

The construction industry as agents of energy demand configuration in the existing housing stock

Keywords: building, construction industry, retrofit, energy demand

1. Introduction

At first sight it can be tempting to think of the entire low-carbon energy transition in terms of ‘disruption’ and ‘continuity’: a set of clear-cut and binary choices about what needs to change. For example, there are debates about whether all gas-fired boilers should be changed for heat pumps; or whether the gas grid could and should be re-purposed and equipped to distribute hydrogen (produced sustainably). However, the introduction to a special issue of Energy Research and Social Science on ‘disruptive innovation and energy transformation’ cautioned that energy transformation requires systemic change, i.e. ‘directed, aligned, multi-scale efforts to innovate more sustainable ways of producing, distributing and using energy’ (Wilson & Tyfield 2018: 211). Another paper in the same special issue argued that ‘preoccupation with disruptiveness as an energy transitions strategy risks marginalising and overlooking important aspects of energy system change: mundane, incremental and continuity-based innovation, and possibilities for adapting existing systems’ (Winskel 2018: p. 235). The debate needs to focus on more than just technology, addressing broader questions of governance and market arrangements, which are needed to overcome carbon lock-in (Unruh 2000).

This paper focuses on one aspect of the energy system, how existing buildings shape energy demand, and what the move to a low or zero carbon economy demands from that system.

Some key terms require definition at the outset. Retrofit is taken to mean any work that

1 alters the physical fabric of a building or the energy services within it, with the explicit goal
2 of improving efficiency, reducing energy demand or reducing associated CO2 emissions. In
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4 contrast, renovation is used to refer to projects on existing buildings, where energy demand
5 and CO2 emissions reductions are not a primary goal. In the construction management
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7 literature renovation services are classed as repair, maintenance and improvement (RMI).
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15 ‘Disruption’ and ‘continuity’ are used to frame a debate about the kind of system change
16 needed to deliver energy retrofit of the UK’s existing housing stock, with a focus on the
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18 (potential) role of the existing construction industry in delivering retrofit at scale. There are
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20 three reasons why retrofit needs to be considered as a construction challenge, rather than
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22 simply an energy technology challenge. First, the sheer scale of the task of retrofitting
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24 millions of homes is consistent with the size of the existing construction industry; second,
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26 doing physical work to alter buildings is, by definition, construction work; and third, if the
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28 construction industry is not successfully mobilised to carry out retrofit, then it has the scale,
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30 reach and influence to work against any retrofit policy, for example by persuading
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32 consumers not to carry out energy-related works.
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44 Retrofit of existing building stock is a key part of an energy transition in numerous scenario-
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46 based studies (e.g. IPCC 2014, CCC 2019a). The availability of mature, market-ready
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48 technology is a common test for inclusion in such studies but – as this paper sets out – the
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50 availability of technology is no guarantee of widespread adoption. A whole systemic
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52 architecture needs to be in place for technology deployment, ‘integrating the ‘what’ (for
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54 example, technical knowledge, targets, technology choices, costs) with the ‘how’ of
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1 implementation (for example, institutional capacity, public engagement, and governance)’
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3 (Dixon et al 2018 p. 256).
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7 In order to investigate the dynamics of disruption and continuity, two sets of literature are
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9 reviewed. First, there is the literature in construction management, which characterises
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11 mainstream industry practice. Second, there is the literature describing how pioneers of
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13 retrofit have managed their projects and business models in order to achieve low-energy
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15 goals. By comparing the pioneers with the mainstream industry, points of synergy and
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17 conflict can be found, and a fuller picture emerges of the kind of systemic change needed if
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19 retrofit is to be achieved in line with climate policy targets.
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28 The remainder of the paper is structured as follows. The next (second) section briefly
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30 reviews recent UK domestic energy efficiency policy and explains the relevance of
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32 renovation for the future of retrofit. The third section proposes an analytical framework for
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34 the brief reviews of industry practices – the mainstream RMI sector in section 4, and the
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36 pioneers of retrofit in section 5. These reviews combine evidence from energy studies,
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38 construction management and labour studies. A comparative analysis (section 6)
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40 summarises the key findings in terms of common features between the two groups
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42 (indicating possible continuity of practice), and points of divergence (indicating potential
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44 disruption). Some broad policy implications of this comparison are discussed in section 7
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49 before a brief statement of conclusion (section 8).
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2. Context

2.1 UK Residential energy efficiency policy

Energy supplier obligations have historically been key to UK residential energy policy, focused on the most cost-effective and easy-to-install energy efficiency measures, e.g. loft and cavity wall Insulation (Rosenow, 2012; Mallaburn and Eyre, 2014). This policy approach has contributed to reductions in residential energy demand, but it is not consistent with the more costly and disruptive interventions required to achieve more ambitious reduction targets (80% or net-zero). The replacement policy for supplier obligations, Green Deal, failed on three principal counts: a lack of delivery targets and sanctions for non-delivery; an expensive and unattractive financing mechanism; and a poor understanding of consumers' real motivations for carrying out home repairs and improvements (Rosenow and Eyre 2016). The technologies required to achieve carbon emission reduction targets (eg solid wall insulation, heat pumps) are well known (CCC, 2019b) but the necessary market arrangements are very immature, and policy-makers have struggled to find effective policy interventions. At the time of writing, no replacement for the Green Deal is in prospect in the UK.

2.2 The scale of the challenge

Building design and use drives the demand for a range of energy services including thermal comfort (heating and cooling), cleanliness and hygiene (water heating and supply), food preparation and recreation (use of appliances). In the UK, energy use in homes accounts for approximately 29% of all energy consumption, and 20% of UK greenhouse gas emissions, if emissions created by electricity generation are included (ONS 2019a; CCC 2019c). While

1 some reductions in energy demand can be achieved through changing building occupants'
2 behaviour or product policy for lights and appliances, the majority of energy demand is for
3 thermal loads (CCC 2019b). Improving energy efficiency and reducing emissions from homes
4 requires work to alter the physical make-up of the building and the heating technologies
5 installed. A policy environment driving for a 'net zero' carbon emission economy goes
6 further than the statutory carbon budgets established after the UK's Climate Change Act
7 2008, but even before the introduction of 'net zero' aspirations, achieving the Act's targets
8 meant that emissions from all buildings in the UK needed to fall by at least 24% by 2030
9 from 1990 levels, and should be effectively zero carbon by 2050. Progress to date has been
10 limited, with policy for zero-carbon new homes being watered down and then dropped
11 altogether, while progress on energy efficiency in existing homes has also stalled (CCC,
12 2019c; Eyre and Killip 2019: 25). Even if all *new* homes were to be zero carbon, the problem
13 remains of the 29 million homes in the existing stock. The scale of the challenge is
14 compounded by the high level of private home ownership in the UK; nearly two thirds of
15 homes are in private ownership meaning that there is no single route to drive change.

2.3 Opportunities in the Repair, Maintenance, Improvement (RMI) market

24 The UK average annual economic output spend on residential RMI sector 2010-2015 was
25 £23.7bn (ONS 2016), which equates to an average of roughly £900 per dwelling per year.
26 RMI covers everything from handyman services (e.g. clearing gutters) to major renovations
27 and extensions. Clearly, the average annual expenditure hides a wide distribution, with
28 some RMI projects costing tens of thousands, while other properties have nothing spent on
29 them in a given year. Equally clearly, not all RMI work is a good opportunity for integrating
30 energy works. Good opportunities for retrofit are likely to be where projects expose the
31 thermal envelope or involve significant change to heating systems. In such situations the

cost and disruption of retrofit can both be significantly reduced by being made marginal (Fawcett and Killip 2014). It has been estimated that a figure of the order of £10bn per year (i.e. 40% or so of current total of RMI expenditure) comprises projects that lend themselves to one or more aspects of retrofit (Maby and Owen, 2015; Killip, 2011).

2.4 Design-performance gap

There is a large and persistent difference between technical potential and energy performance achieved through retrofit activities (e.g. Topouzi 2015; Gupta and Gregg 2016). Design-performance gaps also exist in new-build, where there is more research evidence on underlying causes. In a review of over a hundred such studies the Zero Carbon Hub (2014) identified three broad causes of the design-performance gap arising from the construction phase of projects:

- Lack of technical knowledge
- Unclear boundaries between roles and responsibilities
- Poor communication among project teams

Johnston et al (2016) sought to quantify the size of the design-performance gap from a small sample of monitored projects (all new-build rather than retrofit), finding that there is a high degree of variation in the size of the gap on different projects. However, those which perform well (i.e. achieve close to the design intent) do have several attributes in common including:

- quality control processes during construction;
- a highly skilled, educated and committed project team; and,
- risk of loss to project teams in case of failure (e.g. reputation damage)

1 The smallest design-performance gaps were observed on the projects working to the most
2 exacting standards (Passive House). On this evidence, minimising the design-performance
3 gap requires improvements to processes, better technical competence, internal
4 communication and project management within construction projects. Some process of
5 external accountability is also needed, whether that is through a market-based mechanism,
6 such as risk to reputation, or through a regulatory device, such as accreditation and
7 compliance-checking.
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21 In order to investigate the dynamics of disruption and continuity in the retrofit sector, the
22 remainder of the paper compares the structure and practices of two different industry
23 groups - the mainstream construction industry delivering RMI services and the smaller
24 group of retrofit pioneers.
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34 **3. Analytical framework**

35 In order to investigate disruption and continuity in relation to retrofit, a comparative
36 analysis is carried out of two different (but related) markets: the market for repair,
37 maintenance and improvement (RMI) of homes, in which energy efficiency and energy
38 performance is not of prime importance; and the market for deep retrofit, where energy
39 performance is by definition a key objective of the work.
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52 The characterisation of mainstream and niche markets echoes the socio-technical systems
53 (STS) literature, in particular the idea of the Multi-Level Perspective, where micro-level
54 innovations are seen as attempts to influence and disrupt more established policy, social
55 and economic structures at the meso-level 'regime' (Geels 2002). The interactions between
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1 niche and regime can be complex and reciprocal, in the pursuit of strategic objectives (Schot
2 and Geels 2008).
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7 The technology deployment process typically involves one or more stages of intermediate
8 supply chain activity between producers and final consumers. Parag and Janda (2014) argue
9 that 'middle actors' in supply chains have an influence on consumer choice and market
10 outcomes because those actors have choices and preferences themselves, as well as
11 positions of influence over consumers. The term 'middle actor' is coined to emphasise their
12 agency, both at micro-level on projects, but also in the dynamic processes between micro-
13 and meso-level effects.
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28 Foxon (2011) theorises these processes as co-evolutionary, where several factors come
29 together: technology, business strategies, users, institutions, and ecosystems. Killip et al
30 (2018) found this framework useful in relating broader climate policy to the retrofit sector,
31 but also identified an additional complexity in retrofit, where quality assurance is dependent
32 on the skills and capabilities of installers.
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44 An analytical framework is proposed which combines the concepts of niche-regime
45 interaction, middle actors and skills (Figure 1). The inner triangle in Figure 1 represents
46 some elements of niche-regime interaction, while the outer ring represents mechanisms by
47 which those elements can change. No arrows or other indicators of the process are
48 suggested, and the apparent neatness of the figure is a deliberate simplification.
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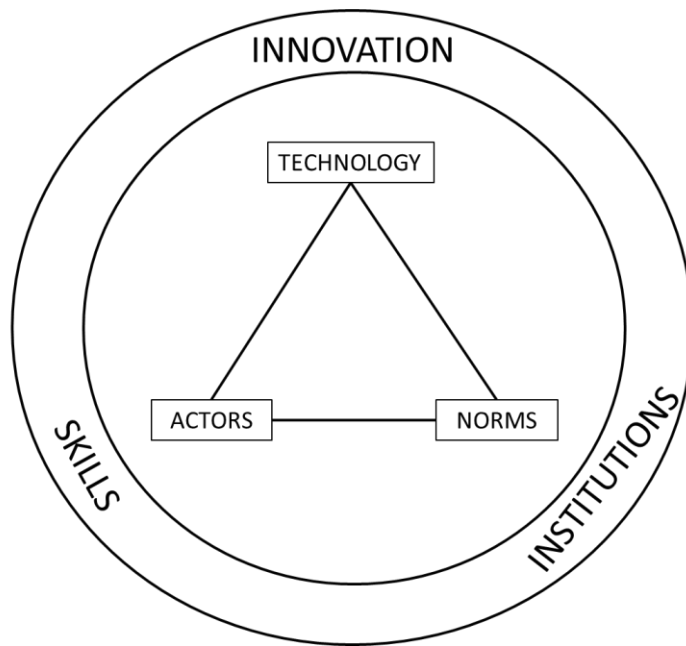


Figure 1. Analytical framework for the comparison of RMI and retrofit sectors

The terms in **Error! Reference source not found.** are all defined quite broadly. ‘Technology’ encompasses all energy-using and energy-generating technology in a building (e.g. appliances, building-integrated renewable energy systems), and also any products and materials (insulation, bricks, lengths of timber, windows etc.) that can be incorporated into buildings in different configurations. By this definition the existing housing stock itself is part of ‘technology’.

‘Actor-networks’ are the people and organisations involved, and the relationships between them. Some combination of clients, tenants, property owners, builders, designers, advisers, regulators, energy companies, and others may be present in these actor-networks. The relationships between actors are as important to understand as the list of actors itself, and both are included in the meaning of ‘actor-networks’.

‘Norms’ is used to denote all the rules of social and technical organisation, whether they are formal and consciously mediated (eg in response to Building Regulations) or informal and customary (eg installer preferences for certain types and brands of product).

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3 These three inter-dependent elements can be diverse and changeable from one instance to
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5 the next. They equate broadly with micro-level processes, be that on individual projects or
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7 in the organisation of multiple projects. Meso-level structures are shown in graphically
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9 encircling the three inter-dependent elements, as the three items 'innovation', 'skills' and
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11 'institutions', which together form the context in which the micro-level components are
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13 selected, used and changed. 'Innovation' here includes new technology but also, crucially,
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15 new products, practices and business models – in isolation or in combination. 'Skills' refers
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17 to physical and cognitive capacities (practical manipulation of materials and tools, as well as
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19 technical knowledge based on theoretical principles). 'Institutions' encompass the range of
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21 structures through which norms are development and made manifest, including policy
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23 making and regulatory bodies but also trade associations, supply chain and financing
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25 arrangements.
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36 The proximity of the three pairs (innovation-technology; institutions-norms; actors-skills)
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38 should not be interpreted as meaning that connections are only bilateral. Instead, it should
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40 be read as meaning that elements and change mechanisms may interact in ways that are
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42 unspecified at the outset.
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49 The combination of micro- and meso-level elements is important because it gives the
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51 analysis a dual focus on the operation of individual projects and the structural context for
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53 reproduction from one project to the next and between actor-networks. The framework
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55 allows for analysis of the 'what' and 'how' questions at the same time.
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1 In the next two sections, the six elements of the framework are used as sub-headings to
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3 organise analysis of the mainstream RMI sector (section 4) and the retrofit pioneers (section
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8 **4. The RMI sub-sector of the construction industry**

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10 **4.1 Technology**

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12 Construction technology can be differentiated between materials sold in standard units and
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14 configured on-site to meet project needs and specifications (lengths of timber, bags of sand
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16 etc) and manufactured products (eg boilers, windows). Standard-unit materials are adapted
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18 (cut, poured, arranged, fixed) to fit the existing building, whereas for manufactured
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20 products it is the interface with the building where any adaptations have to be made (eg
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22 packing between the window and the aperture). RMI technology requires practical, craft-
23
24 based installation (see Dainty et al 2007). Whyte and Sexton (2011) argue that construction
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26 is a 'low-technology' industry because it does not produce 'general purpose technologies
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28 that drive economic development'. Instead, it uses mature technologies for specific
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30 purposes. New technologies are more likely to have their origins outside the industry than
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32 within it. Sexton et al (2006) find that the adoption of technology in construction firms is
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34 contingent on the 'knowledge content' of the technology, and that the capacity of firms to
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36 use technology is heavily influenced by their prior knowledge and expertise. In construction,
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38 where knowledge is largely tacit and unsystematised, new technologies tend to be adopted
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40 when they conform to pre-existing tacit knowledge and confer 'enabling' advantages for
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42 firms (eg cordless power tools increase speed of work and freedom of movement).
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1 The unpredictable nature of working on existing buildings means that unforeseen problems
2 are a normal part of the work, requiring work-rounds and changes of plan (Killip 2013, Owen
3 et al 2014). Perfect foresight does not – and cannot – exist on projects which alter the
4 physical fabric of an existing building because the condition and precise layout of the
5 building are unknowable at the outset.
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16 4.2 Actor-networks

17 The industry is characterised by fragmentation (see Egan 2002, Clarke et al 2017). RMI is
18 dominated by small and medium enterprises (SMEs), especially micro-businesses of 1-3
19 people, working in local markets. These firms are not profit maximisers or engines of
20 economic growth, nor are they focused on building energy performance. Rather they are
21 motivated by autonomy, use of practical skills, pride in helping to maintain the fabric of
22 their local area, and a desire to maintain a good local reputation for quality and value (Maby
23 & Owen, 2015). Teams of SMEs can be configured in different ways for different projects.
24 Even within a relatively small network of firms, there are several possible ways of organising
25 labour and management responsibility on a project, with different profiles of risk for the
26 client, main contractor and subcontractors (Maby & Owen, 2015). These networks can be
27 highly stable over time, often being maintained between generations, using the social
28 capital and trust built up between firms and tradespeople. The nurturing of that social
29 capital is a more important activity for many sole traders than more formal means of
30 selection, retention and performance monitoring (Wade et al 2016).
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Installers do not unquestioningly deliver what their customers want; instead they are highly

1 influential over the decisions and product specifications that customers end up agreeing to
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3 in a process of negotiation (Maby and Owen 2015, Killip 2013, Janda et al 2014, Killip et al
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5 2020). In the negotiation of projects, there is the further complication that technologies in
6
7 retrofit have two different kinds of end-user - the installer firms (for whom the technology is
8
9 instrumental in making a living) and the building occupants (for whom the technology is
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11 intimately bound to concepts of home). It cannot be assumed that their needs and
12
13 preferences will be aligned (Killip et al, 2018). The network of firms may be able to respond
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15 to the knock-on effects of sequencing, delays and problems on projects if the network can
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17 call on substitute firms at short notice. This only works because firms of the same type
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19 conform to set roles (e.g. plumber A can substitute for plumber B because they share and
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21 stick to a clear understanding of what a plumber does).
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31 Manufacturers invest time and money to engage with installers precisely because the
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33 installer is so influential over customers' product choices (Wade et al, 2017, Killip et al
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35 2019). Builders' merchants provide value not just in terms of sales and distribution, but also
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37 in providing credit finance and other services, such as waste collection (Killip et al 2019). The
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39 net effect of these relationships is a stable and largely conservative system, in which
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41 installers prefer to use what is available reliably and quickly through local builders'
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43 merchants, and the merchants stock the things that they know are in demand.
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49 Manufacturers whose products are favoured in this way are likely to remain dominant,
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51 while new entrants offering novel products and technologies need to find other routes to
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53 market, for example by seeking out clients with particular demands requiring innovation
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55 (Killip et al 2020).
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4.3 Norms

In the UK, Building Regulations are, arguably, the most widely recognised set of formal rules governing how buildings are built, although the practices and compliance rates of projects remain under-researched. In one study of 376 new-build dwellings, Pan and Garmston (2010) found that one-third were compliant and two-thirds were partly or non-compliant. In this context compliance refers to the satisfactory completion of the regulatory process, and does not relate to the gap between design intent and as-built performance. With each new revision to the relevant Approved Documents, there is a transition period to allow the industry to become familiar with the new rules, but compliance rates do not seem to improve with experience, suggesting that the causes are systemic, rather than a lack of familiarity (Pan and Garmston 2010). No comparable studies exist for the RMI sector, although it seems reasonable to assume that compliance would not be any better than in new-build, and could be worse, given that smaller RMI projects in particular are unlikely to be inspected. For example, Killip (2013) found evidence in RMI of builders ‘making a judgement’ about regulations, based on an informal risk assessment of several factors: the time and effort required to comply; the tacit understanding of energy in buildings, and the likelihood of non-compliant work being sanctioned (Killip 2013).

Winch (1998) describes construction as a ‘complex systems industry’ with important characteristics in terms of how the industry operates and innovates:

- many interconnected and customised elements
- non-linear properties: small changes to one element of the system can lead to large changes elsewhere

- a high degree of user involvement in the innovation process

As well as managing how technology is installed on individual projects, each installer firm also has to manage the sequencing of multiple projects over time: 'the relationship between business and project processes is paramount for the understanding of project-based firms' (Gann & Salter 2000: 970). There is a paradox at work here, where the collective ability to be flexible on projects is supported and enabled by conservatism in networks (Dubois and Gadde 2002). Debates about whether the construction industry is innovative or not miss the point that it is both innovative and conservative at the same time.

4.4 Innovation

Barret et al (2007) argue that innovation in construction occurs at sector-level, business-level and project-level. Sector-level innovations (eg in response to regulatory change) are the most visible, while project-level innovations are relatively 'hidden' from conventional metrics and definitions of innovation. However, both business- and project-level innovations can lead to sector-level innovation over time as new ideas diffuse. Change agents play a critical role in enabling innovation diffusion and affecting how quickly diffusion occurs, in terms of promoting the relative advantage it confers on users (Rogers, 2005).

There are two mechanisms of decision-making for innovation in construction: the decision to adopt an innovation on any given project, and the decision to adopt the habit of repeated use into the firm's normal practice. Client-led innovations may lead to an increased capacity at firm-level through accruing skills and knowledge (Owen et al 2014). However, doing

1 something new and different on one project is no guarantee that the experiment will be
2 repeated on the next project, even if the initial experience has been positive (Killip, 2013).
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8 4.5 Skills 9

10 The UK construction sector operates in a 'low-skills equilibrium', where low-paid and
11 insecure employment is the norm, delivering projects with low labour productivity and
12 generally low quality (Green 2016). Dainty et al (2007) argue that the low-skills equilibrium
13 results from a strategic choice in the UK construction sector to prioritise flexibility through
14 widespread sub-contracting, even if that means lower productivity. Low skills and high rates
15 of self-employed sub-contractors are correlates of the low-skills equilibrium (Clarke & Wall
16 2000). Industry fragmentation and casualisation will tend to reduce investment in skills
17 because 'the responsibility for skills development is devolved, often repeatedly, until it rests
18 with the individual unskilled worker who is least likely to have information, resources or
19 inclination to embark on a lengthy training programme' (Dainty et al 2007: 20). The number
20 of self-employed operatives in UK construction remains high (46% in Q2 2018) compared
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45 The technical content of vocational training in the UK has been eroded during the second
46 half of the twentieth century (Steedman 1992, Dainty et al 2007). The older system of block-
47 release for college training (whereby trainees spent weeks at a time on taught coursework)
48 has given way to a day-release system, which is not conducive to learning abstract skills and
49 underpinning knowledge because insufficient time is allocated to concentrated periods of
50 study and learning (Clarke and Herrman 2007). Clarke et al (2017) find that the level of
51 qualifications is low in the UK construction workforce compared with other European
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1 countries. They further argue that the narrow focus on practical skill (rather than theoretical
2 knowledge) is insufficient to equip workers with the more general energy literacy required.
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4 These authors conclude that the structure of the industry and the system for vocational
5 education and training both need reform if low-energy construction is to become a reality.
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10 **4.6 Institutions**

11 Building Regulations govern many different aspects of UK construction work, including
12 energy uses other than plug-in appliances. Regulations have been instrumental in improving
13 energy efficiency in new housing over time, and Part L1B introduced the same principle for
14 major renovation projects. These regulations are based on a design standard (and assumed
15 occupancy patterns), so the design-performance gap remains an issue that regulations do
16 not address. Building regulations are typically treated as both a minimum and a maximum
17 standard - a target to aim at, not to attempt to exceed – and it has been argued that the
18 regulations stifle innovation (Gann et al. 1998, Lowe and Oreszczyn 2008). When it comes
19 to compliance-checking, Building Control inspectors report technical and practical
20 difficulties, which effectively lead to energy compliance being neglected (Murtagh et al
21 2017). In a survey of 11 new housing developments Baiche et al (2006) found that
22 compliance problems typically arose from the lack of on-site skills and knowledge.
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47 The task-oriented definition of job roles is reflected in the training arrangements, by which
48 learners specialise early by building trade, in contrast with many other countries where
49 students learn about the industry and building process generally before they specialise
50 (Clarke et al 2017). The lack of a general foundation course for all workers means that the
51 interfaces between tasks and trade roles can go ignored or neglected because the
52 responsibility for doing so is not clearly allocated or defined (ZCH 2014).
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5. Demonstrators and pioneers of retrofit

In this section we present evidence from pioneering projects and business models for retrofit, organising this data to highlight the contrasts with mainstream practice, described in section 4.

5.1 Technology

Retrofit to achieve carbon reduction targets is possible with existing technology (Roberts 2008). The technical potential for improving energy efficiency and reducing carbon intensity of systems in buildings is significant using mature, market-ready technologies, such as heat pumps, insulation, solar panels, control systems (see, eg, CCC 2019c). Various lock-ins and path dependencies exist in the detail of installation and operation, for example heat pumps work best with larger radiators or under-floor heating as well as a well-insulated building (Fawcett, 2011; Stafford & Lilley, 2012). Technology choices can also require more technical understanding from installers, as in the case of heat pump installation compared with gas boilers (Gleeson, 2016).

The only nationally coordinated programme of retrofit demonstration projects in the UK was the Retrofit for the Future programme from 2009-2013. For an individual dwelling, the most ambitious retrofit standards require high quality in design and implementation, and clear alignment with how the occupants use the building. The most ambitious retrofit standards aim for 'net zero' energy / carbon homes, but less ambitious retrofits are also possible (Gupta et al, 2015). Whatever the standard, an integrated design approach is required, based on technical principles, in order to reduce and manage various types of risk: of inefficient use of time; of under-performance; and of unintended consequences later on,

1 e.g. from condensation damage in insulated structures (Topouzi 2017, 2019). Retrofit is
2 more than just the implementation of multiple individual measures.
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7 No uniform set of standards or metrics has been used to evaluate or guide the retrofit
8 projects studied in the literature reviewed for this paper. This is an unavoidable
9 consequence of studies conducted in the absence of consistent government policy or
10 programmes. Instead, pioneers of retrofit have used a wide range of standards and
11 measures of success, from the rigorous (e.g. EnerPhit) to much more informal metrics (e.g.
12 increasing the size of a property but maintaining the same energy/carbon footprint). The
13 results reported here should therefore be read as descriptive of innovative practice, not
14 indicative of energy performance or specific design standards. Interfaces of various kinds
15 are important to ensure quality and minimise the design-performance gap. These include
16 the interfaces between: elements of a building (e.g. wall-floor junction; window aperture);
17 between energy system components (e.g. heating technology, controls, user practices); and
18 between people (communication and shared problem-solving on-site; hand-over and
19 training for building users).
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43 Retrofit projects are inherently underspecified, because the work required to fully
44 understand the starting conditions is so time-consuming and disruptive, that it only
45 practically makes sense to do it as the work proceeds. This is a barrier to developing
46 ambitious retrofit projects (Topouzi et al, 2019, Fylan et al, 2016).
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5.2 Actor-networks

Where no-one has an overview of the project from start to finish, there is an increased risk of decisions being taken without being fully informed, and wrong assumptions being made about previous decisions (Topouzi 2015). Fawcett & Killip (2014) found that many pioneer clients managed the process by playing project team roles themselves – managing the project as well as taking an active part in design and installation. Mlecnik et al (2017) reviewed 24 different retrofit consortia operating ‘one stop shop’ services in five different EU countries, highlighting the importance of a shared vision, trust and fair rewards to sustain collaboration. Killip et al (2014) found similar effects, even where the workforce were consolidated into the Direct Labour Organisation of a social landlord (i.e. employees, not contractors or sub-contractors): team-working and team motivation rely on familiarity, trust, and fair rewards. The social organisation of construction teams can enhance the oversight and continuity of design intent from start to finish, for example through the introduction of a new ‘coordinator’ role (WBCSD 2009) or more traditional project management functions in teams made up of directly employed labour rather than sub-contractors (Killip et al, 2014). Feedback mechanisms are also needed to allow and share learning – from person to person, from firm to firm, and from project to project (Topouzi et al 2017, 2019).

5.3 Norms

Projects may be ‘all in one go’ or ‘over time’ (Fawcett, 2013; Topouzi & Fawcett, 2019). The scope of a retrofit project, and what it can achieve in terms of energy demand reduction, is intertwined with the timing of a project, and the capacity and resources available to the project ‘client’. The typical practice among pioneers of ambitious retrofit projects is to do

1 the energy-related works at the same time as other kinds of work are being carried out,
2 whether that is a comprehensive renovation of an old property, or a planned approach to
3 future maintenance (e.g. waiting to insulate a roof until the whole roof is being replaced
4 anyway). Fawcett and Killip (2014) found that private sector pioneers of ambitious retrofit
5 projects made the cost and disruption of energy-related works marginal by integrating them
6 with other works: they did not do energy retrofit separately from, say, an extension or roof
7 repair, but rather did the extension or roof repair in a way that made best use of the
8 opportunity to incorporate energy-related works at the same time. Pioneers of retrofit have
9 used various strategies to ensure that there is some unity of purpose and continuity of
10 project oversight. Among private home-owners the home-owner may play an active role in
11 the project, as designer, project manager, installer – or some combination of all three
12 (Fawcett and Killip 2014). On Retrofit for the Future projects it was found that, where no-
13 one has an overview of the project from start to finish, there is an increased risk of decisions
14 being taken without being properly informed, and wrong assumptions being made about
15 previous decisions (Topouzi 2015).
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41 The concept of ‘building renovation passports’ (BRPs) similarly articulates a need for
42 continuity of understanding over time (and between successive building owners), requiring
43 audits, data processing, renovation plans and log-books in support of retrofit activity (BPIE
44 2016). The documentation and analysis for BRPs needs to be embedded in professional
45 practices: ‘it is vital to provide craftsmen and energy auditors with the necessary knowledge
46 to understand the benefits of BRPs and how to use them, so they can become
47 “ambassadors” of the BRPs towards building owners.’ (BPIE 2016: 39).
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5.4 Innovation

Brown (2018) identifies five business model archetypes for housing retrofit: the 'atomised' model based on sub-contracting typical of the mainstream market; and four more innovative models offering different combinations of services. He argues that there are several elements of a successful business model for retrofit, including:

- A value proposition based on comfort, well-being, health and aesthetics – not energy
- Guaranteed energy savings (rather than estimated)
- Integrated supply chains able to provide a whole-home approach
- A single point of contact for customers
- An integrated low-cost financing model
- Coordination of all these elements into a smoothly operating whole

In practice, not all of these elements may be present – or equally strong – in a particular offering. For example, Killip et al (2014) investigated three different business/management models for retrofit (two in the UK, one in France) but only one offered guaranteed energy savings, and that guarantee was later withdrawn. Low-cost financing at any significant scale depend crucially on government support, for example the KfW scheme administered through federal banks in Germany, or the national zero-interest loan scheme for eco-renovation in France. Feedback mechanisms are also needed to allow and share learning – from person to person, from firm to firm, and from project to project (Topouzi et al 2017, 2019).

5.5 Skills

Fawcett and Killip (2014) found that private retrofit pioneers had all invested in their own education as a means to make good decisions in the face of contradictory advice from

prospective contractors, much of which was simply wrong. Problem-solving for retrofit in ignorance of underlying principles can lead to errors and failures over time (Clarke et al, 2017). Task-based practical skills need to be complemented with underpinning conceptual knowledge if a worker is to be effective when faced with a problem to solve in an unfamiliar situation (Winch & Clarke, 2003). Retrofit itself adds new risks (e.g. condensation damage in insulated structures), for which the solutions require both technical knowledge and analytical skills (Topouzi et al, 2017). The ability to apply core knowledge in a way that responds to actual rather than assumed design conditions leads to more effective retrofit (Owen et al 2014). Some technical understanding and analytical skill is needed on-site. Owen et al (2014) also found that good communication skills are essential to avoiding work which later proves to be ineffective, and that good communication with the on-site team can improve building occupants' perceptions of retrofit work.

5.6 Institutions

Pioneers of retrofit (and green building more generally) have led the way in setting ambitious technical standards, such as the Passive House Institute's EnerPhit standard, or the AECB's CarbonLite Retrofit standard. Alongside the technical standards, both these organisations offer a range of resources, including design tools, buildings databases, training courses, on-line discussion forums, networks, conferences, and communications for different audiences.¹

¹ See passivehouse.com/ and www.aecb.net/

In the aftermath of the UK's failed Green Deal policy, the Each Home Counts review (Bonfield 2016) has led to the development of new training and accreditation standards for retrofit coordinators and installers. At the time of writing these standards have not been integrated with other policy, but there is potential for them to be used as minimum training requirements for publicly-funded projects (a version of public procurement). The Scottish Government made energy efficiency a national infrastructure priority in 2015, with an energy efficiency Route Map published in 2018 (Scottish Government 2018). A key role for local authorities is identified in the route map, because the development of infrastructure (on the demand and supply side) has an inevitably local dimension, not just for energy efficiency in buildings, but also for local energy networks. Once again, it is too early to know how well this policy will be developed, nor how successful it might be.

6. Comparative analysis

The analysis of the two previous sections is summarised in Table 1.

Table 1 Comparison of governance and market arrangements for RMI and energy retrofit

	RMI	Common to both	Energy retrofit
Technology	Individual measures-based approach to energy efficiency	Use of mature technology Projects under-specified because starting condition is not fully know-able in advance	Integrated design; attention to interfaces and whole-home effects
Actor-networks	Fragmented, informal, trust-based; task-based roles	Project-specific teams	Focus on coordination: specialist role(s); co-operative business models
Norms	Conservatism; installer preferences for	Project- and network-level relationships	Willingness to experiment; values-led climate concerns;

	familiar, available technologies		integration of retrofit in RMI projects
Innovation	Informal, 'enabling', accessible via tacit knowledge	On-the-job problem-solving	Systematised learning via formal feedback mechanisms
Skills	Low-skills equilibrium	Practical, craft-based skills	Technical, managerial and communications capabilities
Institutions	Weak compliance regime	Building Regulations	Voluntary standards; niche networks support learning

6.1 Points of commonality between RMI and retrofit

From Table 1 the 'common to both' column gives a checklist of things which fit broadly into the category of 'continuity'. These are aspects of RMI which either cannot realistically change or do not need to undergo significant change in a transition towards widespread uptake of retrofit. Some policy implications are summarised here:

- Technology – existing, market-ready technologies are available to achieve retrofit; the key challenge is market breakthrough, not technology breakthrough
- Under-specification – the nature of work on existing buildings involves some degree of design and specification as the work progresses, so on-site practices are one key to success
- Project team flexibility – by substituting for one another at short notice firms provide a network-level response to diversity and uncertainty on projects, which is important for managing work-flow over time; policy needs to allow for this flexibility of response

- Norms – widespread technology uptake requires adoption decisions by firms at two levels: on individual projects; and among networks. Otherwise, innovative projects will be unrepeated ‘one-offs’
- Problem-solving – the capability to work out and implement practical solutions to unforeseen problems is a key feature of the work of altering existing buildings
- Skills – Practical, craft-based skills are needed for retrofit just as much as for RMI
- Institutions – Building Regulations are salient across the industry and serve a useful function as a minimum back-stop design standard

6.2 Points of divergence between RMI and retrofit

A reading of Table 1 also provides pointers for elements of disruption, where the shift from RMI to retrofit requires policy intervention and change:

- Technology – the need to consider integrated design, not just individual measures, entrains the need for new and improved capabilities in the workforce in three key areas: technical, managerial and communications
- Co-ordination – actions need to be coordinated, not left to individual firms to self-manage without regard for project outcomes; at network level, more formal structures are needed for learning and continuous improvement. Such co-ordination has been achieved by different means, including new roles, processes and business models.
- Overcoming conservatism in methods and materials – transition support for firms and networks should focus on reducing risks (real and perceived) of doing things differently, with time allocated for learning away from normal project deadlines and

1 cost pressures; new practices and processes will take time to become accepted and
2 embedded
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- 4 • Formalising learning – tacit knowledge and practical problem-solving skills are not
5 sufficient for the more technical challenges of retrofit; some data collection and
6 analysis is important to inform learning about energy performance
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- 8 • Skills and knowledge – the low-skills equilibrium is incompatible with the technical,
9 managerial and communications capabilities needed for retrofit. Because the knock-
10 on effects of on-site actions can be large, the education of on-site operatives is
11 essential. Exactly how different capabilities should be distributed across different
12 trades and professions is an open question, but some foundational principles could
13 and should be taught universally.
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- 15 • Regulations – the use of voluntary standards to stretch the ambition of a regulated
16 minimum standard is a common feature of energy policy development. Public
17 procurement may also help the industry adapt to the more ambitious standards.
18 Compliance regimes need to be strengthened, otherwise ‘tick-box’ compliance will
19 prevail, perpetuating large design-performance gaps and a systemic wasted
20 opportunity to improve buildings.
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22 This analysis of RMI and retrofit pioneers can be distilled to suggest a small number of key
23 themes, which recur in the analysis and are therefore good candidates for further discussion
24 about policy implications.
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7. Discussion and policy implications

The comparative analysis points to the need for improvements in five areas: co-ordination/integration; skills/capabilities; innovation of practices and process; regulation and compliance. Here, some inevitably tentative ideas about policy implications are discussed. These are not presented as fully-formed policy proposals, but as discussion points. Several are relevant not just for policy, but also for future research and practice.

First, better coordination and integration are needed on project design, team management and networks. The capabilities required for this are partly technical (an understanding of energy use in buildings and building physics), partly managerial (the ability to organise teams effectively), and partly strategic (the ability to organise resources into effective business models). These capabilities do not need to be equally distributed among the workforce, and the question of who needs to understand which aspects, to what degree of complexity, is an important level of detail that would need to be worked out and tested on the ground.

Second, the need for new skills and capabilities is also cross-cutting. An underlying challenge is how to overcome the low-skills equilibrium. If new courses are developed without tackling that underlying issue, then the outcome is likely to be poor uptake of courses and a continuation of the status quo. Here, some kind of qualification-based entry requirement may be needed for the construction sector. Exactly how it would work for different grades of worker and different types of firm is another open question for debate, but some kind of labour market reform would create the need for workers to do the training. Work opportunities would be limited or non-existent for those without the relevant qualifications. An obvious challenge for such a policy would be to create transitional arrangements for the

existing workforce, such that firms could stay in business and workers could remain in employment, while the base of knowledge and capability was increasing over time. Achieving this in the face of almost certain resistance would be a major political challenge. The cost of such an education programme would be significant, and so the financing of learning is another key question for debate.

Thirdly, when it comes to innovations of industry practices and processes, the lessons learned from a relatively very small number of retrofit pioneers would need to be applied to the much larger group of mainstream industry firms and organisations. It seems unlikely that what works for the pioneers would necessarily translate across to the mainstream without some degree of adaptation in the process of scale-up. One way to achieve this in a step-wise manner could be to run a series of field trials, coordinated and iterative over a long enough period of time to capture learning from real-world projects and experiments with business models and other network-level innovations. This could be a joint undertaking between industry, policy and research organisations, organised along the principle of a 'Living Lab'.

Finally, regulation for domestic energy efficiency also faces a big shift from its traditional approach if it is to transform the market for RMI into a well-functioning market for retrofit. Building Regulations set minimum design standards, but do little or nothing to foster innovation and embed learning processes in the industry. For that, there needs to be an industrial strategy with a goal of disrupting the low-skills equilibrium and equipping the construction workforce, including the regulators, with the technical, managerial and communications capabilities that are needed to carry out retrofit work to a sufficiently high

1 standard, and to do so not just once, but as a matter of course every time there is an
2 opportunity to do so in the RMI market.
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6 The first three themes highlight the need for much closer alignment between energy policy
7 (the main impetus for domestic energy retrofit) and policy for the construction industry. The
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9 fourth theme (regulation and compliance) is closer to traditional topics for energy policy,
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11 but the compliance question especially needs to be developed with greater understanding
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13 of the practices of construction. Judgements need to be made about inevitable
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15 compromises and 'work-arounds' on construction sites, so the negotiation of compliance-
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17 checking between builders and inspectors will key to successful policy delivery.
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24 **8. Conclusions**

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26 This paper uses 'disruption' and 'continuity' to frame a debate about the kinds of system
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28 change needed to transform the existing building stock to achieve net zero carbon goals. By
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30 contrasting current, conventional construction practice with pioneering retrofit projects, it
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32 has been possible to identify elements which will need to change, and others that will
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34 remain largely unchanged. Far from being a set of binary choices, the picture which emerges
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36 is of a complex system of service provision, some of which will inevitably remain the same,
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38 but some of which will need to change.
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48 The evidence on retrofit is growing, and has taken a welcome turn in recent years towards
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50 the market arrangements and industry practices involved in the uptake of available
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52 technology. Even so, the evidence base is still weak. In this paper, for example, several
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54 studies based on new house-building have been used, where examples from RMI are non-
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existent. The two sub-sectors of construction are not the same, however, so any conclusions drawn from the analysis need to be treated with caution.

The low-skills equilibrium is incompatible with a culture of working that is technically competent, communicative, collaborative and self-reflexive, and yet these are the very qualities required in a workforce delivering retrofit. Other initiatives, such as building renovation passports, may also be needed, but raising the technical, managerial and communications capabilities of workers and firms needs to be central to retrofit policy. The low-skills equilibrium in construction dates back several decades, and provides main contractors with a flexible and cheap labour-force, avoiding many of the responsibilities of direct employment. This situation has not arisen by chance, but by choice.

Market transformation of the residential RMI sector is unlikely to be quick or easy. This has serious implications for energy policy and emissions reduction targets, which have historically been based on assumptions about technology deployment. If retrofit cannot realistically be scaled up quickly, should models and scenarios for climate targets be adjusted accordingly? What would be the knock-on implications of such a shift?

Despite being framed in terms of climate targets and energy policy goals, the task of housing retrofit at significant scale is primarily a challenge for industrial policy. There needs to be much closer alignment and co-operation between energy policy and industrial strategy. Without it, there is a very real risk of failing to deliver anything close to the technical potential of retrofit, and of making climate policy targets that much harder to achieve.

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Table 1 Comparison of governance and market arrangements for RMI and energy retrofit

	RMI	Common to both	Energy retrofit
Technology	Individual measures-based approach to energy efficiency	Use of mature technology Projects under-specified because starting condition is not fully know-able in advance	Integrated design; attention to interfaces and whole-home effects
Actor-networks	Fragmented, informal, trust-based; task-based roles	Project-specific teams	Focus on coordination: specialist role(s); co-operative business models
Norms	Conservatism; installer preferences for familiar, available technologies	Project- and network-level relationships	Willingness to experiment; values-led climate concerns; integration of retrofit in RMI projects
Innovation	Informal, 'enabling', accessible via tacit knowledge	On-the-job problem-solving	Systematised learning via formal feedback mechanisms
Skills	Low-skills equilibrium	Practical, craft-based skills	Technical, managerial and communications capabilities
Institutions	Weak compliance regime	Building Regulations	Voluntary standards; niche networks support learning

Figure(s)

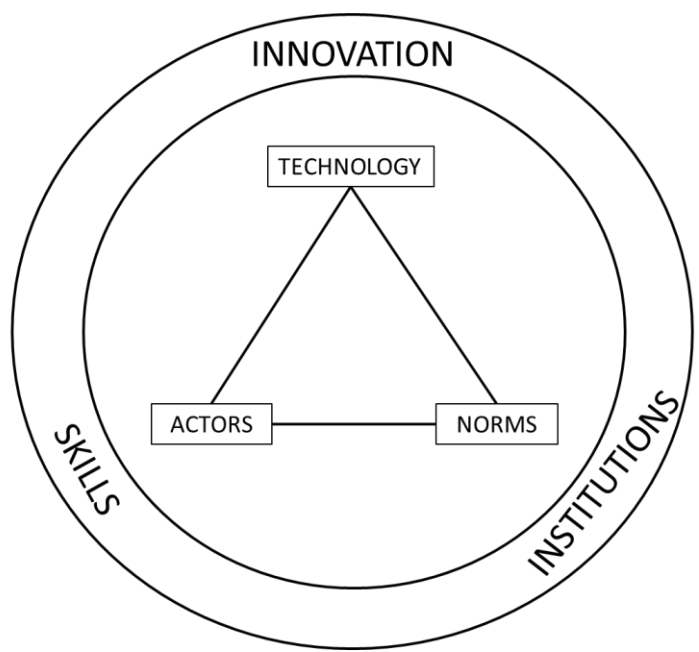


Figure 1. Analytical framework for the comparison of RMI and retrofit sectors

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