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Devices and strategies: An analysis of managing complexity in energy retrofit projects

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ABSTRACT

Energy retrofits in households are an important means of reducing energy consumption and mitigating climate change. However, energy retrofit rates have generally been lower than expected. As a key reason behind non-adoption, the complexity of energy retrofits can be challenging for adopters to handle. In this article, we study how suppliers and retrofit adopters seek to manage the complexity of an energy retrofit purchase. Using interview and mystery shopping data, the article analyses how the complexity is managed through a variety of complexity management devices (CMD) and complexity management strategies (CMS). We identify four complexity management devices, concretizations that help deal with energy retrofit complexity: characterisations, projections, comparisons and references. In addition, we identify four complexity management strategies for managing complexity: pre-exposure, choice simplification, outsourcing and championing. The contribution of the study is in highlighting the role of complexity management in energy retrofits and how CMDs and CMSs are involved in structuring energy retrofit offerings, business models and energy information. This, in turn, provides impetus for developing measures to ease the complexity of adoption.

1. Introduction

A residential energy retrofit aims to improve the energy performance of a residential space by adopting energy efficiency measures and/or low carbon energy generation technologies on site [1–3]. Given the volume of energy consumed by the residential sector – 25.7% of final energy in the European Union alone [4] – energy retrofits in households are an important means of reducing energy consumption and mitigating climate change [5–7].

However, energy retrofit rates have generally been lower than hoped for [8–10], and much research has been devoted to understanding why this is so. Overall, investment measures are typically less favoured by adopters in comparison to reducing energy demand through non-investment measures [11,12]. Indeed, many studies have pointed to the financial barriers to adopting low carbon energy technology and energy retrofits [5,13–16].

The heterogeneity of the existing building stock, the evolving energy technology and energy markets, the varying organisation forms and the economic embeddedness of actors constitute the complexity of decisions regarding energy retrofits [17]. Thus, even if financial barriers are overcome, the complexity of energy retrofits may be challenging for adopters to handle, and this leads to non-adoption [1,6,9,15]. For adopters, the complexity of energy retrofits may be displayed in the overwhelming difficulty of finding relevant and trustworthy information, understanding different energy retrofit measures and their potential suitability for a specific site, and the variables that govern suitability [18,19].

A number of solutions exist to deal with the complexity of energy retrofits, such as expert support [20], business models that offer integrated energy renovations [1,7] or third-party system ownership [13]. Yet, increasingly sophisticated state-of-the-art services and offerings have not solved the issues and wide energy retrofit uptake has remained less than hoped for. Moreover, the challenges and solutions vary between different housing types and country settings. Dealing with complexity remains as a significant issue in most energy retrofit adoption situations and more research is needed to understand it better, particularly from an adopter perspective.

In this article, we study the management of energy retrofit adoption complexity from an adopter perspective, which also reveals how suppliers and intermediaries manage complexity for adopters and what consequences this has for adopters. We build our analysis on insights from market sociology on the qualification of products and goods [21],
the material artefacts that structure markets \cite{22,23} and theory on complexity management in product and system development \cite{24,25} to ground the importance of material devices and market action strategies as a part of dealing with the complexity of energy retrofit adoption.

The empirical context of our study is the Finnish energy retrofit market, which we have studied 1) through an ethnographic “mystery shopping” approach in two sites and 2) by interviewing energy retrofit adopters in 12 sites. Specifically, we approach the market from the perspective of a housing company board, which is a body that holds a prominent role in governing the renovations and maintenance projects in multi-owned housing in Finland. Housing companies are a form of multi-owned housing similar to housing cooperatives, condominiums and homeowners’ associations found elsewhere in the world, where the owners (i.e. regular people) are responsible for decision-making concerning the property and renovations, and where a board formed of the owners holds a key role in managing the property \cite{9,26}. However, members are appointed for an annual term and may have or accumulate little expertise in energy retrofits. In Finland there are approximately 89,000 housing companies \cite{27}, which govern half of the Finnish housing stock \cite{9} and spend in total roughly 2 billion euros on energy annually \cite{27}. Similar multi-owned arrangements are also widespread elsewhere in Europe: 40% of European dwellings are multi-owned \cite{26} and it is the most common ownership form in some countries such as Spain, Italy, Bulgaria and the Czech Republic \cite{9}.

The study adds to existing knowledge on energy retrofits by elaborating the importance of complexity management in energy retrofit adoption and how a variety of means that support energy retrofit adoption act as complexity management devices (CMD) and complexity management strategies (CMS), and how these devices and strategies structure interaction at the marketplace. CMDs and CMSs do not denote a new empirical phenomenon or “best practice”, but, together with analysing market devices, they provide an analytical frame for studying adoption processes of new technologies and evaluating how well the energy retrofit market, actors within the market, and the tools that support adoption help adopters manage complexity.

Should CMDs and CMSs used by adopters, suppliers or intermediaries be exchangeable and hold benefits to both parties, they can mitigate information and capability asymmetries in the market. This can result in enhanced trust towards energy retrofit technologies and markets among adopters, a condition found central to retrofit adoption \cite{18}. Conversely, examining the shortcomings in what market devices, CMDs and CMSs provide for adopters indicates market aspects that could be potentially improved through new business concepts or public sector interventions.

Better understanding energy retrofits and complexity management from the vantage point of adopters in multi-owned housing is instrumental in effective energy policy formulation and market stimulation. Multi-owned housing units govern comparatively significant economic assets and their decision-making is often based on financial rationale. Hence, they may well be a key customer group that can support the creation of functioning energy retrofit markets by increasing the demand that has been lacking to date \cite{28} and helping to reduce risk for companies in the market \cite{3}. In addition, given the commonality of the multi-owned housing arrangements, the reduction of energy consumption and related emissions is dependent on the ability of energy market actors and policy to support the uptake of energy retrofits in multi-owned housing. A focus on complexity management, CMDs and CMSs is therefore important as it can help conceptualise and identify further tools and approaches by which energy retrofits could be better supported in multi-owned housing.

2. Theoretical background

2.1. The complexity of energy retrofits

Energy retrofits and new energy technology adoption are generally referred to as a complex process and situation \cite{10,17,28–31}. Overall, the complexity of energy retrofits stems from multiple sources. First, many authors highlight that energy technologies and retrofits are potentially difficult to understand in terms of their content, what benefits they might create and their maintenance \cite{9,32–38}. Second, the formal procedures for installing and adopting energy technologies may be complex and unclear \cite{32,39–42}. For example, in cases where policy has been targeted to support adoption (e.g. the UK Green Deal), adopters may face challenges in understanding the scope of support and the associated rules \cite{32,39}. In addition, developers in the projects may have problems interpreting building codes and standards relating to energy renovation measures \cite{41}. Third, the management of the energy renovation process can be complex for adopters as they may need to interact with multiple different market actors \cite{1,10,39,43,44}. This complexity is often framed as deficiencies in the business models of energy renovation market actors. Still today, energy renovations are characterised by piecemeal solutions and more integrated offerings are yet to become widely diffused \cite{1,7}.

2.2. Complexity as a qualification challenge in the markets

Sociology of market indicates that to the extent that the adopters and providers of energy technologies and multiple other market actors need to exchange information to settle complexities, these complexities can be framed as matters of qualification \cite{21}. Market activities are not a unidirectional process from supply towards demand (limited to buying) but, instead, they are an interactive process in which adopters play an active part. To act competently in the market adopters need to be able to make sense of product qualities, compare them and establish an understanding of what consequences different choices hold for them \cite{21,45} (see also \cite{46}). Qualification is a multi-stage, continuous process through which the qualities of products and goods are defined and in which goods become objectified or commoditised so that they can become a part of economic exchange \cite{21,47,48}. This often includes a variety of metrological investments that make a good calculable and comparable with other goods in the marketplace \cite{47,49}. Seen this way, calculation is an important characteristic of market activity and actors \cite{45}. For a good to become adopted, qualification should result in singularisation wherein product qualities are matched with the specific conditions of adopters \cite{21}.

The complexity of goods or markets can pose significant barriers to effective qualification processes. Complexity generally concerns how different things are linked to each other and how changes in one element may influence others \cite{50}. As a qualification challenge, complexity is specifically a matter of 1) identifying different “world states” and 2) comparing and understanding linkages between them (following \cite{45}). Put differently, complexity makes the definition of the most suitable market choices and their associated opportunity costs more challenging.

Previous studies of the energy retrofit market \cite{18,19} display these problems in practice as a challenge to find comparable sets of energy retrofit options in the market and understand the relative benefits of different kinds of energy retrofits. Hence, in a market where technological complexity is high and business models remain piecemeal, understanding how the complexity faced by adopters can be managed represents a key question for supporting energy retrofits and provides other market actors with insights into how offerings could be structured.

2.3. Dealing with complexity through market devices, complexity management devices and complexity management strategies

One way in which the calculability and comparability of the complexity in a market can be supported is through a variety of material and conceptual tools, which can be defined as market devices...
Such devices are sociotechnical *agencements* that play a role in market structuration [23] and organisation [47] by helping to reduce and manage uncertainty and complexity in a market [22,53,54]. For instance, market analysts simplify the complexity of company stock valuation in their reports through calculative frames that consist of only a handful of parameters (out of a large number of possible parameters) [53]. Similarly, trading and the associated calculations are often based on simplified versions of complex mathematical models and phenomena in order to facilitate effective communication between market counterparts [22]. Industry analysts continuously structure the markets of complex IT systems for buyers so that buyers can compare the options [55] while IT system suppliers and users invest heavily in achieving comparability of value [56,57]. In solar lantern adoption, warranties can serve to reduce the uncertainty of buyers about the lifetime of the product [54]. As these examples illustrate, intermediaries and suppliers play an important role in the creation and use of market devices. Often (e.g. in analyst reports and warranties), the market devices are targeted at adopters.

In managing the complexity of markets and sociotechnical systems, there is a useful parallel to be drawn with studies on innovation and product development, especially the development of complex products and systems. In these contexts, the complexity of the operational environment [58] and multiplicity of different development paths [59] entail that their development depends on the use of various sociotechnical tools and means for managing and containing technical complexity and risk [25,60].

In this article, we focus on two kinds of complementary means for managing the complexity discussed in the literature on complex product and system development that complement the analyses of market devices. First, complexity can be managed by storing or inscribing it to various material artefacts and devices, which can then be conceptualised as complexity-management devices [24] (see also [61,62]). CMDs are capable of reducing uncertainty over project options and defining possible “future states” of a project or system. From a process perspective, CMDs are important means for solving development issues by storing and encoding decisions about technological configurations and combinations, and hence, ensuring that development projects move forward. Second, the complexity of processes and system configuration is often managed through various complexity-management strategies, such as the partitioning and sequencing of activities. Drawing again from the development of complex products and systems, they are developed iteratively over a period of time with different parts of the system developed during different time frames [24,50,63]. In this regard, the full complexity of the process is not faced at once and by everyone at the same time. As an example of CMD and CMS use in complex product development, measured drawings (a CMD) aid developers in defining the properties of individual components (e.g. the dimensions and manufacturing techniques) and how they are arranged together, without the need to design everything at once. At the same time, a single drawing cannot exhaustively define a complex configuration and solve all relevant development issues, and hence, the production of multiple drawings over time (a CMS) is required [64].

The concepts of a CMD and CMS are useful for advancing the current understanding of market construction and intermediation by focusing on the necessary complexity management that is carried out when energy retrofits are planned. That is, CMDs and CMSs provide an analytical frame for evaluating the degree to which energy retrofit support matches adopter needs in managing complexity. We wish to delineate them from the concept of market devices in two ways. First, while market devices are central tools in exchanges and markets, CMDs are not necessarily so unless they are acted upon in the marketplace. Continuing with the example of measured drawings discussed above, it is only when the drawing is used (for instance, in tendering processes or for determining the amount of material to be bought for production) that they become market devices. Furthermore, a measured drawing is typically preceded by dozens (or hundreds, or even thousands) of sketches that help developers define the final product or good (a CMS). Together, CMDs and CMSs are useful in focusing on the preliminary work that market actors need to perform in order to participate in a market in the first place.

Second, market devices have typically been placed in points of purchase and upstream, in the hands of market professionals and intermediaries [65]. However, since adopters also play an important role in intermediation and qualification processes [21] and as targets of...
these processes [66], it is reasonable to hypothesise that they also use various devices for managing complexity and operating in a market (see e.g. Ref. [47]). Such devices could help in, for instance, dealing with knowledge, persuading decision-makers and supporting decision-making [46] and understanding the relevance of certain technologies in the home [3,67]. Thus, the market devices, CMDs and CMSs that potential adopters use can be expected to play just as important a role as those used by intermediaries and market actors in markets ridden with complexity.

The functioning of CMDs and CMSs in energy retrofit planning is visualised in Fig. 1. The figure follows visualisations presented in Murto [24] and frames CMDs and CMSs as containing and solving some of the development issues in complex processes. In context of the present study, the issues to be solved are framed as qualification issues: for instance, understanding energy retrofit opportunities, judging their suitability for a site and comparing alternatives with each other. Circles in the figure represent the scope of different CMDs, CMSs and market devices and the way in which they contain and handle parts of the complexity involved in an energy retrofit. Hence, the existence of CMDs and CMSs is not a guarantee that energy retrofit adoption takes place, but instead they provide crucial support in energy retrofit processes for adopters and intermediaries.

3. Methods and data

To construct a more nuanced picture of complexity management in energy retrofits, we have adopted a two-track approach. First, we studied the Finnish energy retrofit market through ethnographic participant observation and by using the mystery shopping approach [68], which enabled us to experience first-hand the complexity and challenges faced in the market by adopters. Second, while our mystery shopping formed the initiation of energy retrofit projects in the two sites, we interviewed board members in 12 housing companies (identified as cases C1–C12) where energy retrofits had already been implemented in order to understand the process in its full scope. As such, the mystery shopping and interviews complement each other, with mystery shopping providing intricate detail and the possibility to observe the market directly and the interviews helping to see the wider patterns in energy renovations. In addition, the interviews provided a validity check for the mystery shopping.

The mystery shopping consisted of an information search and contacting market actors in order to achieve an understanding of how the energy systems of S1 and S2 could be improved. Mystery shopping was carried out by the first author in two sites (identified as sites S1 and S2) where the housing company boards had already contemplated energy retrofits. During the 22-week mystery shopping period, the first author sought for information on energy retrofits and contacted market actors to arrive at an understanding of what energy retrofit options are available for the sites and what would be their impact (e.g. in terms of energy cost). The process did not follow a pre-structured plan or external guidance, but instead proceeded based on the recommendations and information received from market actors and intermediaries. The process was documented as field notes, consisting of a table (145 rows in total) where each entry corresponds to an individual activity or task performed by the first author.

The interviews focused on the energy retrofits that had been implemented and covered issues such as the overall process, and where and from whom the housing companies received help for their project. Suitable cases to study were initially identified through public and social media, and later complemented by a search from apartment sales portals to add less vocal energy retrofit adopters to the sample. In all of the studied retrofits, heating systems had been replaced with new technology and some had also added other measures to improve the energy economy of the housing company. Overall, 21 individuals were present in the interviews and they primarily included housing company board members (energy consultants or property managers were also present in some instances). The interviews were carried out primarily in the premises of the housing companies and sometimes included a tour around the technical premises of the properties to display the energy systems in action. All interviews were recorded and transcribed for analysis (duration ranged from 44 to 82 min).

To understand the CMDs and strategies employed in the energy retrofit projects, both datasets were analysed for 1) descriptions and occurrences of material and conceptual tools used in the projects (CMDs) and 2) the strategies at play in energy retrofit planning and implementation (CMSs). In the first round of analysis, CMDs and CMSs were outlined with descriptive labels (e.g. an offer, an offer comparison) and tabulated for each of the cases and sites. In the second round of analysis, the CMDs and CMSs were grouped based on commonalities between them across the cases and sites. In the third round, the CMD and CMS groups were compared with theoretical literature to see how they related to existing research.

4. Results

In this section, we outline the devices and strategies that emerged from our ethnographic mystery shopping and interview data. While the scope of potentially different kinds of CMDs and CMSs is wide, we focus on CMDs and CMSs that played a specifically prominent role in our studies and which illustrate the functioning of the energy retrofit market and intermediaries. Moreover, as our vantage point was that of an adopter in the market, insights on the CMDs and CMSs used by the intermediaries are based on those visible to adopters.

4.1. CMDs

We discovered four types of CMDs that played an important role in the early phase of the energy retrofit process: characterisations, projections, comparisons and references.

4.1.1. Characterisations

The first CMD we discuss is formed of the various characterisations which outline the principal characteristics of, for instance, energy retrofit technologies or the state of the housing company (and its energy technologies). Technological characterisations served as initial cues for adopters in understanding what energy retrofit options might be suitable for their site and which might be unsuitable. For example, solar energy measures were often characterised as suitable for sunny, south-facing roofs. In turn, the characterisations were important in outlining what individual characteristics or “input variables” determine the feasibility of various energy renovation measures. In the mystery shopping study, we discovered over 50 different variables that were used for characterising the sites and which acted as the basis for outlining what retrofit options would be suitable for the sites. For adopters, possession of, access to and conveyance of these variables and characteristics (through e.g. the property management certificate or energy consumption data) were key precedents for acting in the marketplace. Possession of this data was not always a given. While some characterisations could be made simply by observation and limited instrumentation (e.g. building orientation and type), others required time and effort (e.g. access to energy consumption data in S1 and S2) or extensive instrumentation (e.g. test drillings to assess soil quality for ground source heat in C8).

Site characterisations were also relevant for the market actors and intermediaries regarding making energy retrofit recommendations or accurate offers (or projections – see below). In some instances, market actors put forward their own templates or forms for capturing characterisations, such as an offer template or housing company status template. While some of the individual pieces of the characterisations had limited power as a CMD (and rather served as inputs for CMDs), some variables and information had more meaning to the intermediaries than their apparent face value (to the adopters). For example,
the presence or absence of certain commodities or premises (e.g. a sauna, cold cellar, laundry room, cold attic) provided a shorthand for assessing the overall electricity and heat-use profile (i.e. how stable it is over time).

Characterisations were an important first step in singularising and adapting individual energy retrofit measures for the sites, both for adopters and the market actors. Specifically, characterisations paved the way for market exchange between adopters and market actors by providing them with the information (and characterisations) they needed to operate effectively. Simple technology characterisations served adopters as initial rules-of-thumb for understanding both the technologies and what to search for in the market, while site characterisations helped the market actors evaluate energy retrofit opportunities for the sites (as, e.g. energy advisors did in the mystery shopping). In this regard, the exchange of characterisations helped adopters and market actors manage complexity collaboratively and helped them move forward in the project.

4.1.2. Projections

Characterisations of the sites were used as inputs for evaluating the feasibility of different energy retrofit measures in the sites. The purpose of such projections was to understand how certain energy retrofit measures and technologies could be installed and how they would perform in the site. Projections are also commonly referred to in other literatures discussing complex technological settings in the form of, for instance, simulations [25] and calculations [24].

For adopters, projections typically took the form of offers or feasibility assessments for a given technology and responded to central uncertainties about energy retrofits: performance and costs. With some technologies, projections made market exchange very convenient for both adopters and market actors. For instance, online solar PV calculators gave instant estimates on energy yield, cost and payback time right at the early phases of the mystery shopping. The calculators also benefited the market actors in capturing site characteristics and automating much of the work needed to generate an offer. However, in other cases, such as ground source heat pumps, the projections were more complicated and often consisted of multiple documents outlining pump yield, investment breakdowns, terms of service and so forth (and took weeks to get). Hence, they needed a lot of interpretive work from the adopters. In doing so, the housing company representatives had to make projections of their own regarding, for instance, financing the energy retrofit (C4) or project risks (C3).

The projections typically focused on a limited set of energy retrofit measures. Especially during mystery shopping, our demand for wide-scale energy retrofits (and projections of them) was unmet by supply in the form of offers that would have integrated multiple energy retrofit measures. Similar findings surfaced in some of the interview case studies. For instance, in C10, a large number of individual contractors were required for the project, and integration was raised as a key challenge by the interviewees. The adopters therefore needed to do considerable work in managing complexity when they aimed to implement an integrated energy retrofit.

Projections were key CMDs for energy retrofits and, especially during mystery shopping, they were actively sought after (even if sometimes implicitly). However, there were two conditions that decreased the power of projections as CMDs. As projections became increasingly detailed (and reliable), or when their inner logic (i.e. how characterisations influenced projections) was hidden from the adopters, further work was needed in interpreting them. In some situations, the amount of detail itself reduced the power of projections as CMDs as they became difficult to use (as witnessed with the mystery shopping and open-source ground source heat calculators). Thus, in the best case, projections were able to reduce complexity for both the adopters and market actors, but more commonly the complexity-managing role of projections was asymmetric (i.e. they had more CMD relevance for market actors than adopters).

4.1.3. Comparisons

Whereas individual projections were useful for understanding how certain energy retrofit measures would suit a site, they rarely provided much in the way of understanding whether a given measure or projection was any good in comparison to the competition and alternatives. This is where various explicit comparisons were useful for managing complexity and defining what energy retrofit options are best for the housing company (see also [18]).

In their simplest form, comparisons outlined how an energy retrofit measure’s installation compares to the current system of the housing company (these were often included in offers aiming to replace current systems). More advanced comparisons were carried out by neutral energy consultants in the majority of the case study sites in the form of energy system and offer comparisons. For instance, in C6, comparisons were initially made in order to find the overall energy generation system configuration (i.e. ground source heat, exhaust air heat pump or district heating) and were used later for comparing the offers of ground source heat pump installers.

Similarly to projections, comparisons often focused on a limited set of energy retrofit measures, even in ambitious energy retrofits (such as C10). In some of the cases, the housing company members also performed comparisons, especially if they were technically competent at doing so (e.g. through having a background in energy engineering [in C1] or in building automation systems [in C8]). In the mystery shopping, all comparisons were carried out by the researcher (because energy consultants were not discovered to carry these out) and they were relatively wide in scope in order to serve the interest in integrated energy retrofits.

The value of comparisons as CMDs was directly related to their ability to support calculation in the marketplace [see 45]. In practice, the comparisons gave a clearer sense of the differences between different offers and possible technologies and their associated opportunity costs. Yet, expert knowledge of energy seemed to be a key complexity-managing component in the comparisons – not only in making them but also in interpreting them. For example, what read simply as a listing of ground source heat pump manufacturers to the first author prompted an energy consultant to discuss the noise problems of a particular pump manufacturer. Hence, the complexity-managing role of comparisons was tied to the involvement of either energy consultants contracted to work in the project or expert knowledge present within the housing company.

4.1.4. References

The fourth CMD that emerged in the studies was formed of references, which were sites where an energy retrofit or energy technology installation had been implemented [see also 69]. Previous studies on complexity management in technological development place considerable emphasis on references as CMDs [24,25,57]. In the present study, the influence of references was less prominent in managing complexity because the idiosyncrasies of energy usage sites make referencing generally less useful (compared to product development where the linking of individual projects is more beneficial).

Reference sites helped the adopters learn about energy retrofits, hear about experiences, access energy retrofit networks and even helped them receive guidance on their own projects. In the majority of cases, previously implemented projects (found through personal work, property managers or contractors) proved to be important in learning about energy retrofit opportunities (in a few cases, our interviewees knew each other for this specific reason). Distance and access to the reference sites varied considerably, ranging from second-hand knowledge on “housing companies in Stockholm” (C9) to having sites within walking distance (C11, C7). A few of the interviewees were further able to utilise reference sites and items in their own projects by drawing out a list of risks for contract negotiations based on experiences from a failed project (C3) or testing cheap solar panels at a summer cottage (C8). In mystery shopping, a housing company occupying the same lot
as S2 was an important reference and it was also used by a third-party installer for evaluating opportunities in the site.

The complexity-managing role of references lay in understanding the characteristics of the energy retrofit technologies in action and helping contextualise one’s site. References enabled adopters to observe energy retrofits (and following [46], support adoption) and, moreover, improve trust by providing access to information that was not (solely) filtered by commercial actors selling energy retrofit technologies (see, e.g. Ref. [7]). For the market actors and intermediaries, reference sites served as an important part of their marketing: some of the case interviewees mentioned attending ground source heat displays by installer companies, and during mystery shopping, such events were also marketed by the intermediaries. Hence, references served the complexity-management needs of both adopters and installers by displaying the technologies at work (and sometimes, their associated problems).

4.2. CMSs

In addition to CMDs, we discovered a variety of CMSs that could smoothen the path for energy retrofits. The most important CMSs identified in the study are pre-exposure, choice simplification, outsourcing and championing.

4.2.1. Pre-exposure

In our data, we often encountered both the active and happenstance pre-exposure of adopters to knowledge of energy retrofits – sometimes years before the project – which played a supporting role in the projects (see also 69). Pre-exposure was a realised pattern of actions rather than a purposeful building up of knowledge and expertise. The case studies in particular indicate that the usefulness of pre-exposure seemed to only materialise after an external event triggered the need to tap into the accumulated knowledge (e.g. a combination of an energy price rise and the lifecycle of existing technology).

The depth and duration of pre-exposure varied considerably in our studies and across cases. For instance, some interviewees had actively monitored individual technologies or the overall low carbon energy sector prior to the projects (C9, C12) while one interviewee had made a career in the energy sector (C1). There were also cases of more involuntary exposure to energy renovations through encounters with persons knowledgeable of the market and low carbon technologies, sometimes many years ahead of the actual energy renovations (C4, C5) (for similar findings, see Ref. [70]).

We also discovered active attempts by energy advisors to support pre-exposure. During mystery shopping, recommendations by energy counsellors to join their short Energy Expert training targeted to housing company board members were a clear attempt to support pre-exposure, and in one of the case studies (C10), the training had been a central initiating factor for the energy retrofit.

The complexity-managing role of pre-exposure had to do with the accumulation of sufficient knowledge about the energy retrofit market, which helped characterise the site, read projections and comparisons, and identify actors in the marketplace when it became necessary. Thus, the interviewed members of the housing companies rarely began their activity in the market as blank slates when the time came to renovate the energy system. In mystery shopping, the lack of gradual pre-exposure resulted in considerable burdens.

4.2.2. Choice simplification

Another strategy with which complexity was managed and reduced in our studies was choice simplification. Based on the data, we distinguished three modes of choice simplification: supply simplification, demand simplification and sequencing. Common to all of these choice-simplification strategies was a focus on a limited set of technological options, either permanently or temporarily (for similar discussion, see Refs. [71,72]).

Supply simplification was particularly visible during mystery shopping in the piecemeal nature of the market and narrow offerings of market actors [also 1,7]. Integrated energy retrofit offerings that included multiple different energy efficiency and generation measures were simply not found on the market but were recommended by energy advisors. For some market actors, their experience with a certain technology had caused them to narrow or change their offering, while others simply stated their focus to be on certain types of products (such as district heating and cooling). Supply simplification relates to the lack of availability of system-level projections and comparisons to adopters.

Demand simplification was displayed in both of our datasets. In the case studies, the interviewees often referred to focusing on a relatively limited amount of energy retrofit measures overall. In mystery shopping, focusing resulted primarily from learning about the different measures and CMD use, through which different options were ruled in or out. While the interview data does not outline in detail the process by which the housing companies simplified their demand, the mystery shopping data suggests that pre-exposure and learning about energy retrofit options through projections are key components of the simplification process – pre-exposure prior to energy retrofit projects translates into effective demand simplification once projects are initiated.

The sequencing of energy retrofit measures often came up in both datasets [see also 72]. In practice, sequencing meant the distribution of energy retrofit implementation over time so that adopters could temporarily “stabilise” their energy system prior to engaging in new retrofit projects. For example, during mystery shopping, energy advisors recommended sequential energy retrofit models wherein housing companies were encouraged to begin with relatively small and cost-efficient measures (such as insulation and existing-system adjustments) in a specified order – and to only pursue more extensive and radical changes (such as switching from district heating to ground source heat pumps) afterwards, if they are still viable. Sequencing had also been carried out in the case studies to deal with uncertainty: for example, the housing company in C8 was timid about incorporating solar PV into their system right from the start. In the most extensive energy retrofit project (C10), the project had been sequenced in two parts following the overall demonstration project schedule (with some measures having been carried out before the project).

Choice simplification was an effective CMS as it reduced the amount of variables that needed to be addressed in projections (and hence, it helped deal with situations where system-level projections and comparisons were unavailable). Furthermore, choice simplification facilitated the matching of supply and demand as adopters learned about market offerings and the suppliers of demand, and hence, this helped qualify offerings. However, choice simplification may result in disregarding encompassing integrated retrofits even in cases where these would be the optimum solution. For example, sequencing provides limited support for integrating the overall process from the perspective of the housing company as the company is left with most of the responsibility of deciding on what to sequence and which order – questions that have major implications for overall energy economy. Thus, choice simplification may result in a false sense of choice for adopters [73] and steer demand in directions that do not tap into the full potential of energy retrofits.

4.2.3. Outsourcing

In outsourcing, energy retrofit adopters hired a consultancy or another market actor to help with projects and their complexities.

In eight out of the twelve retrospective cases, outsourcing meant that an energy consultant took a position in between the housing company and the energy retrofit technology suppliers (resembling the one-stop-shop business model discussed in Ref. [1] and program design discussed in Ref. [69]). Energy consultants internalised the complexity of the energy retrofit by drawing up characterisations, finding suppliers, managing the contractor interface of the project, generating comparisons for decision-making and acting as a technological expert in the projects. As such, the consultants took a “neutral” position in
support of the housing companies and were able to sell their services as a necessary go-between (e.g. by providing comparisons, as discussed previously). Following Callon [45], this can be viewed as a re-framing by the consultants, resulting in an internalisation of externalities. Finding a neutral consultant was also recommended in the mystery shopping, but such actors were not found.

On the project level, outsourcing did not reduce the complexity of the project but externalised it from the adopters. Access to energy expertise also supported decision-making and selecting the “best” option from among different projections (i.e. it supported qualification and singularisation). For example, as the housing company in C7 put it, their selection of the contractor was based on the recommendations of the energy consultant because he had over ten years of experience of the subject. Furthermore, in some cases outsourcing was considered to be useful for selling the project in the housing company as the consultants had a “neutral” and outsider role in the process. Outsourcing was primarily beneficial for the housing companies but in C2 and C10 the housing company members realised the contractors were out of their league in the projects. Another form of outsourcing adoption complexity is to hand the energy retrofit to turn-key integrated solution providers, the emerging new breed of suppliers in housing company energy retrofit markets. Such option was gauged in the mystery shopping, but the offer materialized with considerable delay, was comprised of a modest suggested set of measures and was 30% more expensive than piecemeal adoption of same measures.

4.2.4. Championing

In a context such as a housing company, energy retrofits call for leadership and processes that bestow individuals with trust and legitimate power over decisions. Many of the studied projects benefited from a situation where an individual adopted a championing role in the project. Championing in the projects was largely similar to that discussed in previous literature on champions in energy retrofits [20,74] and technology transitions [75]. The champions of the project typically helped deal with technological barriers in the projects but also worked as network, process and power champions.

Championing was performed by adopters and market actors alike. In most instances, champions were actors already close to the housing company. The clearest way in which championing displayed itself in the data was through data on technically skilled adopters who possessed strong capabilities to carry out technical duties in the retrofit (this was often associated with strong pre-exposure and similar to findings discussed in Ref. [76]). These individuals acted as key technology champions in the projects (especially in C8 and C9), relieving the burden from the others and reducing the need for outsourcing. In some cases, the property managers also had an important role as network champions, connecting the case sites to technological champions if they had previous experience with them. Many of the interviewed housing company board members had also promoted the projects internally – or “worked the soil” as it was worded by an interviewee in C11 – in their housing companies to ensure acceptance of the energy retrofit project in the annual meeting. This activity corresponds closely to activities carried out by power and process champions. Network champions were particularly beneficial for both the housing companies and intermediaries as they operated as a link between supply and demand. Championing was particularly relevant when facing roadblocks in the projects relating to drilling depth (C11), underground planning (C9) or decision-making (C4), the champions did not quit the projects entirely and continued with them after the circumstances turned their favour.

The complexity-reducing role of championing is similar to outsourcing but “internal” to adopters (i.e. it does not depend on new market exchange). Indeed, technological championing was often performed as a substitute CMS for outsourcing: the four cases that did not utilise outsourcing featured strong technology champions within the housing company. With other types of championing, complexity management had more to do with supporting conditions in which the project could continue or move forward – or it had more to do with facilitation, as worded in research on intermediaries [66]. This was especially the case when housing company members or property managers had adopted the role of a champion in a project. For market actors selling energy retrofit technologies, the existence of strong technical champions within or close to a housing company reduces complexity as it entails a lesser need for outsourcing (but also reduces the business to be made in managing complexity). However, the presence of network, process and power champions can be viewed as beneficial as it ensures that the buyer is competent and/or willing to drive the project forward (with the help of the market actors).

To conclude the results section, Table 1 summarises our results for each mystery shopping site and case regarding the CMDs and CMSs used in the energy retrofit projects.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Empirical examples</th>
<th>Corresponding sites and cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMD</td>
<td>Characterisations</td>
<td>Artefacts that describe and define a site or a technology</td>
<td>- Property management certificate</td>
</tr>
<tr>
<td></td>
<td>Projections</td>
<td>Artefacts that outline future possible states of the housing company energy system</td>
<td>- Energy renovation offer</td>
</tr>
<tr>
<td></td>
<td>Comparisons</td>
<td>Artefacts that compare and rank different characterisations and projections</td>
<td>- Online contact forms of intermediaries</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>Known and observable sites where energy retrofits have been implemented</td>
<td>- Online contact forms of intermediaries</td>
</tr>
<tr>
<td>CMS</td>
<td>Pre-exposure</td>
<td>Active and/or passive exposure to energy retrofits prior to renovations</td>
<td>- Happenstance encounters with energy experts</td>
</tr>
<tr>
<td></td>
<td>Choice simplification</td>
<td>The limiting of energy retrofit options at a given point in time</td>
<td>- Narrow offerings of intermediaries</td>
</tr>
<tr>
<td></td>
<td>Outsourcing</td>
<td>The use of intermediaries or other market actors to handle the energy retrofit process and externalise complexity</td>
<td>- A narrow focus on energy retrofits by consumers</td>
</tr>
<tr>
<td></td>
<td>Championing</td>
<td>The emergence or dedication of an actor who drives the project forward</td>
<td>- The active internalisation of complexity by intermediaries</td>
</tr>
</tbody>
</table>

Table 1
CMOs and CMSs encountered in the mystery shopping sites and cases. Parenthood in “Championing” indicate a weak presence in the mystery shopping.
4.3. The role of CMDs and CMSs in market construction and in navigating the energy retrofit market

When evaluating the role of CMDs and CMSs as a part of market construction, our results suggest that the energy retrofit market worked particularly smoothly in situations where CMDs and CMSs either 1) fulfilled a boundary role and helped manage complexity for both parties or 2) could be exchanged between the parties. To discuss these roles, we frame CMDs and CMSs as having either symmetrical or asymmetrical benefits. In symmetrical cases, or in cases where complexity can be “exchanged”, qualification and singularisation are easier and more straightforward than in asymmetrical cases.

An example of a symmetrical CMD that helped manage complexity for adopters and market actors is an online solar PV calculator. For adopters, the calculators made market exchange very easy: all that is needed is to pick their housing company from a map, enter a few details regarding roof material and overall energy consumption (i.e. characterisation) and the projection was ready. This was coupled with buttons for contacting intermediaries who would instantly have the relevant characteristics of the housing company available once contacted and had knowledge of what it means for the companies’ business (i.e. the components needed, the installation equipment needed, profit etc.). Similarly, reference sites were beneficial for adopters and suppliers and intermediaries alike.

More often than not though, the CMDs and CMSs had asymmetrical benefits which led to considerable work in acquiring, interpreting and translating information for the adopters. For instance, the building year of the sites was used by market actors as a proxy indicator for determining what likely technological solutions, such as insulation levels, are in place in the site. This was hardly evident to adopters during mystery shopping and needed specific attention in order to understand why the building year should be taken into account in the first place. The complexity of ground source heat projections discussed in the previous sections is a similar case in point.

However, our data suggests that adopters deal with asymmetry through exchange, which can be viewed as analogous to the re-framing discussed by Callon [45]. Asymmetric projections, comparisons and characterisations were often asymmetric on their own, but when adopters exchanged them with energy consultants, they became less so. For instance, the property management certificate did not provide much in the way of complexity management for adopters prior to understanding technological characterisations (e.g. what opportunities natural ventilation leaves out etc.). Similarly, market actors were able to reduce the asymmetry of characterisations by visiting the sites and, hence, could improve projection accuracy (especially discussed in S1 and C6). In this way, these CMDs and CMSs functioned as a means of qualification and (for adopters) singularisation.

5. Discussion and conclusions

In the present paper we have scrutinised how suppliers, intermediaries and retrofit adopters interact in the market and seek to manage the complexity of adopting an energy retrofit. Previous research has shown that the complexity of energy retrofits can severely hamper the adoption of more sustainable energy technologies in households. Yet, how to conceptualise and address complexity in energy retrofit research and practice, especially from the adopter perspective, has received less attention in previous studies. Borrowing ideas from market sociology and complexity management in product development, this article shows that there are many different ways with which complexity can be managed and dealt with to support energy retrofit acquisition. First, the material market devices and CMDs that circulate in the market often support the reduction of uncertainty and complexity in energy retrofits. We identify four CMDs, namely characterisations, projections, comparisons and references. Second, uncertainty and complexity can be further reduced and managed by CMSs that support learning and decision-making in the marketplace. The studied actors relied on pre-exposure, choice simplification, outsourcing and championing as CMSs. While the presence and use of CMDs and CMSs is not a guarantee of energy retrofit adoption, the joint use of multiple CMDs and CMSs and their exchange between adopters and the market actors is important in order to manage complexity and support adoption. Ideally, CMDs and CMSs in energy retrofits should respond to the complexity-management needs of both parties.

Our contribution is deepening the understanding of how adopters deal with the complexity of an energy retrofit. The conceptualisation of CMDs and CMSs also supports the structuring of energy retrofit offerings, business models and energy information in a way that eases adoption and its associated complexity. Here, CMDs and CMSs are useful concepts for understanding the processes of energy retrofit adoption and the associated complexity management as an interactive process between adopters, intermediaries and other market actors. The fact that energy retrofit adoption is an interactive process is further emphasised by the housing company and multi-owned housing context, where all renovation projects are negotiated and decided collectively.

The variability of the existing housing stock is a market feature that is not fading away. The long tail of energy solution legacies and unique contextual settings cement the situation where a single solution cannot fix all the problems. It is reasonable to think that complexity is perennial in this market also in the future. In this situation, further improving the functioning of CMDs and CMSs poses a plausible policy avenue for supporting energy retrofit adoption. In particular, the extensive work that adopters need to perform in searching for, interpreting and translating information in order to be able to interact in the market suggests significant potential for improvement in the devices that facilitate market exchange. This requires systematic work that can support learning and help the development of comprehensive but at the same time easy-to-use tools and templates to support solution formulation and decision-making. The focus of this work – both in terms of policy incentives and technical development – should be on integrated energy retrofits in order to break away from system-level sub-optimisation [7].

Future research could look into diversity of market practices. The housing company, board membership and formal decision-making protocols represent a particular organizational set up and energy retrofit demand. With little expertise and scope for direct personal gains and yet formal accountability, housing companies highlight particular problems. The effects of complexity and strategies for managing it will differ for other types of demand side actors. In addition, more research is also needed for understanding complexity management from the perspective of intermediaries and market actors as it is consequential in how energy retrofit offerings are shaped. Finally, as energy retrofits need to account for the idiosyncratic characteristics of different sites, studying CMDs and CMSs in different policy and application contexts with an adopter focus is needed, provided that researchers have the possibility to access energy retrofit markets and adoption processes to study them directly.

Climate change mitigation would certainly benefit from an avalanche of energy retrofits in households. To ensure that households can become true agents in mitigating climate change at large, the complexity that adopters face in energy retrofits must be taken as a central problem to solve through joint efforts in research, business and policy. In this work, the devices and strategies that can help move energy retrofits forward will play a key role in supporting market creation and ensuring that demand will follow – provided that sufficient attention is paid to how well the devices and strategies help adopters deal with complexity.

Declaration of interest

None.
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