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Article

Reducing Carbon from the "Middle-Out": The Role of Builders in Domestic Refurbishment

Kathryn B. Janda *, Gavin Killip and Tina Fawcett

Environmental Change Institute, University of Oxford, South Parks Road, Oxford OX1 3QY, UK; E-Mails: gavin.killip@eci.ox.ac.uk (G.K.); tina.fawcett@eci.ox.ac.uk (T.F.)

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***** Author to whom correspondence should be addressed; E-Mail: katy.janda@ouce.ox.ac.uk; Tel.: +44-1865-285-544; Fax: +44-1865-275-850.

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Abstract: A three-year research project explored the evolving level of "building expertise" for low-carbon housing refurbishment in the UK and France. With a focus on "middle actors" and the evolution of professional practice, this paper reports on "middle-out" responses from the housing retrofit supply chain to top-down policies promoting low-energy retrofits of existing homes. The two countries have comparable long-term policy goals for CO_2 emissions reduction, but there are important differences between their more immediate initiatives to achieve a step-change in activity in the housing retrofit market. Industry responses to these various policy signals were explored in a series of semi-structured interviews with builders involved in innovative, low-energy refurbishment projects. Drawing mainly on four case studies of innovative business models, the paper highlights innovative practices and processes being proposed and trialled by "middle actors" in the building industry. We describe middle-out implications of these innovative practices: upstream to policy makers, downstream to clients, and sideways across refurbishment providers and the retrofit supply chain.

Keywords: building retrofitting; building trade; socio-technical; residential buildings; small and medium-sized enterprises; innovation; professional practices; middle actors; middle-out change

1. Introduction

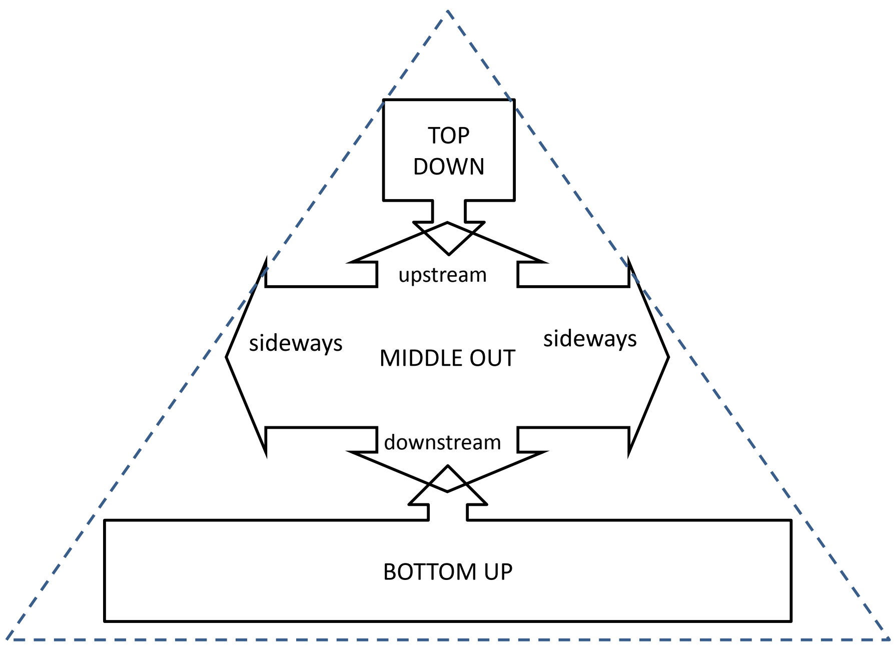
The built environment must undergo dramatic changes to meet climate change mitigation targets. The World Business Council for Sustainable Development [1] calls for a worldwide building sector energy reduction of 77% below projected 2050 levels. Behind transport, the residential sector is the largest energy consumer across Europe, accounting for an average 26.2% of final energy [2]. Residential consumption in both Britain and France is slightly higher than the European average. Housing accounts for 30.7% of final energy consumption in the UK [3] and 29% in France [4]. Both countries have set themselves ambitious long-term CO_2 emissions reduction targets, and both have identified the improvement of existing housing stocks through renovation as an important part of a wider climate change mitigation strategy [5–7]. In France, the Environment Roundtable ("Grenelle de l'environnement") and the inter-departmental "Programme Interministeriel de Recherche et d'Expérimentation sur l'énergie dans le Bâtiment" (PREBAT) both highlight housing refurbishment as the top priority in achieving European and Kyoto Directives. In Britain, the "Green Deal" is designed to help homes and businesses make energy improvements by deferring upfront costs.

The Energy Saving Trust estimates that transforming the entire UK housing stock by 2050 will require 600,000 refurbishments of older, inefficient properties every year [8]. The sheer scale of this transformation requires radical changes in both the demand for housing renovations and its supply. As Horne and Dalton [9] note, there is significant work on the supply of new housing, homeowner renovations, and social movements towards low carbon housing. Eames *et al.* [10], for example, recently looked at how to collectively organise urban retrofit activities at the city scale to deliver significant environmental, social and economic benefits. Despite such efforts, Horne and Dalton [9] (p. 2) argue that there is "little research on the supply side of housing renovations," particularly on the characteristics of what they call "eco-renovation businesses."

Between 2010 and 2013, a collaborative research project called "Building Expertise" contributed to filling this gap in the field by focusing on the responses of builders and building professionals to the growing policy focus on low-carbon housing refurbishment. Due to the paucity of information on the supply side of housing renovation, the team of researchers at the University of Oxford and the European energy efficiency research centre (ECLEER) of Electricité de France (EdF) designed the project as exploratory rather than explanatory research. It aimed to raise questions, rather than produce answers. The project team sought to understand how the need for low carbon refurbishment might change the roles of building professionals and their interactions in the future. It also wanted to learn if and how existing professions in Britain and France were developing to meet the challenge. A number of previous papers examined various aspects of these issues. For example, [11] provides a comparison of policy and energy systems between the UK and France. The authors of [12] discuss the theoretical basis for the project and provide an exploration of how refurbishment in the UK could change; [13] focuses on one case study from each country; [14] discusses the results of a UK "Superhome" survey and interviews with householders. The current paper contributes to the larger body of Building Expertise work by focusing on industry responses to the low-carbon refurbishment agenda through a "middle-actor" lens, as discussed below.

In both the UK and France, housing refurbishment is the preserve of small and medium-sized enterprises (SMEs) which include general builders, specialist builders (e.g., roofing contractors), plumbers, heating engineers, electricians, architects, design engineers, project managers, and building control inspectors. These groups are often considered to be "intermediaries" in the technology adoption process, and as such are expected to provide low carbon refurbishment if their clients demand it and if it is mandated by law. However, these groups have their own habits, practices, ways of thinking about problems, and ways of working that affect their ability to provide (and interest in promoting) low carbon refurbishment. This effect has been identified in supply chains [15], property agents [16], chartered surveyors [17], builders [18,19], and architects and engineers [20,21]. Therefore, Janda and Parag [22,23] identify building professionals as "middle actors" rather than intermediaries to call attention to their active role in the supply chain. They describe how a range of different middle actors foster their own forms of innovation from the "middle-out" rather than reacting blindly to policy push from the top-down and market pull from bottom-up. They show how building professionals effect change *upstream* to top actors (e.g., policy makers), *downstream* to bottom actors (e.g., homeowners and clients), and *sideways* to other middle actors (e.g., other builders and participants in the building supply chain) (see Figure 1). The sideways dimension is of particular interest when considering how different actors in the building industry perform their roles and what level of expertise and authority they might need to fully participate in a low carbon refurbishment regime. Following Parag and Janda [22,23], we propose a "middle-out" approach as a complement to (rather than a replacement for) "top-down" and "bottom-up" strategies.

Figure 1. Middle-out approach to change: directions of middle-actor influences [22,23].



The paper begins by describing the project's overall research approach and the subset of methods used in this paper. Next, we present two country-specific sections that summarise key policies in France and the UK and describe some of the more noteworthy "middle actor" industry initiatives encountered during the research. Each country-specific section concludes with two case studies of innovative refurbishment business practices. Once the four case studies have been introduced, we discuss their implications relative to a "middle-out" perspective and highlight additional topics which have either been raised by interviewees in both countries or deduced by the research team. Based on this evidence, our conclusions consider what new research topics are needed to assist the community of researchers, practitioners and policy-makers seeking to increase the uptake of energy efficiency and CO_2 emissions reduction strategies in the existing housing stock.

2. Research Approach

This section describes the reasons behind and benefits of our international comparative approach, the theoretical basis for the study, and our methodology and methods.

2.1. Why These Countries?

The choice of countries arises from the fact that funding for this project was provided by the UK's Engineering and Physical Science Research Council (EPSRC) and EdF through a joint research programme on "People, Energy, and Buildings." The UK and France are roughly similar in a number of ways: in terms of the size of their populations, the total size of their housing stocks, and also in the broad pattern of tenure. Where they are different is in the mix of built forms, with more detached houses and flats in France; more semi-detached and terrace (row) houses in the UK. The two countries also have rather different fuel mixes for domestic heating. The simultaneous exploration of the role of "building expertise" in two countries allowed for various forms of comparison, particularly in the realm of policy [11]. The work uses international comparison as a means of "questioning national assumptions and the framework of policy debates" [24].

2.2. Theory and Application

The Building Expertise project uses a theoretical approach derived from Andrew Abbott's "system of professions" theory [25]. Through this frame, we see the task of low-carbon housing renovation as a new "jurisdiction" or domain of workplace activity, which is contested by different professional groups seeking to claim it as their own. This perspective is useful because many of the roles played by professionals and trades in France and the UK are essentially the same (e.g., electrician). There are, however, notable differences. For instance, there is no exact British equivalent of the French *bureau d'étude thermique* (BET). On larger projects, this French profession has the role of thermal energy design consultant, responsible for calculating heat loss, heat demand and specifying heat supply technologies. In the UK context this role is diffused: our research in the UK shows some or all of the French BET role being played by architects, engineers, energy consultants, heating engineers and general builders. Linguistic differences also exist. For example, the French *ingénieur* necessarily connotes a professional who possesses a university degree in engineering, whereas the British *engineer* may be either someone who holds a university degree or someone with a vocational qualification—as in the case of the role of a *heating engineer*. The extent to which these designations represent real differences of skill and knowledge is impossible to say based on our exploratory study. However, the notion of contested jurisdictions allows for the evolution of working practices to be investigated in a way that fits within a broader framework guided by the socio-technical systems (STS) literature [26,27].

STS posits that technologies have behavioural aspects and behaviours have material/technological aspects. From this perspective, innovation and change require the co-evolution of both new technologies and new social practices. The term "behaviour" in much energy-related research refers to the social practices of building occupants, but we focus instead on the working practices of those who make a living from making physical alterations to existing buildings: the builders involved in repair, maintenance and improvement (RMI). The artefacts involved include the pre-existing buildings and the products and technologies that can be installed in buildings to improve their energy efficiency and reduce their CO_2 emissions. This research approach to Building Expertise is described in several previous papers [12,28,29].

Product innovations should not be discounted or ignored in the discussion of how to make low-energy housing refurbishment mainstream, but nor should the focus rest solely on new technologies to solve the problem. Indeed, the fact that advanced refurbishments can be achieved using existing technology suggests that the task of retrofitting housing stocks should be considered a market breakthrough problem, not a technical breakthrough problem [30]. It is also worth considering what is meant by "innovation" in this context. In many cases, "innovation" is used as a synonym for "new technology", but here it is taken to include novelty in three domains: products (technology), practices (customary ways of doing specific tasks) and processes (the organisation of all the tasks involved in a project) [31].

Barrett *et al.* [32] and others [33–35] additionally argue that innovation in the context of project-based service industries means "not what is new per se, but what is new to the firm". This understanding of "innovation" helps explain why even well-established products may have only a small market share if they are not embraced by the mainstream practices and processes of the industry. If we wish to increase adoption of technologies (old and new), it helps to understand the working practices of those we are calling upon to do the installation work.

2.3. Methodology and Methods

Our research is exploratory in nature and does not claim to be comprehensive or representative. We deliberately seek to understand innovative practices as a means of prompting new topics for debate, not as a means of finding ready-made solutions. The fact that innovators can be found in this field is not an indication that the mainstream is about to change. However, the innovators have to operate in the same policy and cultural context as mainstream incumbents, and their innovations can provide insights for industry strategy and policy-making. To clarify the ways in which the work practices of innovators have changed and are changing to accommodate a low-carbon agenda, the Building Expertise project studied building professionals on three levels: the micro (immediate work context), meso (system of professions and industry context), and macro (socio-cultural environment). The case studies in this paper focus mainly on the micro (firm) and meso (industry) level; the macro level is represented by a brief discussion of policies in place in both countries. The policy context is discussed in greater detail in a previous paper [11].

We use a case study method, which is appropriate when the research focuses on contemporary rather than historical phenomena, and when the researchers cannot control the events as they could in a laboratory setting [36]. Due to financial limitations and the difficulty of reaching the target population, our project has addressed only a small number of innovations and innovators in both countries. However we have increased the efficacy of these cases by making observations at different levels of analysis [37], and by using multiple methods [38]. Mindful of the need to triangulate, the case studies presented here rely on various combinations of document review, individual in-person or telephone interviews, interviews with multiple participants in a group process, and observations of group interactions, workshops, and conferences. Most in-person interviews were recorded and transcribed. French interviews were transcribed in French; portions of these have been translated by a bilingual team member for inclusion in the results.

Our project collected data from a variety of (sometimes overlapping) sources: 34 interviews that were recorded and transcribed (24 in the UK; 10 in France); numerous site visits with field notes; unrecorded discussions and meetings with practitioners and stakeholders to help us understand innovative industry initiatives in both countries; literature reviews and ongoing monitoring of relevant policy developments; and a small number of interactions with householders living in renovated homes to help us understand the (perceived) benefits and problems from the end-user's point of view. In this paper, we focus on a subset of our data: two cases of innovative practice in each country that focus on innovative business models. Table 1 provides a synopsis of the data collected that construct each of the four cases.

Table 1. Building expertise case studies: data from innovative businesses.

France	**UK**
Case F1:	**Case UK1:**
Cooperative Retrofit Company—Energy Performance Guarantee • 5 recorded & transcribed interviews (#11–15); • Additional discussions with EdF commerce.	Large Social Landlord—Retrofit Work Force Innovation • 8 recorded & transcribed interviews (# 22–29); • 6 additional interviews; • Attended conferences organized by landlord.
Case F2:	**Case UK2:**
Small business—Integrated Approach to Retrofit Project Management • 1 recorded & transcribed interview (#32).	Microbusiness—Brokering Scheme for Green Deal • 2 interviews (1 recorded & transcribed) with same interviewee (#34); • Attended talks given by interviewee; • Participation in industry working groups.

In case study research, cases can be made or found; they can be objects or conventions depending on the case conception and unit of analysis [39]. As Table 1 shows, each case in our analysis contains different types and clusters of data, and each case is framed around a pre-existing central business idea or specific work scheme. The unit of analysis is the business scheme, not the individual interviewee. For this reason, we do not count individual perceptions (e.g., pro-environmental builders) or calculate the impact of different professions (e.g., carpenters, plumbers, roofers, plasters) in each model. Some cases have more interviews than others because there are more people involved in larger firms. This does not mean that the quality of the case study research at smaller firms is less robust.

3. Innovative Renovation in Professional Practice: France

This section sets the policy, industry, and work context for findings from our two French case studies; the following section describes the policy, industry, and work context for findings from our two UK case studies. After the cases in both countries have been introduced, we provide a comparative discussion of the importance of these cases from a "middle-out" perspective.

3.1. Macro Level: French Eco-Renovation Policy Framework

The long-term strategic policy framework for France is provided by the "environment roundtable" (Grenelle de l'Environnement), which calls for a fourfold reduction in energy consumption by 2050 across the entire economy. One significant enabling policy is consistently identified by interviewees: the zero interest "eco" loan (éco-prêt à taux zéro, abbreviated as PTZ). The introduction of the PTZ in 2009 was largely a response to the limited improvements being made to the thermal envelopes of buildings through the system of income tax credits for sustainable development (crédits d'impôt développement durable, abbreviated as CIDD), introduced in 2005. In the early years of the CIDD the eligibility criteria for supported measures did not change in response to the different speed of change in different markets, which meant that nearly half of credits went towards window replacements in 2007 (85% of windows on the market being eligible). In contrast, only 5% of CIDD expenditure contributed to wall and roof insulation. The rules were changed in 2007, effectively tightening the standards for eligibility of windows under CIDD. The PTZ has a different structure. To qualify for the loan there are two routes: one based on packages of measures and one based on a design standard. To qualify for the loan via the package-based route two or more work packages must be undertaken from a prescribed list:

- High-performance roof insulation;
- High-performance wall insulation;
- High-performance windows and doors;
- Installation or replacement of a system for space heating or hot water;
- Installation of thermal renewable energy technologies for space heating;
- Installation of thermal renewable energy technologies for water heating.

Alternatively, the loan can be used to pay for improvements achieving a design standard for the whole home, with the required standard post-works being based on a modelled assessment of energy demand pre-works. Thus, where modelled (primary) energy demand pre-works is over 180 kWh/m^2-year, the qualifying standard required in order to be eligible for the loan is 150 kWh/m^2-year (also modelled and in primary energy). Where the modelled energy demand is below 180 kWh/m^2-year, the qualifying standard is 80 kWh/m^2-year.

Under the PTZ scheme 150,000 loans had been made by the end of 2010 (against a target of 200,000) but numbers have fallen away since the rules were changed, effectively disallowing the use of both CIDD and PTZ on the same project.

France also has a feed-in tariff (FIT) for microgeneration technologies, such as solar photovoltaics (PV). But the tariff arrangements are not linked to policies and programmes designed to improve energy efficiency.

3.2. Meso Level: French Building Industry Practices and Innovations

In France there are two accreditation schemes for skilled practitioners, each supported by a different trade association: the "éco-artisan" scheme, supported by the Confédération de l'Artisanat et des Petites Entreprises du Bâtiment (CAPEB); and the "pros de la performance énergétique" scheme, supported by the Fédération Française du Bâtiment (FFB). France has pioneered the QualiBAT voluntary training programme for building-related trades, and two programmes for microgeneration and low-carbon conversion technologies (QualiEnR for renewable energy and low-carbon technologies; and QualiSol for solar installations).

Within this context, there are a number of industry responses and innovations. For example, the firm Pouget has developed a multi-skilled method for insulating the interior of cooperatively-owned blocks of flats. This multi-family living arrangement poses a collective action problem, as all flat owners would have to jointly agree to pay to upgrade the exterior of the building to insulate it externally. Individual flat owners could decide independently to insulate the interior of their own flat, but hassle and disruption of internal building works could be a barrier. Pouget offers an innovative service that minimizes this hassle by taking detailed measurements in one site visit, cutting materials offsite, and using multi-skilled workers to complete the installation. Their quick fit internal insulation installation takes only 10 h to complete on site and raises the energy rating from an "E" to a "C" [40]. This process is similar to United House's award-winning "Whole House *In-Situ* Carbon and Energy Reduction Solution (WHISCERS)" innovation in the UK [41]. This is a "middle actor" innovation which could not have been "demanded" by customers nor mandated by government. As such, it has *downstream* effects by giving potential customers a new choice of how to insulate their properties. Below, we provide two more examples of industry innovations from our research case studies.

3.3. Micro Level: Case Studies in France

Case studies in France were selected by a snowball sample. EdF partners advised on innovative housing projects recently completed or underway, and researchers from Oxford and EdF explored these leads.

3.3.1. Case F1: Retrofit with Energy Performance Guarantee

One innovative business model in France has been explored through discussions and 5 recorded interviews with co-op members, founders, and affiliates (interviews #: 11, 12, 13, 14, 15), and numerous meetings and discussions with staff from EdF Commerce, which has provided start-up capital and ongoing technical and managerial assistance. The venture is an SME with a co-operative governance structure offering guaranteed performance contracts to clients for its refurbishment services. This model was new at the time of the research, aiming to start with 15 renovations in the first year and 35 in the second year, so as to allow time for learning and making any necessary changes to the systems before extending the client base. The company is run by its founders with the assistance of consultants for certain kinds of office support (e.g., information technology and marketing).

A central technical function uses bespoke modelling software to generate a predicted energy performance based on the design standard of the renovation works and a detailed list of energy-using behaviours (occupancy, internal temperatures, washing and cooking habits, *etc.*). These parameters—both technical and behavioural—are used to create an energy performance standard, which underpins the contract between the client (resident) and the co-operative (renovation service provider). Then, should energy consumption fail to meet expectations, a review of contractual obligations on both sides is carried out. If the contracted behaviours are being honoured by the occupants, the contracting firms are deemed to be at fault and take responsibility for rectifying the renovation work or reimbursing the client. If, on the other hand, the contracted behaviours are not being honoured by the occupant (for example, if a family member or friend has come to live in the home since the contract was drawn up), then the new occupancy pattern is modelled, and a new contract is drawn up. Ongoing monitoring systems (temperature, humidity and CO_2 sensors updating data on a constant basis) allow the co-operative to notice atypical energy use patterns or other signs that might require remedial action. So, a sudden drop in CO_2 concentrations in the indoor air would suggest that a window has been opened and, if this continues over a long period, the monitoring system is able to send an automatic text message or email to the client asking them to check.

The contractors doing the refurbishment works are all members of the co-operative, as are the clients. This structure is designed to maintain a balance of voices in the ongoing development of the organisation—both operationally and strategically. Start-up finance for the co-operative was supplied by EdF. However the co-operative governance structure ensures that control is not in the hands of a single large share-holder, but is shared between all, regardless of the size of each financial stake.

For contractors, co-operative membership is conditional on key personnel being trained under the Eco-Artisan programme. The contractors themselves operate a form of quality control through regular review meetings, in which any concerns about the quality of a member firm can be discussed and action taken. Ultimately, the co-operative has the right to throw out any member who consistently fails to meet the commitments of the contractors' charter, although the preferred course of action is to raise the quality of such members' work through encouragement and training.

From a middle-out perspective, this case has implications for reconfiguring *downstream* relations with clients, as well as *sideways* impacts on how the co-op itself develops, including who is "good enough" to participate. It also has elements in common with the "energy services company" (ESCo) concept. The domestic sector, however, is thought to be the "hardest market for ESCos to break into, especially in the short term" [42].

3.3.2. Case F2: Integrated Approach to Retrofit Project Management

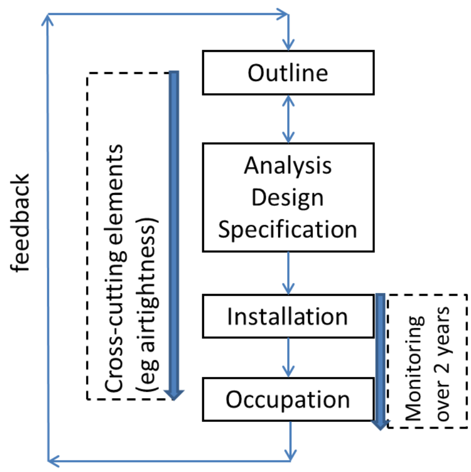
This case is based on an interview with the senior consultant engineer (Interviewee #32) in a small firm (approximately 30 employees, but growing), providing thermal energy design services (covering strategies to reduce thermal energy demand as well as specifying systems to meet that demand): a BET. This particular BET has wide experience of multiple low-energy projects. This experience has led them to conclude that there is a need for: (1) an integrated approach to project management, including the oversight of cross-cutting elements of the refurbishment work (such as achieving airtightness standards); and (2) a mechanism for feeding back monitored energy data from the occupation stage of one project to the inception and design stage of the next. Interviewee #32 drew a diagram of this approach freehand during the interview, which has been translated into English and redrawn (Figure 2). Cross-cutting elements and feedback loops for learning are not common practice, but the technical requirements of achieving real low-energy renovations (as opposed to modelled outcomes) make both of these new practices essential.

In explaining the need for this management model, the interviewee (#32) commented:

"Each project is unique. Clients tend to think a renovated building is like a new car, with everything working perfectly and all you have to do is turn the key and off you go. But it's never like that. For any big or medium-sized project you need at least two years for monitoring, adjusting, optimising. And that's the thing that no-one does, that no-one has responsibility for. No-one is willing to pay for it."

This model is innovative, but as yet untested. From a middle-out perspective, this BET engineer wants to have a *downstream* influence on potential clients. Ideally, he wants to convince clients to pay for a service that they need but do not yet recognise. He thinks monitoring is necessary and makes sense, but he has yet to sell it to a potential client. This is an area where *upstream* inputs to policy might help to create the market conditions that #32 envisions as necessary.

Figure 2. Management model for design—construction—operation proposed by the bureau d'étude thermique interviewed (#32).



4. Innovative Renovation in Professional Practice: UK

This section moves from France to the UK, providing information on the policy, industry and work context of our case studies in Britain.

4.1. Macro Level: UK Eco-Renovation Policy Framework

The UK is in the process of moving away from a system based solely on energy company obligations ("Carbon Emissions Reduction Target" in their 2008–2012 form) which delivered high numbers of low cost individual energy saving measures. The new system retains an element of the (renamed) Energy

Company Obligation (ECO). In addition, the "Green Deal" (GD) was introduced in January 2013 as a major regulatory innovation to instigate "a revolution in British property" which will put "consumers back in control" [43] (p. 10). The GD is an on-bill financing method by which the duty to repay capital is attached to the property through utility bills, rather than to a person. A key feature of the GD is the "golden rule", by which the (modelled) energy savings achieved over 25 years must be equal to (or greater than) the costs of investment [44].

The UK's FIT for PV, the most widely adopted small-scale renewable energy technology, was revised in April 2012 to make an explicit link between energy efficiency and renewable energy for the first time. The revised tariff is now higher for installations in homes which are rated D or better on the Energy Performance Certificate. Homes with a lower rating can still get the FIT, but at a lower rate per kW ħ generated [45]. In France, as noted previously, the FIT level is not linked to energy efficiency.

4.2. Meso Level: UK Building Industry Practices and Innovations

If we follow the logic that the kinds of innovation needed in this service market are related to practices and processes as well as products; and if we accept that the important measure of "innovation" in this context is that it is new to the firm, not necessarily "new" per se, then an important first step is to understand what current practices and processes are. The UK construction industry as a whole (not just the residential RMI sub-sector) has published its own reviews in the last twenty years, led by recognised leaders—first Sir Michael Latham in 1994 [46], then Sir John Egan in 1998 and 2002 [47,48], and most recently Andrew Wolstenholme in 2009 [49]. The second Egan review characterised the construction process as "a series of sequential and largely separate operations undertaken by individual designers, constructors and suppliers who have no stake in the long term success of the product and no commitment to it" [48] (p. 13). The most recent report summarised the impact of the earlier reviews as "skin deep" [49] (p. 4), with many of the issues highlighted by Egan still very much in evidence. The following case studies of innovative practices and processes should be read in the light of this rather bleak assessment of where the industry currently stands.

Although the industry as a whole may not be innovative, there are certainly niches where change is occurring. For example we note an effort made by B&Q, a large UK DIY retailer, to increase the level of loft insulation. B&Q's initial interest was prompted by the anticipated growth in demand under Green Deal, so they conducted their own market research and trials on a small scale. Working in partnership with the UK cabinet office's "behavioural insights team" (often called the "nudge" unit, after Thaler and Sunstein [50]), they discovered that the key impediment to loft insulation was clutter, not cost. In a trial, homeowners were offered "subsidised loft clearance" instead of subsidised insulation—with unwanted items being taken to local charity shops—on the condition that they got the space insulated as part of the process. "The scheme cost people more, but they loved it, and uptake rates tripled" [51]. Again, this is a case of a solution being offered by middle actors —in this case in partnership with government—that clients would not have demanded nor policy mandated. The connection between B&Q and the cabinet's "behavioural insights team" points to the upstream connections that a large middle actor can develop. We provide two more examples of middle actor industry innovations below from our research case studies.

4.3. Micro Level: Building Expertise Case Studies in UK

4.3.1. Case UK1: Social Landlord Retrofit Work Force Innovation

Case UK1 was found during the course of the research. It features a social landlord with 16,000 properties, who sought to undertake a series of 36 low-carbon retrofits of near-identical houses in southern England. This work was supported by European Regional Development funding. As part of this agreement, the social landlord held public conferences to disseminate lessons learned from their retrofit process. Oxford researchers attended two of these conferences and followed up with contacts to set up interviews with the trades and workers.

This particular landlord has an in-house repair and maintenance team, many of whom have been with the organisation for many years. These tradespeople therefore have a lot of shared history. Fourteen of the team members involved in this work were interviewed (8 were transcribed, interviewees #22–29), in order to build up a picture of their different accounts and experiences.

As might be expected, the work became faster and more efficient as the team grew in experience. This learning process was facilitated by an early decision to renovate an initial four properties as a kind of test-case. The aim was to learn from mistakes as much as possible, with the added advantage that it would be easier to manage the temporary re-housing of tenants from the other properties if a small number of homes were ready to be occupied before new works got under way.

Early on, the site manager was found to have insufficient experience and organisational skills for the project, so the task of site management was passed on to a more experienced colleague who was a qualified architect. A site office was set up on-site so that problems could be reported and resolved quickly. A three-person site management team was found to be very effective, with three areas of responsibility: supervision of the team of tradespeople; advocacy of the needs of the landlord client in terms of budget, specification and quality control; and engagement with tenants to ensure good communication between residents and the on-site team. Interviews were conducted with the site supervisor and the client advocate, but it was not possible to interview the tenant liaison officer.

A system of financial incentives was introduced by the site supervisor to promote efficient working, based on a bonus scheme, which was to be shared by all operatives on a pro rata basis. Thus, wherever a task was unfinished, those without enough work to do at that point in the project in their own area of skill and expertise were expected to help out. In this way, carpenters might find themselves doing work for plasterers, or *vice versa*. In fact, the task of external wall insulation was the one where this system of teamwork was most noticed, both because of the quantity of work involved and because of the hard physical nature of rendering outside walls in cold weather. This practice of “multi-skilling” was remarked on by many in the team as being unusual and innovative, and many commented that it was only workable in this case because the individuals had a long history of working together for the housing association, which meant that they knew one another, trusted each other’s skills and knew where best to deploy each person in the team in order to play to the strengths of each. Where two people had worked for a long time in a team, one interviewee likened the relationship to being in “a couple”, managing the division of labour quite meticulously so that each one did the tasks which they enjoyed and were best at:

"It's like any couple, one person in the couple is more domineering, they like taking charge of doing that. When you work in a team, you know they're going to go and do that side and you'll do this, whereas if you get a new team, you're both wary of each other, what's he going to want to do, what am I going to want to do" (#28).

The process of learning over the course of doing work on over 30 houses led to significant improvements in labour productivity. After the first two renovations had been completed, the whole project was running over-budget: but by the end, significant budget savings were being made, leading to a healthy level of bonuses for the team.

The demands of the low-carbon renovation itself led to unforeseen practical problems. The most striking of these was the negative impacts on the health of two plasterers, whose elbows became painful through prolonged periods applying render to wall insulation. A special mechanical spraying device could have been hired but the decision was taken to apply the render by hand in order to save money.

Other problems emerged too, which required on-the-job solutions. For example, where residents had satellite television dishes on the outside of their home, a means had to be found to re-attach the dish through a 150 mm thickness of insulation without compromising the weather-proof properties of the render and with minimal loss in performance through thermal bridging. This type of on-the-job challenge resulted in frequent "skip meetings" where the workforce downed tools in order to talk through how best to resolve issues as they arose. The organisation of the team was characterised by good communication, shared responsibility and a collective focus on finding practical solutions. Moreover, a number of the workers (#22, 26, 28, 29) showed a new interest in understanding why these renovations were undertaken and how effective they were. At the behest of management, a Building Expertise team member gave a seminar on project findings to the workers. From a middle-out perspective, the findings from this case could be replicated *sideways* in other large firms with in-house RMI departments.

4.3.2. Case UK2: Brokering Scheme for Green Deal

The originator of the brokering scheme discussed in Case UK2 was known to members of the Oxford research team as an industry innovator prior to the project's start. He is one of the UK's "retrofitterati", a rather small group of experts who frequently participate in events on energy retrofits and eco-refurbishment (The term "retrofitterati" was coined by one of the other members of this group). In Case UK2, we discuss this interviewee's most recent industry process innovation, but this is one innovation among many over time.

Many of the SMEs in the construction industry have, through their trade associations, identified low-carbon renovation as an economic opportunity for SMEs (see, e.g., [18]) but many also perceived that the bureaucratic requirements of the GD would be too large a burden for many smaller firms. There was a concern that the GD would attract larger corporations who would fulfil the administrative functions to satisfy government (e.g., accreditation of installers, certification of works, form-filling for finance and monitoring purposes) and then pass on the practical work through sub-contracting to SMEs. The drawback of this arrangement from the SMEs' perspective is the drop in profitability of working with a corporate "middle man" compared with working autonomously.

In response to the GD, a new brokering scheme has been extensively debated in a series of industry working groups. This process has been led by the founder of a start-up company, which has managed several home renovation projects, carried out stock surveys for social landlords, devised and conducted training courses on eco-renovation, and been active in policy debates. The originator of the brokering scheme idea (#34) was interviewed for this research, and two industry working groups were observed.

The brokerage scheme is designed to allow the SMEs themselves to club together in a co-operative structure, fulfil the "middle-man" role collectively through shared "back office" functions, and thereby secure a greater share of the profits from GD work for themselves. Much of the discussion around the detail of this proposed scheme has focused on finding a fair and effective means of allowing firms flexibility in how they respond to requests for work ("leads"). This debate has boiled down to designing a scheme that gives its members three choices when they first receive a lead: to take the work on entirely by themselves; to do part of the work themselves but engage other firms to carry out certain specialist tasks; to pass the lead on to the brokering service in return for a finder's fee, thereby giving other members the opportunity to carry out the work.

The model for this new venture is a co-operative owned by small companies, designed to allow for flexible and efficient sharing of business opportunities. The co-operative allows SMEs to compete for more ambitious projects by providing a pool of specialist firms to call upon and technical support services for energy-related issues. The co-operative's technical service department also provides an independent energy assessment service to customers, which is not tied to any particular installer organisation. The idea is to give the small businesses who are already talking to homeowners about refurbishment projects the support needed to "upsell" those projects to include energy efficiency measures and low-carbon technology options.

The co-operative structure is open to other types of organisation besides construction, who are not themselves able to provide the renovation service, but who are well placed to find property owners who want the service on offer (e.g., local authorities, community groups). In the proposed model such organisations could then pass on these potential customers in return for a finder's fee. All co-operative members are expected to use shared branding and consistent information to help build consumer trust. In addition to providing "back office" functions to satisfy the administrative demands of the GD, the co-operative provides two key technical services: (1) an assessment methodology to show people (householders) their options; and (2) training courses for the supply chain.

The training courses cover "everything that a building tradesperson needs to understand about how to upgrade buildings—the design and the installation" (#34). This is a set of skills which is not yet the preserve of any recognised profession, but it matches quite closely what the World Business Council for Sustainable Development have termed the "system integrator" role [1]. According to this interviewee (#34) the key attributes for this job are:

- Ability to control budgets;
- Good understanding of design;
- Very wide but shallow knowledge (with recourse to specialist assistance when necessary);
- Good people management skills ("getting people to do stuff that they don't really want to do necessarily").

The point about only needing a shallow level of technical knowledge is worth unravelling further. What it suggests is that an experienced project manager can operate effectively on low-carbon projects without being an energy expert (so long as more expert advice is available). However, the reverse is not generally true: an energy expert with deep technical understanding but shallow project management skills cannot operate successfully on these projects. When questioned further about the essential characteristics of a low-carbon refurbishment project manager #34's answer was: "it's about managing the interfaces". And in this context "interfaces" means:

- efficient organisation of resources, for example communicating with other contractors to make best use of scaffolding;
- being a responsible professional, doing things that will help other trades who follow, or communicating with those who go before so that the hand-over from one person to the next is efficient.

In contrast with the French co-operative (Case F1), this brokerage scheme stops short of offering energy performance guarantees, based on the judgement that contractors would not feel willing to expose themselves to the risks of failure. Instead, the model contracts promise "best endeavours" on behalf of the contractors, but not actual results in terms of energy performance.

The need for a project manager can easily lead to the assumption that this will entail additional cost to the project, but #34 put forward the opposite argument, based on several years' experience working on these projects and being involved in training tradespeople: "[having a project manager] makes the job easier and cheaper … we need these project managers on site to make these things happen. On every job I think they would pay for themselves." More fundamental to the question is the tiny pool of currently available talent: "my worry is I don't think there's more than about 20 people in the country who can do that project management job well."

This industry innovation came about as a direct result of the new Green Deal policy being announced, but the process of cause and effect between the new policy and industry innovation is far from straight-forward. The high interest rate on Green Deal finance—which varies with amount and loan term, with examples between 7.9% and 10.3% annual percentage rate (APR) when annual finance charges are included [52]—has been a regular source of comment and concern. Interviewee #34 was quite sanguine about that, however, and described the new policy's effect in terms of being a "wake-up" call to the SME construction sector.

"I actually think [the brokering scheme] will do more work outside the Green Deal than inside […] but the Green Deal is the current panic that will get everybody joined up. […] in other words most of the homeowners who [use the brokering scheme] won't need the Green Deal finance. I think they just want good contractors who understand eco stuff […] they just want a good supply chain. They want an assessment done."

The recent change in feed-in tariff rules has led to some PV installation companies beginning to do energy performance certificates (home energy labels) in-house, and some are also doing loft insulation, so that the D rating can be achieved. The policy "push" is not necessarily welcomed whole-heartedly by the industry, but it does help stimulate innovative new ways of working. As #34 put it: "quite a few of the PV guys don't want to do loft insulation, but they want to find a mate who does and the "brokering scheme" can help them do that in any area of the country." The change in FIT tariff rules has received far less industry attention than the Green Deal, but according to interviewee #34 its effect is beginning to be seen in new practices and processes: "It has slipped under the radar. No one really complained about it. It's a subtle thing but now we are beginning to see whole-house retrofit emerging."

From a middle-out perspective, Case UK2 has implications upstream, downstream, and sideways. *Upstream* implications include the fact that the Green Deal is not configured in a way that enables the structure of the RMI market to participate. *Downstream* implications include making it easier for clients to find the services they want from a wider pool of talent than they might otherwise find working with a single contractor. *Sideways* implications include the emphasis on greater levels of project management than are typical in small projects, with an eye towards further work in the future.

5. Discussion: British and French Builders as Middle Actors

The previous two sections articulated findings at the macro, meso, and micro level within France and the UK. This section summarises and discusses the micro-level middle-actor results across both countries (see Table 2). First, it examines the extent to which the case studies are "French", "British" or context-independent. Next we discuss themes evolving from the research that show how builders could foster (or inhibit) change from the middle-out.

Two of the research cases (F1 and UK2, shaded in Table 2) are relatively "special" responses to the country-specific broader policy context. The energy performance guarantee business model in Case F1 might not find a market without the policy and financial support in the form of zero-interest loans in France for ambitious low energy renovation. The F1 business model *should* be able to work in the UK for people who are funding their own ambitious renovation, such as Superhome owners. However, there are only 180 recorded Superhomes across the UK [14,53], which suggests the current UK market for self-funded ambitious renovation might not be large enough to support the F1 model. Similarly, Case UK2 was prompted by Green Deal, even though the founder (interviewee #34) sees it as useful for other reasons. It also shares some structural aspects with F1, in that it is a co-operative of SMEs that provides shared administrative functions. In both these cases, country-specific policy contexts prompted business practice innovations; however, the shape of these innovations relates to industry structures common across both countries.

In contrast, the other two case studies (F2 and UK1) are not responses to national carbon reduction policies. Case F2 is an innovative idea about how a BET should be run. To some degree, this case is specific to France because Britain does not have BETs. But the two innovative elements—optimising work practices between projects and learning from them over time—are generally applicable to middle actors in the UK building industry, including the various architects, engineers, energy consultants, heating engineers and general builders who provide the BET role for British projects. Although Case UK1 responds to a specific EU research project opportunity, it is not a direct response to a particular policy measure. Instead, it is a practical response to the need to motivate an in-house labour force to work in unfamiliar ways. The generalizability of innovations in Case UK1 applies mainly to large organisations with in-house RMI labour forces, such as other social landlords, rather than the bulk of the RMI labour market, which is composed mainly of SMEs. The learning outcome for UK1 is the same as for Case F2: to advance the field, workers on the supply side of housing renovation need to better understand not just how to change products, practices, and processes, but also the effects these changes have on building performance, particularly over time.

Table 2. Building Expertise Case Studies: Implications of Innovative Businesses Models.

France	**UK**
Case F1:	**Case UK1:**
Cooperative Retrofit Company—Energy Performance Guarantee • Special to France (aided by zero-interest loans); • Middle-out implications: ○ *Downstream*: requires clients to establish "normal" energy use patterns for their homes; ○ *Sideways*: other specialists who want to join the co-op must be certified; other new or existing groups could learn from the cooperative approach.	Large Social Landlord—Retrofit Work Force Innovation • Relatively independent of country-specific policies (although prompted by EU-level research funds); • Middle-out implications: ○ *Sideways*: similar groups, particularly those with relatively large labour forces internal to the organisation, could learn from this case.
Case F2:	**Case UK2:**
Small business—Integrated Approach to Retrofit Project Management • Relatively independent of country-specific policies; • Middle-out implications: ○ *Downstream*: would require clients to pay for monitoring over time; ○ *Sideways:* would require builders to learn from the longevity of previous projects; ○ (*Upstream*): would need policy framework to support the need for learning over time.	Microbusiness—Brokering Scheme for Green Deal • Special to UK (response to Green Deal); • Middle-out implications: ○ *Upstream*: policymakers could alter Green Deal to better fit an industry composed of SMEs; ○ *Downstream*: could make it easier for clients to find coordinated services; ○ *Sideways*: other new or existing groups could learn from the cooperative approach; emphasis on greater levels of project management.

Beyond these specific cases, what does Building Expertise have to say about the importance of builders as middle actors in mainstreaming low-carbon housing renovation? Some topic areas relevant to this question have recurred throughout the research process or been deduced by the research team. We discuss these below and relate each to a direction of influence that middle actors have or could have—upstream, downstream, and sideways. Through this discussion, we further show how using a "middle-out" lens to view the building industry illuminates new aspects of change and attendant areas for research.

5.1. Upstream Influences: Implications for Policy

Our research found tensions between technical potential, which is often the focus of policy targets, and market potential, which is what builders can actually get paid to do. These tensions are important to note because it means that middle actors can potentially disable policy targets in various ways. Some innovators with a good technical understanding of issues like thermal bridging and whole-home ventilation systems have forged ahead with more advanced building energy standards, and in many cases these efforts are supported by policy and modelling studies. However, the most advanced standards are only possible with meticulous attention to detail and excellent quality control. They may be achievable at scale in the future but the doubts about industry capacity that we have encountered when carrying out this research suggest that a much more concerted effort is needed to build skills, knowledge and experience of workable solutions across a wide range of industry actors. The insight that monitoring results from pioneering renovation projects needs to be fed back into the next round of projects is not new, but the case still needs to be made for this important work, as the interviewee in Case F2 emphasised, and as the Building Expertise team found in Case UK1. Despite its importance, we have not found any evidence of systematic learning from monitoring and evaluation projects. Killip [54] suggests that these feedback mechanisms are of crucial importance to a model of market transformation that is adapted to service delivery (such as home renovation) rather than the more familiar application in product markets (such as fridges and washing machines).

Such advanced standards are also only technically achievable when the project is done in one go as a whole-home renovation, rather than using “over time” approaches, which can achieve slightly less ambitious technical standards in a room-by-room approach [55]. The “over time” model is arguably more in tune with market demand, which is for projects at a smaller scale than “whole-home”, such as new kitchens, new bathrooms and decoration [56]. These tensions between technical and market potential have been addressed in different ways by some of the innovators we have met. While some have chosen to specialise in only providing a “whole-home” service to a high technical standard, others offer an “over time” approach as well, with the innovation of an assessment report and home-specific renovation plan which home-owners can refer to in future home improvement projects.

These tensions are important for policy makers and evaluators to understand. If they expect to achieve instant technical potential through high-quality whole-home renovation but the market delivers variable quality renovations piece by piece over time, a significant lag will occur between expected and actual CO_2 reduction. Resolving these tensions will require further negotiations between top and middle actors.

5.2. Downstream Influences: Implications for Customers

5.2.1. Low-Carbon Refurbishment as “Up-Selling”

In France the zero-interest loan system is viewed by some contractors as a good vehicle for “up-selling”—recommending larger packages of energy interventions than usual—because the additional service is available at no additional cost to the customer. The availability of finance helps the contractor in Case F1 present low-carbon refurbishment as an opportunity to be taken, rather than as a set of barriers to overcome.

In a similar way, the proposed brokering service for SMEs in the UK (Case UK2) aims to create a home refurbishment plan for each property, highlighting which low-energy interventions are needed and guiding customers towards considering when best to carry out those interventions, based on the concept of “trigger points” [57]. Thus, where a householder is considering, say, a new kitchen, the home refurbishment plan provides a checklist of interventions to consider at the same time as having a new kitchen fitted (e.g., wall and floor insulation, ventilation).

5.2.2. Low Carbon Refurbishment and Behavioural Control

The need to account for variation in occupant behaviour is well recognised by industry respondents. There has long been a debate about how to reconcile the need for physical interventions in buildings with the need also for behaviour change by occupants. This boundary of responsibility has always appeared difficult to resolve. It is too early to tell whether the French model with guaranteed energy performance contracting (Case F1) will work in the residential sector; or whether the British model of brokering with the promise of "best endeavours" (Case UK2) can make enough of a difference, when so much of energy consumption relates to the choices and practices of building occupants. Tackling these problems at multiple levels is an intrinsic difficulty of the task of achieving genuine reductions in energy consumption and CO_2 emissions from housing stock.

The French policy framework avoids this source of uncertainty and complexity by rewarding physical installations. However, the co-operative model of guaranteed energy performance contracts in France (Case F1) seeks to contractualise the uncertainty and make it the subject of ongoing monitoring and communication. In contrast, the UK model under Green Deal makes energy cost integral to the process under the Golden Rule. It is not clear that either of these approaches will work: the guaranteed energy performance contract requires a very high level of engagement with energy consumption, and so may only be effective with a small minority of consumers. But the Golden Rule under GD may serve to limit activity to only the most immediately apparent cost-effective measures according to a general model of energy use. These measures may not, in fact, be the most cost effective measures for that particular circumstance, since the GD recommendations will not include behavioural modifications.

5.3. Sideways Influences: Implications for Builders and Building Professionals

5.3.1. The Organisation of Project-Based Work

Low-carbon refurbishment represents a profound challenge for industry capacity to deliver, and can perhaps be summarised in terms of integration, communication and risk management. Contractor roles are typically fragmented, each person seeking to minimise their own time on the job and their own exposure to risk. A contractor will tackle a given task with a focus on minimising their own time spent on it, regardless of the knock-on consequences for another contractor working on the same building afterwards. Overcoming this fragmentation and lack of concern for the "whole" is not easy, as it goes against some very deeply ingrained practices. Where there have been calls for the industry to change its culture, this is one of the key areas of concern. It is an issue in the mainstream industry and, where there are low-energy and low-carbon goals to achieve, the technical risks and issues involved make it doubly important.

Two models have been seen to be effective to overcome these issues: the multi-skilled team based on shared tasks, shared risks, and shared problem-solving (Case UK1); and the involvement of an effective "integrator" to manage on-site teams, and provide an important link between the physical work being carried out, the technical demands of the energy targets in the design, and the interaction with the client (Case UK1, Case UK2, Case F1). These two models are not mutually exclusive, however, and the need for flexibility in the varied RMI market may mean that some combination of both approaches will be necessary, depending on the circumstances of each project.

Another innovation observed in this research is the organisation of "back office" services to provide administrative and technical support services. The need for such services is partly brought about by the requirements of policy initiatives (e.g., for training and accreditation, and for securing financial incentives), but that is not the only motivation. Where innovators have practical experience of the technical demands of doing low-carbon refurbishment, the need for a cost-effective form of specialist technical assistance to be available to site managers has led to the development of on-demand help-desk services, providing a model where the more expensive technical expertise is not on site all the time (particularly evident in Case UK2).

5.3.2. Vocational Education and Training

The need for better integration of workers and their tasks, linked to an over-arching commitment to improved quality does indeed require a cultural shift in the building industry. Case UK2 and Case F1 have developed some practices designed to work within specific co-operative groups, but how can such a shift be achieved in the housing refurbishment sector? This question does not have an easy answer. Indeed, an initial reading of the construction management literature suggests that there are deep structural problems. Dainty *et al.* [58] argue that industry fragmentation and casualisation will tend to disfavour investment for skills. For example, the UK's national vocational qualification (NVQ) system has been criticised for its "lack of academic rigour and dilution of technical content" [58] (p. 9). These authors suggest that repeated calls for the industry to change its culture have not taken account of the context within which the industry operates, and have therefore had little effect. Most research done in the name of construction management is research *for* management, not research *of* management, resulting in incremental improvements to the status quo but failing to address the structural failings which perpetuate the overall system architecture. Short-term solutions are found through expedient means, such as increased employment of migrant workers to meet labour shortages.

In the skills arena, a common topic of debate is on how to "innovate away" the skills shortages by turning to increased mechanisation and the need for a residual (low-skilled) workforce to assemble increasingly complex components manufactured off-site. However, this approach has limited success, especially in repair and maintenance, which is intrinsically labour-intensive and hand-wrought.

The question of how to train and educate the workforce to meet the low-carbon refurbishment challenge is one that needs further research and, ultimately, political action. The issue of education and training may prove to be just as intractable as the issue of energy efficiency: the benefits and challenges can be fairly easily identified, but finding long-term solutions is much harder, because of the deeply embedded structural inertia of existing systems.

5.3.3. Professional Boundaries: Responsibility and Integration

If, as has been argued, the prevailing culture in the refurbishment industry is to avoid risk and avoid taking more than a minimum of responsibility, then the call for greater integration both within and between projects raises the question of where the boundaries exist (or should exist) between different areas of responsibility. Such boundaries currently exist at several levels simultaneously: between individual contractors and the tasks that each has to perform; between a project manager and the project team; and between contractors and their clients. These boundaries are familiar, but are they inevitable?

The World Business Council for Sustainable Development (WBCSD) has suggested that the building industry suffers from operational islanding and knowledge gaps between professionals [59]. To overcome this problem, the WBCSD [1] suggests that a new "system integrator" profession is needed to develop the workforce capacity to save energy. The need for such a role is echoed by our research findings, notably in Case F2 and Case UK2. However, an entirely new building profession could challenge the existing shape and nature of the industry. If a forensic approach to renovation were to combine with a scientific approach to project learning, might the "cowboy builders" turn into "building surgeons"?

6. Conclusions and Further Research

From 2010 to 2013, the Building Expertise project conducted research in the UK and France to explore how builders involved in low-carbon housing refurbishment. It contributed a number of papers to the literature (e.g., [11,12,14]) and helped fill the recognised research gap on the supply side of low-carbon housing renovation [9]. This paper used a "middle-out" lens to address four different case studies of innovative business models, two in France and two in the UK. The case studies suggest that some builders innovate in response to carbon-reduction policies (Cases F1 & UK2); others innovate as a response to specific needs they have, either on a specific job (Case UK1) or to make their work more effective overall (Case F2). Through a middle-out lens, all of the cases we studied have implications for innovation *upstream* to policy makers, *downstream* to clients, and *sideways* across the building industry. A major finding of the research is that the building industry itself needs change if it is to deliver the extent and level of high-quality refurbishment required by policy.

Cost has long been considered a barrier to greater energy efficiency, based on cost-benefit analysis of capital outlay on energy-saving interventions *versus* operational energy cost savings. A different kind of cost-benefit analysis is suggested here, in which the costs of greater integration and professionalism in the refurbishment industry might be offset at least partly by the benefits of greater labour and resource productivity. The calculations are both measured in monetary terms, but the input and output variables are very different from what is normally thought of when we talk about cost-benefit analysis for residential energy efficiency investment. It could be that the realisation of energy cost reductions is more intimately bound up with a problem of fragmentation and risk-aversion in the construction industry, which energy efficiency research has tended to ignore. Does the future of energy efficiency research need to expand its remit to encompass labour relations and change management?

While cost is clearly an important factor, it is not the only one. A recurrent and over-arching aspect of our discussions with innovators in the field of low-carbon refurbishment has been the need to ensure quality. "Quality" itself refers to several domains: quality of physical work, quality of design, and quality of communication. There is a tacit agreement among innovators that all of these areas need to be improved simultaneously, and that this task is made very difficult by the prevailing culture of fragmentation in the industry. Similarly, the need for better integration exists at several levels simultaneously. Integration is needed at the interfaces between products and buildings elements; between the traditionally separate roles played by contractors; and between the effects of physical interventions to buildings and the supposed behavioural response of occupants; and between innovations among products, practices and processes. But there is also a higher-level need for better communication and integration between policy, practice and research. This is perhaps best exemplified by the need for feedback mechanisms to allow the monitoring from one project to inform the development of the next. Some innovators have taken steps to build such feedback mechanisms into their own practices, but these lessons are not being coordinated in any systematic way that might help accelerate the diffusion of new practices across the industry more generally.

From a system of professions standpoint [12,25], growth in knowledge—in this case, the need to reduce global carbon emissions—can create a "new" legitimate set of problems and therefore an opportunity for new professional group(s). But who is going to do this work and how? The focus on advanced standards and whole-home approaches has led to a shift in emphasis in energy efficiency policy debates, moving away from a sole reliance on specialist insulation installers, and including many more of the different trades involved in the general RMI sub-sector of the construction industry. This shift in emphasis offers a new challenge to the energy-efficiency research community, as the task of integrating energy-related works with the operation of the complex and fragmented RMI market means that technical expertise on energy efficiency is necessary but not sufficient to make progress. A greater understanding is needed among the energy efficiency community of "middle actors" in the RMI industry and the complex markets involved in housing refurbishment (*i.e.*, not just energy efficiency projects, but all home renovation projects).

From a "middle-out" perspective Parag and Janda [23] suggest that two essential elements for successful systemic change are actors' agency and capacity, where "agency" refers to actors' abilities to make their own free choices, and "capacity" refers to actors' abilities to perform the choices they made. Due to their position between top and bottom actors, middle actors play crucial functions in the transition process from a high-carbon society to a low-carbon one. The cases studies presented here suggest that at least a handful of innovative builders in Britain and France are actively seeking to increase both their agency to make decisions and capacity to make change. A further study of these two elements across a broader range of middle actors in the building industry would be an important next step.

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All authors completed interviews and contributed ideas for this paper and the conference paper on which it is based. Kathryn Janda was primarily responsible for revising and expanding the conference paper; Gavin Killip and Tina Fawcett provided additional insights.

Conflicts of Interest

The authors declare no conflict of interest.

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