Bobrova et al., 2021; Fawcett and Killip, 2014; Gram-Hanssen, 2014a; Pettifor et al., 2015; Wilson et al., 2015). It can be argued that, a process perspective is useful – or even necessary – to understand and facilitate the movement of a household through the retrofit stages (Langley, 1999; Mohr, 1982; Van De Ven, 1992).

This paper takes a process perspective to present a qualitative metasynthesis of 18 empirical energy retrofit cases from the literature. A qualitative metasynthesis goes beyond a standard literature review, as it offers novel interpretations of findings, and though that, a possibility to construct larger narratives than in any individual study in the synthesis (Sandelowski and Barroso, 2007). For analysis purposes, the chosen theoretical lens integrates: (i) three stages relevant to the process of low-carbon retrofit and post-retrofit reduction in energy use; (ii) the importance of alignment of socio-technical aspects of the built environment to achieve a deep retrofit solution during retrofit and a sustained reduction in energy use post-retrofit. The analysis reveals some policy relevant insights: (i) the depth of the technological solution implemented during the retrofit depends on the goal alignment of several actors involved in retrofit, as well as on several socio-technical dynamics prior to it; (ii) the actual energy use reduction post-retrofit depends on the depth of the technological solution achieved and the level of homeowner involvement in the development of a technological retrofit solution.

The rest of the paper is structured as follows. Section 2 provides the theoretical underpinning for the conceptualisation of domestic retrofit process in three stages necessary to capture socio-technical dynamics that shape retrofit depth and energy use in homes. Section 3 provides the methodology for qualitative metasynthesis and describes the literature sample. Section 4 describes the synthesis findings. Section 5 discusses the insights drawn from the synthesis in line with current literature, derives possible implications for policy, considers the limitations of the study, and provides suggestions for future research. Section 6 concludes the paper.

2. THEORETICAL CONCEPTUALISATION

This section discusses the two elements used to frame the metasynthesis: (i) the socio-technical aspects of the built environment and (ii) the process perspective on retrofit.

2.1. Socio-technical aspects of the built environment in energy retrofit

The socio-technical systems approach is broadly used to capture the deep interaction between society and technology (Bijker et al., 2012; Hughes, 1983), and can be found in studies on energy use in dwellings (Chiu et al., 2014; Love and Cooper, 2015) and domestic energy retrofit (Gram-Hanssen, 2014b; Karvonen, 2013; Tweed, 2013; Wilson et al., 2015). In energy retrofit, such interactions manifest in: (i) the level of retrofit depth, and (ii) the level of energy use post retrofit (Love and Cooper, 2015). The social and technical aspects of the built environment should be jointly considered to understand such interactions (Cooper, 2017; Du Plessis and Cole, 2011; Hassler and Kohler, 2014; Love and Cooper, 2015; Moffatt and Kohler, 2008), as, for example, the materiality of the dwelling pre-configures its energy use, while values specific to a particular social context, including the ones of homeowners and building professionals, influence the depth of the technological solution achieved during the retrofit.

The socio-technical perspective does not attribute energy use and the level of achieved retrofit depth solely to social or technical aspects of the system (Gram-Hanssen, 2013). To understand domestic energy use, research should focus on various practices that energy makes possible, and the way they are conditioned by one's social context (Wilhite et al., 2000). For instance, research on domestic retrofit highlights repeatedly that pre-retrofit energy-related practices, such as cooling and heating, tend to carry over to post retrofit, even if they cannot be considered suitable or desirable in the new technical configuration of the house (Chiu et al., 2014; de Feijter and van Vliet, 2021; Vlasova and Gram-Hanssen, 2014). Similarly, in line with this perspective, the level of achieved retrofit depth is not attributed solely to the materiality of a dwelling and technology available on the market, or to the homeowner goals and motivations, as homeowners' concerns for the environment are only weakly linked to their retrofit activities (Maller and Horne, 2011). The analysis scope should include and consider in tandem a variety of socio-technical influences.

2.2. Process perspective on domestic energy retrofit

Process research on domestic retrofit conceptualises stages specific to homeowner retrofit-decision processes, sometimes with a very detailed differentiation between the stages (Bobrova et al., 2021; Broers et al., 2019; Nair et al., 2010; Owen and Mitchell, 2015; Pettifor et al., 2015). This paper takes a simplified perspective for the purposes of the metasynthesis and distinguishes three stages, sufficient to capture the socio-technical dynamics that shape the level of retrofit depth and energy use post-retrofit:

(i) *Pre-retrofit stage*, at which a household is not considering renovations in any way. During this stage different dynamics relevant to a specific retrofit are formed;

(ii) *Retrofit stage*, at which the household thinks about, plans and carries out retrofit. The depth of the conceived retrofit solution and the quality of its implementation determines the technological potential for energy use reduction.

(iii) *Post-retrofit stage*, at which the household experiences the renovations and adapts domestic life to the structural changes made to their home. Occupant behavioural patterns and physical structure of the house and its components determine the actual energy use.

The process perspective on retrofit allows to differentiate between proximate and ultimate influences[1] on retrofit decisions and outcomes. A proximate influence comes from an event which is closest in time to an observed outcome. In this paper, proximate influences and observed outcomes occur at the same stage of retrofit process. An ultimate influence is further removed in time from an observed outcome. In this paper, ultimate influences and observed outcomes are found at different

[1] The distinction between proximate and ultimate causation was developed in evolutionary biology (Mayr, 1961), and has since been used in various disciplines. For instance, Wilson et al.(2015) used the distinction to categorise influences on homeowner energy efficient renovation decisions. Note, that unlike Wilson et al.(2015), we do not use the word 'ultimate' to imply that such influences are more fundamental than the proximate ones, but simply to suggest that they are temporally further removed from the observed outcomes.

retrofit stages, with influences occurring at least one stage before the outcome. For instance, construction works quality can be enhanced by a retrofit coordinator on a proximate level during the *retrofit stage*. However, such quality will ultimately depend on builders' expertise at the *pre-retrofit stage* prior to the retrofit project.

In the outline, the theoretical framework brings together the two elements to explain the level of achieved retrofit depth and the level of post-retrofit energy use: (i) pre-retrofit, retrofit and post-retrofit stages; (ii) socio-technical aspects of the built environment that shape its development patterns. These two elements are used to categorise the results of the metasynthesis, and produce the graphical representation of the results juxtaposed to the elements of the framework that can be found in Figure 2 in *Section 4. Results*.

3. METHODS AND DATA

A *qualitative metasynthesis* approach is used to integrate a process perspective on energy retrofit in single-family dwellings from 10 papers reporting qualitative studies with homeowners. Qualitative metasynthesis is a systematic approach for the collection and analysis of qualitative studies with a focus on synthesising their findings from these studies with the use of qualitative methods (Sandelowski and Barroso, 2007, 2003), which originates in Noblit and Hare's (1988) method of meta-ethnographic synthesis. Metasynthesis is more than a summary of findings, as it offers novel interpretations of findings and a possibility to construct larger narratives than in any individual study (Sandelowski and Barroso, 2007). It is, therefore, useful to build new theoretical insights into the phenomenon of energy retrofit and the processes to accelerate their rate, building upon already available research findings.

3.1. Sampling strategy

The sampling strategy focused on finding case studies, as case studies often include in-depth descriptions of *processes* of interest (Yin, 2018), which is the critical element for the analysis in this paper. All qualitative studies, with a rich description of energy retrofit processes in owner-occupied dwellings, were eligible for inclusion. 'Qualitative research' was liberally defined as empirical research with human participants that uses, what are commonly viewed as qualitative techniques for sampling, data collection, data analysis and interpretation. 'Energy retrofit' was liberally defined as any retrofit activity, commonly viewed as one that has the technological potential to reduce operational energy use and carbon emissions from energy generation in dwellings. The focus was on households, as couples in committed relationship are likely to share their viewpoints towards energy use (Pelenur, 2018).

Potentially relevant articles were identified by search with no timespan or geographic restrictions in Web of Science, Scopus and International Bibliography of the Social Sciences (IBSS) databases. Studies had to be written in English, and only peer-reviewed original journal articles were included. Five search terms were used: *energy*, *home*, *retrofit*, *homeowner* and *qualitative research*. These five key terms together with their synonyms formed 61 search concepts used in the synthesis, which are presented in Appendix A. The articles identified early on were subject to footnote chasing, citation search and author search to identify more relevant papers (Sandelowski and Barroso, 2007). Energy Policy, Energy Research & Social Science and Building Research and Information journals were manually searched for the same purpose. The titles, abstracts and key words of the newly identified papers were scanned to reveal more synonyms to the main terms to make the search more thorough and inclusive. The articles were last retrieved on 26th January 2021.

The search return was 1,676 articles, after the duplicates were removed. Their titles were scanned. 127 abstracts and full-text articles were assessed for eligibility (Figure 1.) 25 articles depicted qualitative studies on energy retrofit in single-family owner-occupied homes, and their characteristics can be found in Appendix B. Fifteen of these articles used a qualitative approach for data collection and analysis, however, the findings were presented in a variable-oriented (process-invisible), rather than case-oriented (process-visible) manner, probably due to the word limit imposed by academic journals. As it was not possible to see the processes in these reports, they were excluded from the synthesis. The insights from these articles were nevertheless used to position metasynthesis results in the broader literature. The remaining 10 articles comprised the primary data for the synthesis. This small number indicates the scarcity of the 'process-visible' case study research on dwelling retrofit (Kivimaa and Martiskainen, 2018). At the same time, the small number is not a limitation or constraint to our study. In line with qualitative research practice, a sample of 4 to 10 in-depth studies is considered sufficient to generate enough complexity for theory development, while at the same time keeping the volume of the data manageable (Eisenhardt, 1989; Miles et al., 2014; Sandelowski and Barroso, 2007).

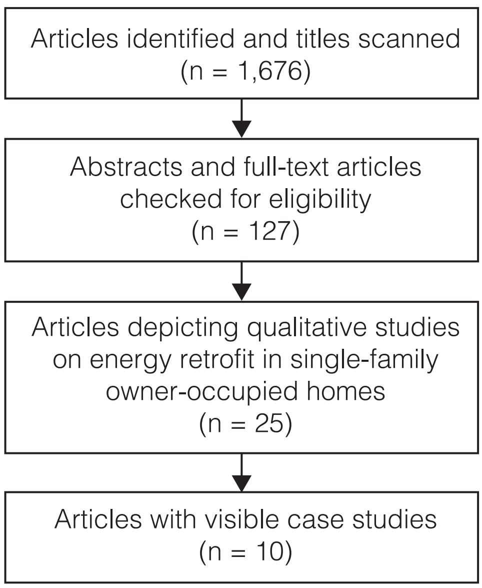

Figure 1. Selection process for the metasynthesis.

3.2. Profiles of selected studies and individual cases

The ten identified articles were published between 2010 and 2019. Four articles were from Scandinavian countries, one from Australia and five from the UK. Three out of these five British articles were based on the same case sample. The disciplinary affiliation(s) of the leading author in seven out of ten articles was in the field of built environment, ranging from architecture to engineering, management and planning. In the other three articles the disciplinary affiliation of the leading author was in energy, social science and social anthropology. The sample size in the articles ranged from one to 20 cases. The sampling strategy was one of convenience in most cases. All articles used pre-existing theoretical frameworks to guide the inquiry, and some of them used more than one framework. Four articles used social practice theory. Other theoretical frameworks were only used once and included one-stop-shop framework, the notion of socio-materiality, generic project development stages, socio-technical systems theory, human centred research approach and phenomenology of dwelling. The profile characteristics of the qualitative studies used in the synthesis are listed in Table 1.

Table 1. Profile characteristics of qualitative studies in the metasynthesis

Study and cases	First author affiliation	Country	Theory	Method	Sampling plan	Relevant sample*	Data collection strategy, timing and period
Bjørneboe et al., 2017 (BSH-A)	Built environment: Civil engineering	Denmark	One-stop-shop framework and Vanhoutteghem's stages of renovation process	Case study	Volunteer	1 case of energy home retrofit using one-stop-shop approach	Longitudinal study of retrofit project from the beginning to completion. Retrofit carried out in summer 2013.
Buser & Carlsson, 2017 (BC-B)	Built environment: Architecture and civil engineering, construction management	Sweden	Socio-materiality	Qualitative, part of a broader action research study	A subsample from larger qualitative study	1 case of home retrofit with initial intentions for energy efficiency (from 8 sampled)	1-year observations of retrofit practices and interviews.
Fyhn and Baron, 2017 (FB-C)	Social anthropology	Denmark, Norway	Shove's practice theory and Ingold's concept of dwelling	Presents two separate studies, each is called a case**. No references to case study methodology.	1st study – a subsample from a larger study; 2nd study – maximum variation.	1st study – 2 cases of home retrofit (from 5 sampled); 2nd study – 0 cases of the installation of the PV panels (from 11 sampled)	1st study – interviews and observations between spring 2012 and autumn of 2013 at the point of retrofit decisions; 2nd study – interviews in November 2012
Judson & Maller, 2014 (JM-D, JM-E, JM-F)	Built environment: Urban planning	Australia	Social practice theory	Qualitative, no method citations	Convenience	2 cases of self-identified 'green-renovators' (from 16 sampled); 1 case of a heritage home retrofit (from 20 sampled)	Retrospective interviews and walk-through tours. 1st interview set — from April 2008 to March 2009; 2nd interview set — from February to May 2011.
Martiskainen & Kivimaa, 2019 (MK-G, MK-H)	Social science	UK	Non-specified, uses project development phases	Case study	Convenience	2 cases of low-energy domestic retrofit (from 6 sampled)	Retrospective interviews and other relevant documents.

(continued)

Table 1. Profile characteristics of qualitative studies in the metasynthesis *(continued)*

Study and cases	First author affiliation	Country	Theory	Method	Sampling plan	Relevant sample*	Data collection strategy, timing and period
Mlecnik, 2010 (M-I)	Built environment: Housing management	Belgium	Rogers' innovation diffusion	Case study stated, survey for data collection	Maximum variation	1 case study of domestic retrofit to Passivhaus standard (from 15 sampled)	Questionnaires with open ended questions.
Galvin & Sunikka-Blank, 2014	Energy: environmental science	UK	Socio-technical systems theory	Qualitative, case study and grounded theory references	Convenience	7 cases of thermal home retrofit (from 9 sampled)	Retrospective interviews and walk-through tours, carried out in February – May 2014.
Sunikka-Blank & Galvin, 2016	Built environment: Sustainable architecture	UK	Human centred research approach	Qualitative, case study reference	Convenience	7 cases of thermal home retrofit (from 9 sampled)	Retrospective interviews and walk-through tours, carried out in February – May 2014.
Sunikka-Blank et al., 2018	Built environment: Sustainable architecture	UK	Bourdieu's habitus and Schatzki's social practice theory	Qualitative, no method citations	Convenience	7 cases of thermal home retrofit (from 9 sampled)	Retrospective interviews and walk-through tours, carried out in February – May 2014.
Vlasova & Gram-Hanssen, 2014 (VG-Q, VG-R)	Built environment: Socio-technical research	Denmark	Social practice theory and Moore & Karvonen's types of sustainable architecture production	Case study	Maximum variation	2 cases of energy-focused home retrofit (from 3 sampled)	Observations, interviews and other documents. Longitudinal study of retrofit projects from the beginning to completion.

Note: Shading is to show cases GS-J, GS-K, GS-L, GS-M, GS-N, GS-O, GS-P, which are based on the same sample.

* Indicates number of cases from a particular report that are used in the metasynthesis.

** The paper reports on two separate studies. The first is a study of retrofitting in Norwegian homes based on the stories of 5 households, which were identified as part of a broader project on the implementation of climate-related policy in home retrofitting. The second is a study of Danish homeowners' responses to policies aiming at promoting the installation of photovoltaic (PV) solar panels on private houses, which is based on interviews with 11 households. The paper calls each study a case, which makes it two cases. However, for the purposes of the metasynthesis we consider each individual retrofit journey a case, and therefore, this paper reports 15 cases.

The entire content of every article was analysed using a 14-item reading guide, adapted from Sandelowski and Barroso (2007). Overall, the ten articles used in the synthesis constitute a combined sample of 94 cases, 24 of which were presented in great detail. Eighteen of these 24 cases depict energy retrofits in single-family owner-occupied dwellings, one case describes retrofit in a flat, one case describes an adoption of a solar PV, one case has a geographical area as a unit of analysis and three cases describe construction of new dwellings. Selected profile characteristics of the 18 cases, which are most crucial to comprehend the insights presented in the *Results* section, can be found in Table 2. More detailed characteristics of each case are presented in Appendix C. All households comprised of at least two members. The dwellings were of varied construction type with the age range from 19th century to mid-1960s. Sustainability-related retrofit activities ranged from light fabric insulation measures to in-depth retrofit to Passivhaus standard.

Table 2. Profiles of visible cases presented in the articles (*continued*)

Case & Country	House age/ type	Homeowner energy-related professional background	Retrofit depth**	Retrofit coordinator***
BSH*-A Denmark	1965, $160m^2$, one floor, typical construction	Not stated	Potentially deep	Researcher-coordinator
BC*-B Sweden	1956, 6-room, detached	Not stated	None	Owners themselves
FB*-C Norway	1912, villa	Not stated	Light	Owners themselves
JM*-D Australia	Early 19th century, three-bed, cottage	Technical engineer	Potentially deep	No explicitly stated coordinator
JM*-E Australia	Edwardian, two-bed, terraced cottage	Environmental economics	Potentially deep	No explicitly stated coordinator
JM*-F Australia	Late 19th century, four-bed, detached villa	Not stated	Potentially deep	No explicitly stated coordinator
MK*-G UK	1860, three-bed, terraced	Not stated	Potentially deep	No explicitly stated coordinator
MK*-H UK	1867, four-bed, terraced	Engineer with masters from CAT****	Deep	Homeowner-engineer

Table 2. Profiles of visible cases presented in the articles (*continued*)

Case & Country	House age/ type	Homeowner energy-related professional background	Retrofit depth**	Retrofit coordinator***
M*-I Belgium	Mid 19th century, two-floor, terraced	Architect	Deep	Homeowner-architect
GS*-J UK	Victorian, 3-storey, semi-detached	Non-energy-related	Potentially deep	No explicitly stated coordinator
GS*-K UK	1930s, semi detached	Non-energy-related	Potentially deep	No explicitly stated coordinator
GS*-L UK	1930s, two-storey, semi-detached	Non-energy-related	Light	No explicitly stated coordinator
GS*-M UK	1930s, two-storey, semi-detached	Non-energy-related	Potentially deep	No explicitly stated coordinator
GS*-N UK	1960s, three-storey, end-of-terrace	Non-energy-related	Light	No explicitly stated coordinator
GS*-O UK	1930s, semi-detached	Non-energy-related	Light	No explicitly stated coordinator
GS*-P UK	1930s, two joined semi-detached houses	Academic physicist	Light	No explicitly stated coordinator
VG*-Q Denmark	19th century smallholding	Energy consultant	Potentially deep	Owners themselves
VG*-R Denmark	1970s, single family detached house	Not stated	Deep	Contracting company

Note: * **BSH** – Bjørneboe et al. (2017); **BC** – Buser and Carlsson (2017); **FB** – Fyhn and Baron (2017); **JM** – Judson and Maller (2014); **MK** – Martiskainen and Kivimaa (2019); **M** – Mlecnik (2010); **GS** – Galvin and Sunikka-Blank (2014), Sunikka-Blank and Galvin (2016) and Sunikka-Blank et al.(2018); **VG** – Vlasova and Gram-Hanssen (2014).

** The depth of the retrofits was judged by the first author of the metasynthesis. A retrofit was judged to be "deep" only if significant (above 60%) calculated or measured savings were shown. A retrofit was judged to be "potentially deep" and of "light" based on the combination of the technologies installed.

*** Where no explicit coordinator is stated, a coordination by the owners themselves is assumed.

**** CAT – Centre for Alternative Technology

3.3. Strategies used to synthesise findings

The synthesis took the following steps. First, relevant article information was sorted into 18 cases visible in the articles. The interviews were coded by the first author, the analysis and results were continuously reviewed by all authors to raise further the confidence in data interpretation. Second, the data was arranged into a chronological account for each case. Second, the theoretical framework was used thematically (Braun and Clarke, 2006) to identify socio-technical aspects that shape the level of retrofit depth and energy use post-retrofit across pre-retrofit, retrofit and post-retrofit stages (Figure 2 captures the identified aspects). Third, these dynamics were traced back to the previous stages of the process to identify ultimate influences. The insights from each of the ten articles were used in the synthesis. The full coding scheme is presented in Appendix D. Cross-tabulation was used at this stage to support constant systematic comparison (Miles et al., 2014). The analysis process included the documentation of all procedures, changes in procedures or results.

4. RESULTS

The analysis takes a process perspective on the socio-technical dynamics of proximate and ultimate causal influences that shape the retrofit depth and energy use post-retrofit. A strong pattern across the case studies emerged around the concept of alignment (e.g., Papachristos et al., 2020b, 2020a). For this paper, the concept use is twofold in relation to energy retrofit. First, it concerns the alignment of socio-technical aspects necessary to achieve deep retrofit during the retrofit stage. Second, it concerns the alignment of socio-technical aspects necessary to achieve and sustain low-energy use post retrofit[2]. The temporal sequence of proximate and ultimate causal influences is revealed in Figure 2. First, at the proximate level, the retrofit depth depends strongly on a combination of different motivations and expectations about the renovation process of actors involved in the retrofit, such as homeowners, builders and planners. At the ultimate level, the technological solutions implemented during the retrofit are strongly shaped by prior socio-technical realities, such as homeowner expectations, construction industry expertise and technological solutions available on the market.

[2] The 'level of retrofit depth' and its potential for low 'energy use in buildings' refer to the calculated technological potential of the overall solution for the house. Energy use is measured in kWh/m^2 per year. Retrofit depth is measured, for instance, in in the percentage of calculated reductions in the in-use emissions of the property compared with 1990 average performance levels (Technology Strategy Board, 2013).

Second, at the proximate level, the actual reduction in energy use depends on the energy-related behavioural patterns of the homeowners. The degree to which the owners change their behaviour post-retrofit to reduce energy use and maintain such reductions is shaped at the ultimate level by the degree they were involved in the development of a technological solution for their retrofits. The rest of the section presents these results in more detail.

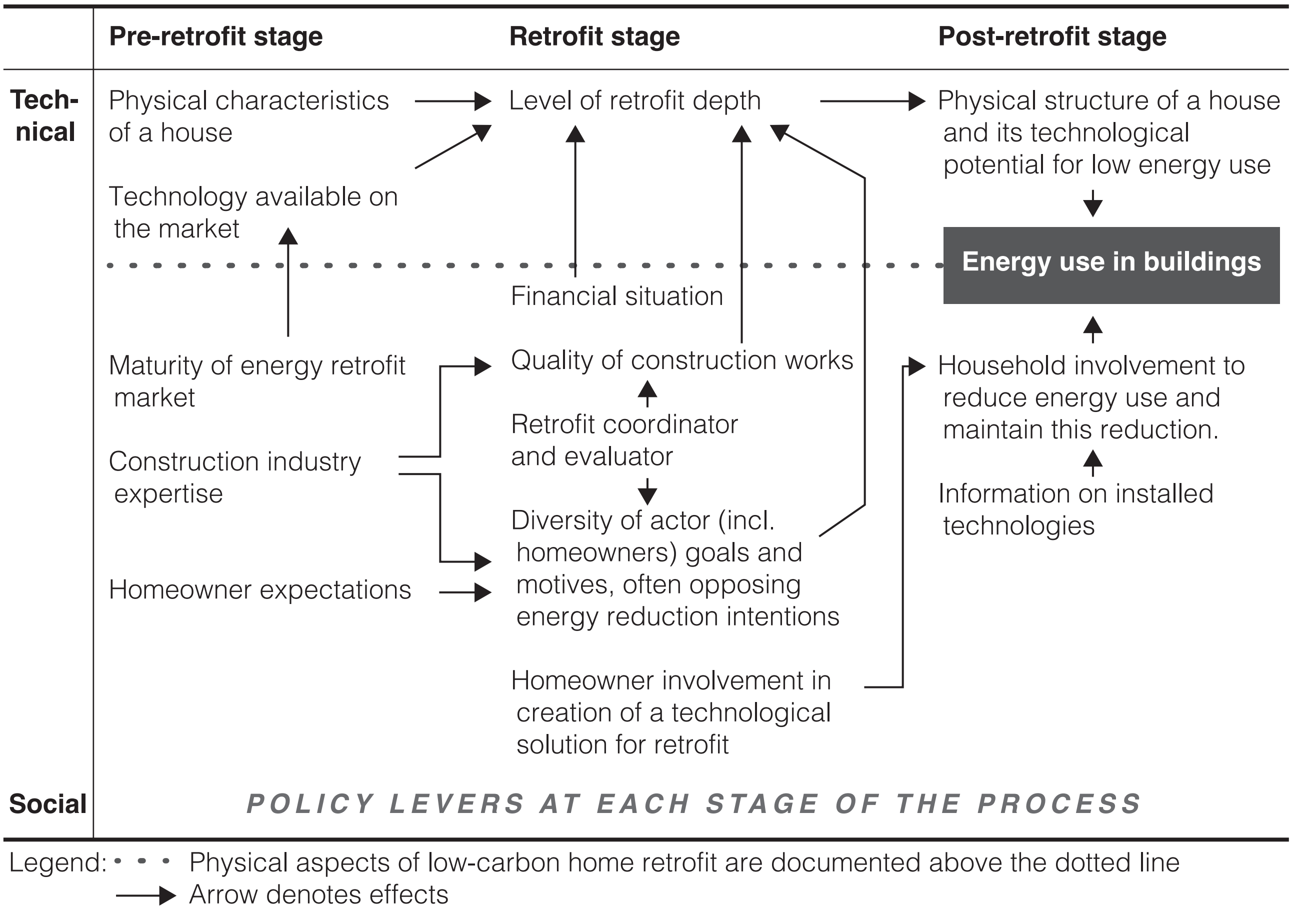

Figure 2. Causal influences: proximal (cause and outcome at the same stage) and ultimate (cause and outcome at different stages). They explain the level of achieved retrofit depth and the level of post-retrofit energy use captured across: (i) pre-retrofit, retrofit and post-retrofit stages; (ii) socio-technical patterns of the built environment that shape its development patterns.

4.1. Alignment of socio-technical aspects for low-energy use

The review reveals that homeowner behaviour in post-retrofit ranges from the behaviour that is most productive to realise the technological potential of a particular solution, to one that is counterproductive. The review shows that the degree to which the owners were involved in the development of technological solutions for their retrofits was closely linked to the degree they were later involved with the installed technology to minimise energy use post retrofit.

The owners in the review sample, who spent considerable time making decisions about their retrofit options, showed a capacity to change their pre-retrofit practices to new, more sustainable ones. In case VG-Q, it was a change from heating a house with oil to a solution including a heat pump, a stone oven and solar thermal panels. The owners in cases JM-F and JM-E adopted passive cooling strategies post retrofit, instead of widely used air-conditioning, even though in case JM-F an air-conditioning system was actually installed. In case M-I, the owner reported behaving consciously regarding energy use, even though his Passivhaus construction already offers very comfortable living conditions with minimum energy use. In case GS-K, the owners adopted an elaborate zonal heating practice, so that their energy consumption was only 55% of that predicted for their house by the Green Deal software.

The opposite dynamics were observed in case VG-R, in which the technological solution for retrofit was conceived and implemented without owner involvement. An independent contracting company initiated the retrofit as a demonstration project for their portfolio and covered the costs of the retrofit. The family was only consulted about the colours of the finishes, and was not included in the cooperation process between different experts to find an economically and technically viable energy retrofit solution. The owner in this case eventually switched off the ventilation system after the retrofit, as he thought it used too much energy. In case BSH-A, which also featured an external retrofit coordinator, the owners were heavily involved in the retrofit process and had weekly meetings with the advisors and craftsmen. No behavioural patterns that could potentially undermine the effectiveness of technological solutions installed were reported in this case.

Fyhn and Baron (2017) suggest that energy use becomes meaningful to the homeowners in the process of developing a retrofit solution. For instance, they show how in one of their cases on the adoption of solar PV panels, electricity went from something the owners merely paid the bills for, to something more meaningful and visible, something they generate and monitor themselves. Energy use within the proposed retrofit solutions becomes meaningful as owners investigate these solutions. In the case in Fyhn and Baron's study (2017), one of the owners monitored the household electricity use down to the hour via their electricity company website prior to the installation, in order to find out whether PV solar panels would fit their electricity use patterns. In most cases in the metasynthesis, the owners showed a tendency to carry out their own research about their retrofit. In some cases, they did so to find suitable solutions and ensure these are realised (cases JM-D, JM-E, MK-H, VG-Q and cases in Galvin and Sunikka-Blank, 2014; Mlecnik, 2010; Sunikka-Blank et al., 2018; Sunikka-Blank and Galvin, 2016). Often the research was done to verify the solutions proposed by building professionals (Buser and Carlsson, 2017; Galvin and Sunikka-Blank, 2014; Judson and Maller, 2014; Mlecnik, 2010; Vlasova and Gram-Hanssen, 2014).

4.2. Alignment of socio-technical aspects for the level of retrofit depth

Deep retrofit requires a complex systemic solution and, therefore, it is beneficial to have a person with relevant technical competence to oversee the creation of a retrofit solution and to ensure the overall quality of construction. A deep retrofit solution was developed and realised in cases MK-H, M-I and VG-R (Table 2). In case VG-R the retrofit was coordinated by a contracting company. In cases MK-H and M-I the coordinator role was fulfilled by one of the homeowners themselves. In case MK-H, the owner was an engineer, who took an environmental masters' course at the Centre on Alternative Technology, UK. In case M-I, the owner was an architect, who retrofitted his house to a Passivhaus standard and extended his professional expertise by doing so. A coordinator can help the owners towards a retrofit solution that is more energy conscious than they themselves initially envisioned. This was true in case BSH-A, in which the researchers took a role of the project coordinator in line with one-stop-shop approach. Without a coordinator, the owners might do less than they initially envisioned. For instance, in case BC-B, conflicting information regarding energy retrofit created "doubt for the owners, complicating their decision-making process" (Buser and Carlsson, 2017, p. 283). The owners eventually dropped their sustainability retrofit intentions altogether and bought a hybrid car as an expression of their environmental concerns.

The review showed that no industry actor within the traditional construction practice is suitable for the role of a deep retrofit coordinator. Building professionals and tradespeople "tend to keep to their own roles" (Sunikka-Blank and Galvin, 2016, p. 105), so a person who makes a house airtight might not know if there is any appropriate ventilation strategy in place and, vice versa, a person who installs mechanical ventilation might not know if the building is appropriately airtight. The homeowners had difficulties in finding an architect willing "to think in an integrated approach" about the needs of a property (Mlecnik, 2010, p. 44). They sometimes approached specialised energy consultants to determine the best set of technologies for their house (Mlecnik, 2010).

The construction quality in deep retrofit might be even more crucial than in traditional construction, in order to avoid changes in the material structure of the house that can result in a "domino effect" with unintended consequences (Buser and Carlsson, 2017, p. 283). Traditional construction practices do not align naturally with the goal to ensure quality of deep retrofits.

The builders might take shortcuts at the expense of quality to finish the job as soon as possible and avoid additional expenses (cases GS-J, GS-L). Often, the owners took it upon themselves to supervise the quality of construction (case GS-M and cases in Mlecnik, 2010). In case GS-J, the owners were able to persuade the builder to do the job properly. However, in case GS-L, the were not able to do so. In this case, loft and cavity wall insulation were subsidised jobs, the headworkers were on strict time budget and were only willing to do jobs in standardised ways. In case BSH-A, an independent site engineer was appointed to check the work for faults and ensure the quality of construction, which was found to be crucial for the successful implementation of the project.

The review revealed a diversity of homeowner retrofit goals and motives. These can be grouped into the following categories: (i) structural and utility works, e.g., a replacement of a worn-out roof in case M-I; (ii) amenity retrofit, e.g., a reconfiguration of a living space in case JM-E into an open plan one, in which family could socialise; (iii) aesthetics and lifestyle retrofit, e.g., a preservation of Victorian indoor plaster details such as cornices in case GS-J; (iv) health and comfort retrofit, e.g., a provision of a health indoor environment for asthmatic child in case M-I; (v) sustainable and low-carbon retrofit, e.g., a desire to reduce household carbon footprint in case GS-M. The categories are not mutually exclusive, and several motives usually coexist behind retrofit intentions. The same combinations of retrofit intentions were found to have a potential to push the owner retrofit decision closer to or further away from a low-carbon solution in different cases. For instance, external wall insulation was rejected in case GS-K to preserve the aesthetics of the façade, while in case GS-N external wall insulation and render was used to enhance aesthetical appeal of the façade, which owners found lacking. Financial considerations were also found to be of significance in all the cases and are discussed later in the section.

Two underlying processes that can trigger owners to carry out retrofit works were visible in the metasynthesis: (i) a structural deterioration of the house, which tends to trigger structural and utility works, e.g., a change of doors and windows, as they started showing the signs of wear in case BC-B; (ii) a change in household lifecycle stages, such as a change in the number of household members, their age and income, which tend to trigger an amenity retrofit, e.g., the owners in case MK-H were looking to increase living space in line with increase in family size. Figure 3 captures the diversity of homeowner retrofit goals, as well as underlying processes that can trigger a retrofit decision.

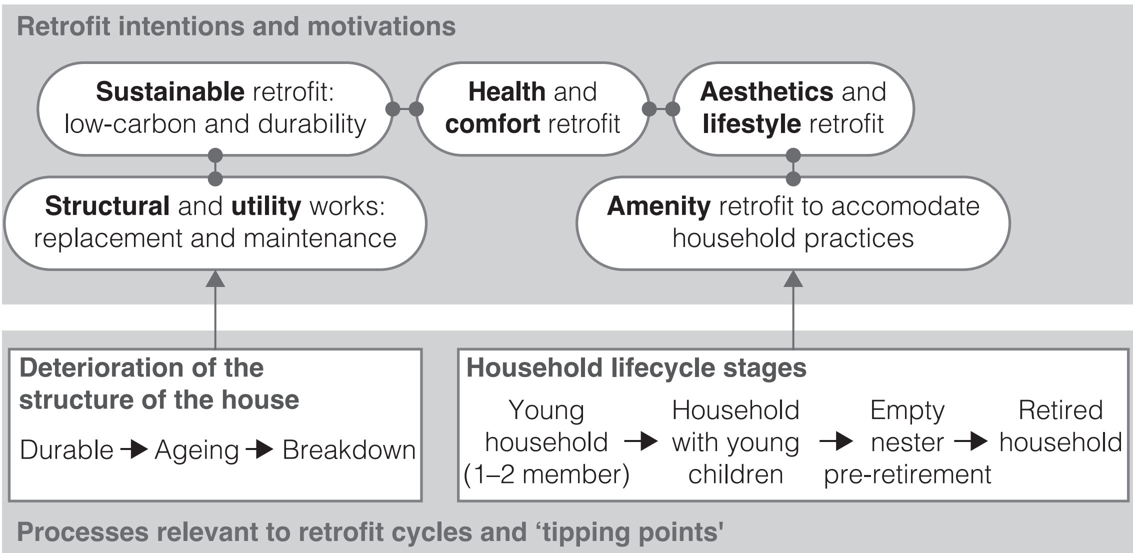

Figure 3. Diversity of homeowner retrofit goals and motives and underlying processes that trigger retrofit works.

The narratives around retrofit usually include some economic rationale and potential savings. Capital costs are always a major consideration, as owners need to find a compromise between their retrofit ambitions and the price they are prepared to pay (e.g., case BC-B). Reduction in energy bills is often stated as one of the motivations for retrofit (e.g., cases MK-G and MK-H). However, these are by no means the only, or the primary motives driving retrofit decisions. The diverse intensions behind homeowner retrofit decisions are often misinterpreted by other actors. Building professionals often believe that energy bills reduction is a primary concern for homeowners, and thus, would only offer solutions that can guarantee such reductions (Owen and Mitchell, 2015). For instance, in case BC-B the building professionals discouraged the owners from installing some sustainability-related measures as not economically viable. Building professionals' perception of what a comfortable indoor environment is, often differs from the one of homeowners. In case VG-R, the solution was designed by engineers to meet ideal technical performance criteria (class 1 low-energy house, Denmark). The solution aimed to provide a place in which building systems take over some manual jobs such as airing the house, while ensuring a stable indoor temperature and elimination of draughts. The owners were not consulted on their views about what a comfortable indoor environment is.

The builders might also regard non-sustainability related homeowner goals as unimportant. For instance, in case GS-K the building professionals were fixated on the theoretical thermal potential of a building and were not willing to consider ways on how to incorporate owners' wishes to preserve the brick façade. In case GS-O, the owners had to convince their building professionals to do the extra work necessary to preserve the features they wanted. These observations do not apply across all cases. For example, in cases GS-N and GS-O the owners praised their building professionals for listening to their concerns and working to find creative retrofit solutions to accommodate several objectives.

4.3. Dynamics of socio-technical realities prior to retrofit

A retrofit project coordinator can help align different actor goals to develop and implement a deep retrofit solution. However, when a particular project is about to start, the options of a coordinator are already constrained by pre-existing socio-technical dynamics such as: (i) the materiality of a given dwelling, (ii) the types of technologies and materials available on the market,

(iii) the expertise of the builders and their familiarity with various technologies and (iv) homeowner expectations.

The sample in the review includes many pioneer projects, which complexity was often not compatible with prior builder experience. This posed a challenge of finding the technological solutions, which were often not available on the local market (M-I). At the same time, the builders were more reluctant to retrofit with the solutions that had just became available on the market, in order to avoid potential liability in case such solutions failed in the long-term (Galvin and Sunikka-Blank, 2014). However, the review showed that when the market is developed, it conditions the retrofit decisions towards sustainable options. For instance, in case FB-C the owners installed energy efficient windows, even though they did not actively make a decision about it. Rather, it was a standard product already available on the market.

Homeowner pre-existing beliefs largely shaped the choice of technologies installed. The owners in case VG-Q expressed reluctance to retrofit with a vapour-resistant membrane to avoid living in a "plastic bag"; chose a straw insulation over a standard mineral fibre one, because it was considered to be healthier; and decided against a mechanical ventilation as it was considered not in line with an idea of "natural" environment (Vlasova and Gram-Hanssen, 2014, p. 517). Homeowner beliefs prior to the retrofit also shaped the choice of activities to reduce energy use. The narratives of environmental sustainability in the studies were often associated with products, such as environmentally friendly materials, rather than changes in everyday routines to reduce consumption (Judson and Maller, 2014; Mlecnik, 2010). Even though the owners demonstrated a capacity to change their everyday practices to more sustainable ones, many others remained unchanged and unquestioned (Judson and Maller, 2014).

The synthesis revealed that it is possible to use certain yardsticks to anchor homeowner expectations on which works need to be done. Some owners used the information obtained through a

Passivhaus network (case M-I and GS-J) as yardstick for a general deep retrofit solution. One way to help the owners form their expectations about their particular dwelling is forward planning. For instance, the project coordinator in case BSH-A outlined all relevant improvements when planning the retrofit, the ones to be implemented straightaway and the ones to prepare the house for future improvements, so the owners have a pathway to eventually achieve a deep retrofit outcome. In their paper, Vlasova and Gram-Hanssen (2014) analyse a municipality-led project that targeted energy retrofit in private housing in a village in Denmark as one of their case studies. The municipal environmental consultant visited individual families to recruit to the project, and subsequently energy reports were produced, which included recommendations for the changes to be made. Each energy report was coupled with a practical retrofit offer from a local builder, and some families volunteered to participate. Some owners in this case admitted that they would not have carried such an extensive retrofit, if it were not for the municipality project. The wider initiative by citizen-based retrofit community was also found to be important in shaping homeowner expectations and beliefs in the Cambridge cases (Galvin and Sunikka-Blank, 2014; Sunikka-Blank et al., 2018; Sunikka-Blank and Galvin, 2016).

4.4. Policy levers at each stage of the retrofit process

The results section so far discussed the socio-technical dynamics across different retrofit stages without explicitly mentioning policy instruments. It is worth noting though that policy instruments can and do affect the retrofit process by accelerating or impeding the dynamics at each stage of it.

Existing building regulations have the potential to influence homeowner expectations of the depth and quality of construction required to reach low-carbon solution. For instance, in cases MK-H and VG-Q, the retrofits were carried out in line with the standards of building regulations for new construction at the time, even though such standards were not required for retrofit. Existing legal constraints, especially in conservation areas, can also make deep retrofit solutions more difficult and costly to achieve. Various grants and incentives can help minimise capital costs, such as in cases MK-G and MK-H, where parts of the capital costs were funded through governmental grants. Further ways in which policy can accelerate the socio-technical dynamics across the retrofit stages are discussed in the next section.

5. DISCUSSION

The analysis looked at the socio-technical dynamics that drive homeowners towards or away from: (i) conceiving and realising a deep low-carbon retrofit solution; (ii) post-retrofit behavioural change necessary to realise technological potential for carbon savings. The process perspective helped to reveal both proximate and ultimate causes for the dynamics. Such insights pave the way for policy recommendations and solutions to address proximate causes and gain time while working on the fundamental solutions to address ultimate causes. This discussion draws some general implications for policy aimed to encourage energy retrofit among homeowners. It then positions the implications in the realities of the UK energy policy, which the authors are most familiar with. However, it should be possible to consider them also in the broader context of European energy policy.

The first set of insights and policy recommendations relates to the conception and realisation of a deep low-carbon solution in domestic retrofit. Homeowner energy retrofit activity (or the absence of it) and the achieved retrofit depth are often used as indicators of homeowner goals, aspirations and often conflicting priorities (Fouseki et al., 2020; Judson et al., 2014; Maller et al., 2012; Tjørring and Gausset, 2019). However, attributing retrofit outcomes to homeowner intentions only is a simplification of reality. Homeowner retrofit decisions and solutions are shaped by various actors, such as contractors, advisors, planners and conservation officers (Owen and Mitchell, 2015; Yarrow, 2016). In particular, the homeowners and other actors involved in the retrofit might: (i) not have sufficient technical competence to conceive and successfully realise a deep retrofit solution; (ii) have sufficient knowledge of current policies and incentives to source applicable grants and reduce capital costs, while fulfilling legal requirements; while actors other than homeowners might (iii) misjudge the complexity behind homeowner retrofit intentions, both sustainability and non-sustainability related ones.

A proximate policy suggestion is to have a project coordinator for a given retrofit, who would outline a system approach to retrofit. A system approach is beneficial for two reasons. First, it is more efficient to optimise a technological system as a whole, rather than optimising the efficiency of each individual component (Lovins, 2004). Second, a system approach is necessary to anticipate and prevent unintended consequences usually associated with energy retrofit (Shrubsole et al., 2019, 2014). The project coordinator can engage the building professionals to create an integrated design, so they are not solely focused on their specialised areas (Palm and Reindl, 2016), which should help energy retrofit to become an integrated construction practice (Bartiaux et al., 2014). The coordinator can increase homeowner trust in retrofit solution and outcomes, an issue widely highlighted in the literature (de Wilde, 2019; Horne et al., 2014; Risholt and Berker, 2013). Finally, the coordinator could help homeowners to navigate through national and local policies, in order to meet legal requirements and source various grants to reduce capital costs of energy retrofit.

These recommendations have partially found their way to the UK policy through PAS 2035 document, which is the overarching best practice guidance framework about domestic retrofit projects, published by the British Standard Institution (BSI, 2020). While this PAS is not to a British Standard, it is likely to have a major effect on the way UK homes are retrofitted. The PAS 2035 document requires a building team to propose an integrated retrofit plan to improve energy efficiency and reduce carbon emissions for all retrofit projects, even if only small improvements are carried out in the short term (BSI, 2020). A Retrofit Coordinator has an overall role to "protect both the Client's interest and the public interest" (BSI, 2020, p. 13) and responsibilities to prepare an energy-efficiency improvement plan and organise project evaluation for quality assurance.

The success of guidance outlined in the PAS 2035 is yet to be seen. It should be noted that the above-mentioned guidance addresses the problem at the retrofit stage itself, i.e., at the stage of proximate influences, while the strongest points for impact are found prior to retrofit (ultimate influences). An ultimate policy suggestion is to influence the formation of the socio-technical realities found in the *pre-retrofit stage* in the desired direction. Such realities include homeowner expectations, maturity of the market and expertise in the construction industry. The tasks of building construction industry expertise and market development are already supported by various UK policies. For instance, the PAS 2035 document already requires each member of the retrofit team (Retrofit Advisor, Retrofit Assessor, Retrofit Coordinator, Retrofit Designer and Retrofit Evaluator) to have working knowledge of building physics and acquire appropriate qualifications for their jobs (BSI, 2020). At the same time, the UK clean growth strategy focuses on nurturing the market for low-carbon technologies (UK. BEIS, 2017). However, investments in shaping homeowner expectations at the *pre-retrofit stage* are usually absent on the national level. National policies tend to focus on the information provision and financial support of individual homeowners during the *retrofit stage* (Wilson et al., 2015). The insights from the metasynthesis suggest that the temporal focus of such policies need to be broadened to include expectations formation prior to retrofit by, possibly, investing in community-based mechanisms.

Expectation formation is by no means a trivial task. Each person's journey through life is unique, and motives that can resonate with some individuals, will not resonate with others, or even the same individual at different points in time. It is likely, that a wide range of benefits associated with energy retrofit, beyond return on investment through savings on energy bills, need to be recognised and promoted to motivate action (Eyre and Killip, 2019). A promising route seems to be a proactive delivery of general and house-specific information on deep retrofit options to homeowners, complemented with the information on the diversity of benefits associated with energy retrofit and low-carbon living (Gupta and Chandiwala, 2010). Nevertheless, targeting each individual household might not the most efficient option to promote benefits of energy retrofit. Homeowners tend to use informal networks, such as friends and fellow homeowner-retrofitters, to gather information on energy retrofit solutions (Bobrova et al., 2021). Such networks, if formalised, can serve as a mechanism to promote benefits of energy retrofit and low-carbon living. The benefit of such mechanism is that it can became self-sustaining after initial investment, thus minimising costs of reaching out to individual homeowners. Community interaction through 'open home' events is one such mechanisms, with positive impacts well-documented in the literature (Berry et al., 2014; Gupta et al., 2014; Mcmichael and Shipworth, 2013).

The second set of insights and policy recommendations relates to the post-retrofit behavioural change necessary to realise technological potential for carbon savings. A persistent energy-efficiency gap in domestic retrofit (DellaValle et al., 2018; Gilbertson et al., 2010; Tweed, 2013) suggests that policy should focus not only on technical characteristics of deep retrofit, but also on how low-carbon retrofit can assist new and lower resource consumption (Gram-Hanssen, 2015). A proximate policy suggestion is the provision of relevant information, and the PAS 2035 document already requires a provision of " '[s]implified', 'user friendly', plain-language user manuals" (BSI, 2020, p. 25).

Even though information provision is crucial for homeowners to engage with technology post-retrofit, information provision alone is unlikely to guarantee behavioural change (Heiskanen et al., 2020; Kersten et al., 2015; Pelenur, 2018). Existing literature highlights a mismatch between actual household energy-related practices and engineering assumptions (Willand et al., 2019), especially for projects initiated and governed by institutional actors rather than homeowners themselves (de Feijter et al., 2021). The metasynthesis highlighted that the homeowners were more likely to adapt their practices, if they were involved in the creation process of a technological solution for retrofit. Therefore, it is suggested here that policy should outline pathways on how occupants, including homeowners, can be actively included in the process of design development.

This insight has implications for the future of retrofitted properties. The question is how to ensure that owners, who move into an already retrofitted property, adjust their practices. It is quite possible that the processes responsible for adjustment of practices are different in such cases. An energy efficiency place identity (Smaldone et al., 2005) that property acquires through energy retrofit, can serve as a trigger for the new owners to adjust their behaviour to maintain low energy use, when the property is passed onto them. Surely, new owners who move into a house, retrofitted to a Passivhaus standard, expect that their energy use will be low, even if they are yet to learn to live in an airtight building with mechanical ventilation. This issue is beyond the scope and research design of this paper, so a different theoretical lens focused on place identity and, possibly, post-occupancy auditing and information provision, is required to further investigate the question.

The work in this paper has a number of limitations. One limitation concerns generalisability of findings. In qualitative research, generalisations are done on the basis of a match to the underlying theory based on conceptual grounds, not on representative grounds to a larger population (Miles et al., 2014). The findings are drawn from the studies carried out in Denmark, Sweden, Norway, UK, Belgium and Australia. It is possible to make these findings more robust, by showing that they hold true in other settings. This could be achieved by extending the approach we took in this study to include other European countries, where economic, societal and political conditions differ from countries, which formed the basis for the synthesis. To partly overcome this limitation, the findings were positioned in the broader literature. Another limitation concerns the nature of a qualitative metasynthesis, which is essentially an act of re-representing representations (Sandelowski and Barroso, 2007). It constitutes an interpretation at least three times removed from participants' lives. The detailed description of the sampling strategy and procedures to data analysis clarifies how the synthesis was created.

Future research can investigate how homeowner retrofit intentions are formed, how they can be recognised and how energy-related ones can be promoted. In most cases of the synthesis, the data was collected through retrospective interviews, which allows the possibility that interviewees make sense of their experiences retrospectively (Kahneman, 2012). A simultaneous approach with retrospective and longitudinal data collection in real time can mitigate this issue (Leonard-Barton, 1990). Such longitudinal data is more likely to be collected in the evaluation of programmes targeting energy retrofit rather than evaluation of individual retrofit journeys. A qualitative metasynthesis of such programmes, both successful and not, is suggested (e.g., Fyhn et al., 2019; Hoicka and Parker, 2018; Vergragt and Brown, 2012; Watson et al., 2015).This paper focuses on households as a unit of analysis. Future research can look into the internal household dynamics in shaping retrofit decisions, as they can play a role on retrofit decision (Tjørring, 2016).

6. CONCLUSIONS AND POLICY IMPLICATIONS

EU governmental policy that aims to encourage low-carbon home retrofit among homeowners has traditionally focused on the identification of drivers and barriers to domestic retrofit with the intention to strengthen the former and remove the latter. However, the static juxtaposition of drivers and barriers, while valuable, cannot capture their temporal dynamics during a retrofit process. This paper takes a process perspective to capture the socio-technical dynamics that shape the level of achieved retrofit depth and post-retrofit energy use to synthesise qualitative findings on energy retrofit in single-family owner-occupied dwellings available in the literature. This paper contributes to socio-technical literature on energy use by raising attention to the temporal dynamics of socio-technical elements in the system.

The paper documents various influences across three stages – pre-retrofit, retrofit and post-retrofit – that shape the level of retrofit depth and the level of post-retrofit energy use. It is evident that the depth of a technological solution for a given retrofit cannot be attributed solely to homeowner motivations, but can only be explained by the degree of goal alignment among different actors involved in the retrofit, pre-existing homeowner expectations, expertise of the building professionals and the maturity of the market. The actual energy use in post-retrofit depends also on the homeowner behavioural involvement to reduce energy use and maintain its level, which depends on the degree of owner involvement in the creation of a technological solution for their retrofits.

The results from the synthesis provide the basis for recommendations on low-carbon retrofit policy in the EU private residential sector. First, it is suggested to engage local authorities to proactively deliver information on general as well as house-specific retrofit options to homeowners, in order to form their expectations on a systemic deep retrofit approach. It is also recommended to support community engagement prior to retrofit, as through it is possible to create mechanisms to promote energy retrofit, which are self-sustaining after initial investment. Second, policy should focus on finding ways to engage occupants, both owners and tenants, in the development of a retrofit solution.

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APPENDIX A

This appendix provides the list of search concepts that were used in the metasynthesis (Table A.1). Search concepts are different from search filters. The development of search filters is based on the search concepts to perform a search in a specific database. Different databases might require different searching procedures, such as a difference in the truncation symbols used, or different rules for punctuation and capitalisation required to perform a search. The list presented here is a list of search concepts. The list was transformed into search filters specific for Web of Science, Scopus and IBSS databases.

Table A.1. Search concepts used in the metasynthesis

Search term	Related search concepts
Energy	Carbon (incl. carbon dioxide, low-carbon, zero-carbon), CO_2, deep, eco, efficient (incl. high efficiency), energy (incl. energy efficient, energy neutral, energy saving, low-energy, reducing energy consumption, zero energy), environmental, green, passive (incl. Passivhaus, passive house), sustainable, thermal, whole-house. Energy-efficient, energy neutral, energy saving, environmental, green, high efficiency, low-energy, Passivhaus, passive house, sustainable, thermal, zero-carbon, zero energy.
Home	Domestic, dwelling, house, residential.
Retrofit	Improvement, modernisation, modification, rebuilding, reconstruction, refit, refurbishment, renovation, remodelling, repair, upgrade.
Homeowner	Householder, private household, owner, owner-occupier.
Qualitative research	Case study, constant comparison analysis, content analysis, descriptive study, discourse analysis, ethnography, exploratory, field research (incl. field study, field observation), focus group, grounded theory (or grounded study), hermeneutic, interview, lived experience, mixed method, narrative, naturalistic inquiry, participant observation, participatory action research, phenomenology, purposeful sample, purposive sample, semiotics, social theory, social inquiry, thematic analysis, Q methodology.

APPENDIX B

Characteristics of 25 papers that present qualitative analysis of individual energy retrofit journeys in single-family owner-occupied homes are presented in Table B.1.

Table B.1. Profiles of papers that present qualitative analysis of individual energy retrofit journeys in single-family owner-occupied homes

Year	Country	Authors	Source
(2020)	Greece, Mexico, UK	Fouseki, K., Newton, D., Murillo, Camacho K.S., Nandi, S. and Koukou, T.	Atmosphere
(2019)	Netherlands	Broers, W.M.H., Vasseur, V., Kemp, R., Abujidi, N. and Vroon, Z.A.E.P.	Energy Research & Social Science
(2019)	Netherlands	de Wilde, M.	Energy Research & Social Science
(2019)	UK	Martiskainen, M. and Kivimaa, P.	Journal of Cleaner Production
(2019)	Denmark	Tjørring, L. and Gausset, Q.	Building Research & Information
(2019)	Australia	Willand, N., Maller, C. and Ridley, I.	Energy Research & Social Science
(2018)	UK	Kaveh B, Mazhar MU, Simmonite B, Sarshar, M. and Sertyesilisik, B.	Energy and Buildings
(2018)	UK	Sunikka-Blank, M., Galvin, R. and Behar, C.	Building Research & Information
(2017)	Denmark	Bjørneboe, M.G., Svendsen, S. and Heller, A.	Journal of Architectural Engineering
(2017)	Sweden	Buser, M. and Carlsson, V.	Construction Management and Economics
(2017)	Denmark, Norway	Fyhn, H. and Baron, N.	Society & Natural Resources
(2016)	UK	Sunikka-Blank, M. and Galvin, R.	Energy Research & Social Science
(2016)	Denmark	Tjørring, L.	Energy Research & Social Science
(2016)	UK	Yarrow, T.	The Historic Environment: Policy & Practice
(2014)	Belgium, Denmark, Latvia, Portugal	Bartiaux F, Gram-Hanssen K, Fonseca P, Ozoliņa, L. and Christensen, T.H.	Building Research & Information
(2014)	UK	Fawcett, T. and Killip, G.	Building Research & Information
(2014)	UK	Galvin, R. and Sunikka-Blank, M.	Energy Policy
(2014)	Australia	Horne, R., Maller, C. and Dalton, T.	Building Research & Information
(2014)	Australia	Judson, E.P., Iyer-Raniga, U. and Horne, R.	Journal of Housing and the Built Environment
(2014)	Australia	Judson, E.P. and Maller, C.	Building Research & Information
(2014)	Denmark	Vlasova, L. and Gram-Hanssen, K.	Building Research & Information
(2013)	Norway	Risholt, B. and Berker, T.	Energy Policy
(2012)	Australia	Maller, C., Horne, R. and Dalton, T.	Housing, Theory and Society
(2011)	Australia	Maller, C.J. and Horne, R.E.	Urban Policy and Research
(2010)	Netherlands	Mlecnik, E.	Open House International

APPENDIX C

Detailed characteristics of the 18 visible cases in the synthesis are presented in Table C.1.

Table C.1. Profiles of visible cases presented in the reports *(continued)*

Case & Country	Household(s) characteristics	Property/ area characteristics	Retrofit characteristics
BSH*-A Denmark	A couple, who are willing to spend enough for an extensive renovation.	*Age*: 1965 *Size*: 160 m^2 *Type*: single-family, one floor, no basement (typical construction) *State of repair*: in a need of renovation; *Energy use*: measured total energy use (electricity + gas) 173.3 kWh/m^2 per year. Simulated energy use for heating 216.5 kWh/m^2 per year.	*Timing*: summer 2013. *Work done*: roof, windows and doors; cavity insulation and MVHR. *Depth**:* potentially deep. *Coordinator:* researcher took the role of the coordinator; an independent site engineer was appointed to check the quality of construction. *Tech. potential*: Simulated energy use for heating 125 kWh/m^2 per year (42.3% reduction). *Actual savings*: measured total energy use (electricity + gas) 131.2 kWh/m^2 per year (24.28% reduction).
BC*-B Sweden	A household of at least two (referred to as 'owners').	*Age*: 1956 *Size*: 3-storey (6 rooms) with a concrete cellar. *Type*: detached wooden-framed house, district heating. *State of repair*: in a need of renovation. *Energy use*: grade D.	*Timing:* The owners moved in the house in February 2015. *Work done:* none. A year later, no sustainability-related improvements have been made. *Coordinator:* owners themselves. *Other*: The owners bought a hybrid gas car to express their environmental concerns.
FB*-C Norway	Family of five	*Age*: 1912 *Size*: single family house converted from a two-family house *Type*: villa	*Timing:* no later than autumn 2013. *Work done:* Ground-to-water heat exchanger; floor heating in the living room; replacing windows and upgrading the walls that support the windows. *Depth**:* light *Coordinator:* Owners themselves (DIY retrofit). *Other*: €1,000 covered by a grant for the ground-to-water heat exchanger (overall installation cost €24,000).
JM*-D Australia	A married couple (number of children unknown). *Prof. background:* Husband is a technical engineer.	*Age*: early 19th century *Size*: three-bed *Type*: single-family, weatherboard cottage.	*Timing:* no later than 2014 *Work done:* Internal layout adjustment; two-storey extension, adding two common areas and en-suite bedroom; extension designed to passive solar principles (insulation, double-glazing, a solar hot water system, PV panels and hydronic heating); evaporative air-conditioning. *Depth**:* potentially deep.

Table C.1. Profiles of visible cases presented in the reports *(continued)*

Case & Country	Household(s) characteristics	Property/ area characteristics	Retrofit characteristics
			Coordinator: coordinated between owners themselves and project architect
JM*-E Australia	A family of four (two young children). *Prof. background:* Husband has background in environmental economics.	*Age*: Edwardian *Size*: two-bed *Type*: brick terraced cottage.	*Timing:* no later than 2014 Work done: Two-storey extension, adding a common area, two bedrooms and two bathrooms; extension designed to passive solar principles (underfloor heating, ceiling fans and natural ventilation, high-performance insulation, triple-glazing of all but one window, solar hot water and PV panels); *Depth**:* potentially deep. *Coordinator*: coordinated between one of the owners (husband) and a sizable team of building professionals. *Actual savings*: limited evidence that household energy consumption had reduced due to the extensive expansion of the interior space.
JM*-F Australia	A mature couple, both work from home.	*Age*: late 19th century *Size*: four-bed, 4 bathrooms and a separate guest annex. *Type*: detached villa of heritage value, constructed of weatherboard and stone; a primary source of heating — electricity; wood heater is used in winter, and liquefied petroleum gas for cooking.	*Timing*: 2007–2011 *Work done*: wall, ceiling and floor insulation; draught sealing of doors, windows and chimneys; secondary glazing to selected windows; and heavy curtains; electric wall-mounted convection heaters to individual rooms, and a split system unit for heating/cooling in the kitchen; an electric-boosted solar hot water system. *Depth***: potentially deep. *Coordinator*: no explicitly stated coordinator. *Actual savings*: 13% electricity consumption reduction according to electricity bills.
MK*-G UK	At least two household members (referred to as 'owners').	*Age*: 1860 *Size*: three-bed, 126 m^2 *Type*: terraced house with solid walls.	*Timing*: during 2013 *Work done*: external wall insulation, loft insulation, double glazing, condensing boiler, low-energy lighting and appliances. *Depth***: potentially deep. *Coordinator*: no explicitly stated coordinator. *Other*: £10,000 covered by a governmental grant. *Actual savings*: 13% reported reduction in gas consumption.

Table C.1. Profiles of visible cases presented in the reports *(continued)*

Case & Country	Household(s) characteristics	Property/ area characteristics	Retrofit characteristics
MK*-H UK	At least two household members (referred to as 'owners'). *Prof. background:* One of the owners is an engineer and took environmental masters' courses at the Centre for Alternative Technology (CAT).	*Age*:1867, *Size*: four-bed, 125 m^2 *Type*: terraced house	*Timing*: during 2008–2009 *Work done*: external and internal insulation, loft insulation, double glazing, solar thermal, wood burning stove, low-energy lighting and appliances, natural paints and materials throughout; loft conversion. *Depth***: deep retrofit. *Coordinator*: homeowner-engineer. *Other:* £35,000 covered by private finance and local authority grant *Actual savings*: 65% reduction in carbon emissions compared to an average UK home (estimated based on measured annual energy use).
M*-I Belgium	At least two household members: an owner and an asthmatic child. *Prof. background:* the owner is a professional architect	*Age*: 150-year old *Size*: two-floor *Type*: 'modest' workman's terraced house of simple construction.	*Timing*: no later than 2010 *Work done*: retrofit to Passivhaus standard, which included internal insulation, airtightness, triple glazing, mechanical ventilation with air-to-air heat recovery including a ground-to-air heat exchanger, and the use of a pellet heater and external sun protection using solar collectors. Re-arrangement of internal layout, demolition of an old and re-construction of a new wooden-framed annex, new roof. *Depth***: deep retrofit. *Coordinator*: homeowner-architect. *Tech. potential*: Calculated heating demand post-retrofit 12 kWh/m^2 a year.
GS*-J UK	Middle-aged couple, no children. *Prof. background*: professional	*Age*: Victorian *Size*: 3-storey *Type*: semi-detached brick house of considerable heritage value (judged by the researchers). Existing heat recovery ventilation system. *State of repair*: in a need of renovation.	*Timing*: no later than 2014. *Work done*: Internal wall insulation to preserve period details, new roof, double glazed windows, contemporary bay window; combined space-heating and mains-pressure water heating system that integrated solar thermal panels, a highly efficient gas boiler and an outdoor temperature sensor. Garden side extension, replacement of an old part of the facade, which had originally been a shop. *Depth***: potentially deep. *Coordinator*: no explicitly stated coordinator.
GS*-K UK	At least two household members (referred to as 'homeowner' and a 'partner'). The owner is a middle-aged male.	*Age*: 1930s *Type*: semi-detached brick house. Heritage values somewhere between minimal and considerable (judged by the researchers).	*Timing*: no later than 2014. *Work done*: External wall insulation, floor and loft insulation, new windows and doors. *Depth***: potentially deep. *Coordinator*: no explicitly stated coordinator.

Table C.1. Profiles of visible cases presented in the reports *(continued)*

Case & Country	Household(s) characteristics	Property/ area characteristics	Retrofit characteristics
	Prof. background: professional	*State of repair*: Cold and draughty prior to retrofit.	
GS*-L UK	Middle-aged coupl, one child with special needs. *Prof. background*: professional	*Age*: 1930s *Size*: two-storey *Type*: semi-detached house, brick, minimal heritage value (judged by the researchers).	*Timing*: no later than 2014. *Work done*: Loft and cavity insulation (entitled to a subsidy), internal insulation in the main bedroom; garden side extension, suitable for the child's needs. *Depth***: light. *Coordinator*: no explicitly stated coordinator.
GS*-M UK	Middle-aged couple. Female lives in the house during weekends only. *Prof. background*: professional	*Age*: 1930s *Size*: two-storey *Type*: semi-detached brick house, heritage values somewhere between minimal and considerable (judged by the researchers).	*Timing*: no later than 2014. *Work done*: Internal wall insulation for the front facade with bay, external wall insulation to the rest of the house, floor insulation, double glazing, solar panels. *Depth***: potentially deep. *Coordinator*: no explicitly stated coordinator.
GS*-N UK	Middle-aged couple, no children. *Prof. background*: one retired, one self-employed	*Age*: 1960s, *Size*: three-story *Type*: end-of-terrace house, minimal heritage value (judged by the researchers).	*Timing*: no later than 2014. *Work done*: Externally insulated facades (with the exception of brick pillars), double glazing. *Depth***: light. *Coordinator*: no explicitly stated coordinator.
GS*-O UK	Middle-aged couple, with children. *Prof. background*: professional.	*Age*: 1930s *Type*: semi-detached brick house of considerable heritage value (judged by the researchers) *Energy consumption*: the house was cold prior to retrofit.	*Timing*: no later than 2014. *Work done*: Internal wall insulation, bay window restoration and double glazing, heavy curtains; garden side extension and a side extension that acts as a thermal buffer. *Depth***: light. *Coordinator*: no explicitly stated coordinator.
GS*-P UK	Middle-aged couple, no children. *Prof. background*: Male is an academic physicist.	*Age*: 1930s *Size*: two 2-storey semi-detached houses joined together. *Type*: Cambridge white brick facades, old slate roof. Heritage values somewhere between minimal and	*Timing*: over time, no later than 2014. *Work done*: Internal wall insulation in the kitchen, installed in 1979. A zonal heating system introduced after the houses were joined together. Reconfiguration of the condensing boiler for improved efficiency. *Depth***: light. *Coordinator*: no explicitly stated coordinator.

Table C.1. Profiles of visible cases presented in the reports *(continued)*

Case & Country	Household(s) characteristics	Property/ area characteristics	Retrofit characteristics
		considerable (judged by the researchers).	
VG*-Q Denmark	A couple in their mid-30s and their two small children. *Prof. background*: Husband works as an energy consultant.	*Age*: 19th century *Type*: poorly insulated smallholding. *State of repair*: In a need of a deep retrofit.	*Timing*: Open-ended time-frame of the project (10 years would not have been considered a problem), no later than 2014 *Work done*: Insulation of the building envelope, new roof, new floor, new windows; floor heating, stone oven and heat pump; solar thermal and PV panels; reorganisation of the floor space and room distribution, and conversion of the attic into a habitable second floor of the house, doubling the living space of the house. *Depth***: potentially deep. *Coordinator*: homeowners themselves (DIY retrofit)
VG*-R Denmark	A middle-aged couple with one teenage child.	*Age*: 1970s Size: single family house *Type*: detached *State of repair*: needed extensive energy-focused retrofit.	*Timing*: 2010 over one year. *Work done:* The whole building envelope insulation, vapour-resistant membrane throughout, mechanical ventilation, heat pump, floor heating, windows replaced; solar thermal and PV panels. *Depth***: deep retrofit. *Coordinator*: initiated and coordinated by a contracting company *Tech. potential*: Class 1 low-energy house. *Actual savings*: The owners turned down the heating and ventilation system after the retrofit, as they perceived it used too much energy.

Note: * **BSH** – Bjørneboe et al. (2017); **BC** – Buser and Carlsson (2017); **FB** – Fyhn and Baron (2017); **JM** – Judson and Maller (2014); **MK** – Martiskainen and Kivimaa (2019); **M** – Mlecnik (2010); **GS** – Galvin and Sunikka-Blank (2014), Sunikka-Blank and Galvin (2016) and Sunikka-Blank et al.(2018); **VG** – Vlasova and Gram-Hanssen (2014).

** The depth of the retrofits was judged by the first author of the metasynthesis. A retrofit was judged to be "deep" only if significant calculated or measured savings were shown (above 60%). A retrofit was judged to be "potentially deep" and of "light" based on the combination of the technologies installed.

APPENDIX D

Table D.1 illustrates the coding scheme.

Table D.1. Coding scheme *(continued)*

Themes and codes	Description	Reference
Stages relevant to domestic retrofit and energy use post-retrofit		
i. Pre-retrofit	A stage, at which a household is not thinking about renovations in any way.	Wilson et al. (2018)
ii. Retrofit	A stage, at which the household thinks about, plans and carries out renovations.	Wilson et al. (2018)
iii. Post-retrofit	A stage, at which the household experiences the renovations and adapts domestic life to the structural changes made to their home.	Wilson et al. (2018)
Retrofit depth		
Deep	A retrofit, for which more than 60% of estimated of measured carbon or energy savings were shown.	Mostly derived inductively from the data, the value of 60% is from EC (2019)
Potentially deep	A retrofit, for which a combination of installed technologies allows to assume that significant carbon or energy savings were achieved. The actual savings are, however, either less than 60% or not reported altogether.	Mostly derived inductively from the data, the value of 60% is from EC (2019)
Light	A retrofit, for which a combination of installed technologies does not allow to assume that significant carbon or energy savings were achieved.	Derived inductively from the data
Socio-technical aspects of the built environment		
Physical aspects	Machinery, equipment, etc., developed from the practical application of scientific and technical knowledge. In energy retrofit, the notion captures the application (and the products of such application) of building physics and systems engineering ideas for the purposes of reducing energy use, while mitigating unintended consequences usually associated with energy retrofit, such as reduced air penetration and inadequate ventilation rates due to increased airtightness.	Love and Cooper (2015); Shrubsole et al. (2019, 2014)
Socio-technical aspects	Aspects of the built environment necessary to understand: (i) the difference in levels of retrofit depth achieved during retrofit; (ii) the level of energy use post retrofit. Social and technical aspects should be jointly considered as, for example, materiality of a dwelling preconfigures its operational energy use, while values specific to a particular social context, including the ones of homeowners and building professionals, influence the depth of the technological solution achieved during the retrofit	Love and Cooper (2015); Moffatt and Kohler (2008)
Alignment of socio-technical aspects of the built environment		
Alignment	A result of arranging into appropriate relative position. In relation to energy retrofit, the concept use is twofold. First, it depicts the alignment of socio-technical aspects necessary to achieve deep retrofit during the retrofit stage. Second, it depicts the alignment	Papachristos et al. (2020b, 2020a)

Table D.1. Coding scheme *(continued)*

Themes and codes	Description	Reference
	of socio-technical aspects necessary to achieve and sustain low energy use post retrofit.	
Misalignment	An instance of a bad or imperfect alignment.	Papachristos et al. (2020b, 2020a)