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1. Introduction

1.1. Existing buildings and climate policy

Buildings are an important sector for energy end-use worldwide, with a large potential for climate mitigation through reduced energy consumption and associated CO₂ emissions (Inter-governmental Panel on Climate Change 2014). In the UK, buildings account for a total of 36% of emissions: from direct combustion of fuel (mainly for heating and hot water); and from indirect emissions arising from the consumption of electricity for lighting, cooling, appliances and other services (Committee on Climate Change, 2018). The statutory targets of the UK Climate Change Act are consistent with near zero emissions from buildings by 2050 – a huge and profound shift.

Renovating existing buildings to reduce their energy demand and related carbon emissions (termed ‘retrofit’) is a major challenge because of the large size of the stock and the very slow replacement rate. The majority of buildings that need to be zero carbon by 2050 are already built and in use (SDC 2006). Existing buildings can be improved to achieve lower carbon, through insulation of the building envelope, changing heating and energy systems, including on site generation of renewable energy, for example with solar panels (Roberts 2008).

UK policy for energy efficiency in the housing stock was for many years predicated on large-scale installation of relatively cheap and minimally disruptive individual measures (e.g. insulation of lofts and cavity walls; replacing boilers). These installation programmes were designed to support the cheapest means to make the largest savings, paid for by obligations on energy supply companies (Mallaburn and Eyre 2014). More recently, the Green Deal was a policy intended to support more expensive measures (especially solid wall insulation) through an innovative finance mechanism with accreditation of installers, but it failed to attract sufficient take-up and was progressively abandoned by Government from 2015, only two and a half years after it was launched (Rosenow and Eyre 2016). From a policy perspective, the Green Deal failed because it relied on voluntarism and high (unsubsidised) interest rates, informed by neo-liberal market dogma and ignoring four decades of experience of successful energy efficiency policy (Mallaburn and Eyre 2014).

There are good technical reasons for questioning a policy approach based on individual measures when the policy objective is as ambitious as ‘net zero’. The scale of ambition is consistent with ‘deep’ retrofit, which involves more costly and disruptive work, and also the need to pay very close attention to detail at all stages of design and implementation (Topouzi 2015). Deep retrofit carries additional risks and uncertainties: process risks to do with the need to manage sequencing of tasks differently from conventional projects (Topouzi et al 2019); and technical risks of structural damage or underperformance when multiple measures are fitted without understanding the building physics of the construction as a whole (Topouzi et al 2017a). The quality of project management and delivery is key to minimising the gap between design and as-built performance (ZCH 2014). Feedback mechanisms are needed if learning is to be shared between different stages in the construction process and between different actors (Topouzi et al 2017b).

The need to shift away from relatively cheap and easy individual measures towards more expensive, holistic and bespoke interventions has turned increasing research focus on the construction industry as potential agents of change (e.g. Killip 2013; Owen et al 2014). Rather than treat energy efficiency

as a separate kind of intervention, these researchers have shown that the existing market for general repair, maintenance and improvement (RMI) is a significant opportunity for deep retrofit (Killip 2011).

However, the RMI market operates by its own rules, which need to be understood if the opportunities are to be realised of integrating this market with low-carbon outcomes for buildings.

Earlier research has shown that installers are influential over technology choices and project specification, especially in the private, owner-occupied sector (Owen et al 2014; Wade et al 2016). But the installers are also influenced by firms 'upstream' in construction supply chains. Products and technologies which are available locally tend to be favoured over other products, because delayed delivery of materials has serious knock-on effects for the project and the firm's flow of projects over time (Killip 2013; Maby and Owen 2016). Once a product or technology has become familiar to the installer firm, there is a tendency for that product to be preferred, for a number of reasons: brand loyalty; compatibility of parts and system components within a manufacturer's product range; the availability of discounts, which can boost profits if the discounts are not passed on to end customers; a practical appreciation of product quality and reliability; a desire to avoid call-backs to fix faulty equipment or problems in operation (Killip 2013). The relationship between installers and the product supply chain is therefore important, as it helps to explain conservatism in product specification, and also provides the context in which any product innovation has to compete with established product lines.

This paper presents findings of research with merchants and manufacturers in the RMI supply chain. What are the strategies of merchants and manufacturers in selling products to installers and other actors? How do they view (and engage with) the conservative tendencies of installers? In what circumstances do they choose to introduce new products (or not)? What do they do to develop markets for products and services – both established lines and new innovations?

The focus on these supply chain actors does not preclude the possibility of innovations coming from elsewhere. For example, two innovations have attracted particular interest within the industry in recent times. The first of these is Building Information Modelling (BIM), which is a concept for creating and managing digital information about a building, including information on products and materials, design and three-dimensional representations of the final assembly. The UK government set a target of having fully collaborative 3-D BIM on centrally procured government construction projects by 2016, and the Construction Strategy for 2016-2020 seeks to further embed this across government departments (Infrastructure and Projects Authority 2016). The second innovation is off-site manufacture, which is viewed by some industry stakeholders as a way of radically altering the sector to improve efficiency and labour productivity (Farmer 2016).

The processes by which innovations are selected (or not) need to be better understood if the existing markets for construction work are to be successfully enrolled in innovations like BIM and off-site manufacture. This research uses the concept of 'middle actors', who occupy a position that is between top-down policy and bottom-up consumer demand (Janda and Parag 2013). 'Middle actors' have their own practices, culture and ways of operating, which mean that they are more than just passive agents for policy delivery or unquestioning providers of what customers want. In this framing, middle actors wield influence *upwards* to shape policy, *downwards* to shape consumer demand, and also *sideways* to influence other actors in the 'middle'. The concept of 'middle actors' represents organisations involved in complex project-based industries as active agents in decision-making, seeking to influence

and shape decisions in the light of their own experience and preferences. This ‘middle actor’ framing highlights the interaction of different working practices, preferences, and values in decision-making.

[INSERT FIG 1]

Figure 1: Middle actors in the construction value network (adapted from Janda and Parag 2013)

This paper contributes to these debates by exploring the role of builders’ merchants and manufacturers in the actor network of construction. Merchants and manufacturers have the potential to influence installers, who themselves are influential over detailed project design, and product choices by clients. How do merchants and manufacturers operate in the wider actor network of construction? And what factors affect the ability of these construction supply chain actors to introduce new products or processes to achieve lower carbon outcomes?

The remainder of the paper is structured as follows: section 2 provides a brief literature review of construction as a complex systems industry, leading to a discussion of linear and network-based concepts of ‘supply chain’; Section 3 outlines the study’s methodology; Section 4 presents results in a thematic analysis of interviews; Section 5 discusses the implications of these results; and Section 6 draws out some key conclusions with pointers for policy and future research.

2. Literature review

2.1 Construction as a complex systems industry

Winch (1998) argues that the construction industry needs to be understood as a ‘complex systems industry’ delivering buildings, which are ‘complex product systems’. Other examples of complex product systems include ship-building and electricity supply systems (Winch 2003). The key characteristics of these complex products are: multiple interconnected and customised elements; non-linear and emergent properties whereby small changes in one element can lead to large changes elsewhere; and a high degree of user involvement in the innovation process (Winch 1998: 269). Construction product supply chains are very different from supply chains in manufacturing sectors. A manufacturing approach seeks to reduce or eliminate these emergent properties and user involvement, by delineating in advance as many aspects of design as possible and systematically designing out uncertainties. However, construction projects, which must be responsive to site specific factors, cannot achieve the level of certainty that efficient manufacturing requires. The characterisation of construction as a complex products industry justifies a research focus on the processes and actor networks of production. Patterns of influence can be traced through relationships and flows of information, not merely through the financial transaction of product sales.

Dubois and Gadde (2002) identify a systemic tension in the operation of firm- and project-level processes in construction, whereby flexibility and on-the-job problem-solving at project level lead to unpredictability over time about the flow of work at the firm level. The industry as a whole copes with this tension by having firms which can substitute readily for other firms of the same type (e.g. if Plumber A is unavailable, Plumber B can be called in at short notice to do the same work). For substitutability to work, the tasks conventionally allocated to each type of firm need to be consistent. In effect, this means that the industry manages to be innovative and flexible on projects by being simultaneously conservative and inflexible in its allocation of roles and responsibilities among firms.

Janda and Parag (2013) make a related point when they argue that lasting innovation in construction requires two mechanisms to work synergistically: a mechanism by which firms can decide to use materials and products (the project level in Dubois and Gadde's terms); and a mechanism for embedding those choices in their practices and processes (the firm level). Firms working on projects make product choices at least partly based on what is available locally and quickly from merchants, creating a self-reinforcing preference for established product lines (Killip 2013). Manufacturers and merchants clearly have a stake in this decision-making process, whether they are incumbent firms with a large market share to protect, or smaller firms with new or specialist products. This research investigates how merchants and manufacturers seek to have influence over product specification on projects and over the ways in which processes and practices of other firms in the supply chain are affected.

2.2 Construction supply chains, value chains and value networks

A supply chain is often considered as a linear model, supporting the flow of resources from raw material to consumer. The 'value chain' model (Porter 1985) incorporates support functions such as firm infrastructure and human resource management (including workforce skill development) as important aspects running alongside the flow of materials. However, the focus of the value chain is usually a single firm and the concept becomes more difficult to apply to a project or series of projects involving several firms. While clearly a powerful management tool, in terms of supporting analysis the value chain misrepresents a construction project in the same way as a linear supply chain does, because it makes the assumption that all activities are undertaken with a unified aim. For a linear supply chain, that aim is the transformation of materials into a good or service. For the value chain, the aim is to secure competitive advantage for a firm so that it gains market share, revenue and profit. In a construction project undertaken through the collaboration of multiple firms or tradespeople, there will be multiple aims. For example: meeting the client's stated need, complying with regulations, using skills and knowledge effectively, getting paid enough and on time.

Vrijenhoef and Koskela (2000) provide a useful categorisation of four 'roles' or points of focus among supply chains in construction, which aids understanding of the dynamics that can exist between firms, whether in manufacturing, distribution, sales or on-site construction (**Error! Reference source not found.**). The roles include providing the interface between product suppliers and the construction site, or participating in the internal dynamics of manufacture and distribution before reaching the construction site. These different roles start to show how value is generated by a range of different project actors, not all of whom will be directly involved in the practicalities of construction.

[INSERT FIG 2]

Figure 2: The structure of four roles within the supply chain management in construction of (source: Vrijenhoef and Koskela 2000: 171)

The variety of roles and aims co-existing in a construction project lead to developing the idea of a value chain into a value network, recognising that a firm in the network must be strategic and adaptable to future opportunities, not just satisfying the current needs of their customer (Normann and Ramirez 2000; Kelly and Marchese 2015). In a value network there will be influences forwards along the supply chain, backwards from customer feedback, sideways between trades and disciplines, downwards from regulations and strategy and upwards from project specifics.

Walters and Lancaster (1999) identify the need for different forms of information to flow around the value network, in order to support the different forms of value sought by different actors i.e. relationships are multi-faceted, and the information flowing around the network is also complex. Relationships in supply networks involve more than commercial firms, and there is a need to acknowledge, and potentially reframe supply networks, around a variety of drivers and motivations (Josserand et al, 2018).

Each of these models – supply chain, firm-based value chain and strategic value network – can co-exist in a construction project. In the web of relationships and actions that come together to deliver a project, each actor will have only a partial view of the web. A merchant may see several intersecting linear supply chains where they receive materials from a set of suppliers and sell those materials on, in different, project-specific combinations, to builders.

3. Methodology

A qualitative approach was used for this research. Primary data was collected from original interviews. Other sources include the authors' collective experience of nearly three decades participating in industry-convened meetings, informal discussions and events focused on retrofit. While this experience is not used as part of the primary data analysed here, it enriches the qualitative research approach and informs the analysis of data collected from the semi-structured interviews (Creswell 2009, especially Chapter 9).

Eleven semi-structured interviews were conducted July 2017 – February 2018 (two directors of one firm were interviewed together in one interview, so there were 12 viewpoints expressed in total). Interviewees were recruited largely through personal contacts, but also through networking at industry-convened events. Ten interviews were conducted face-to-face; one was done over the phone. Interviews lasted 54 – 115 minutes (mean length 79 minutes). All interviews were recorded, transcribed and coded using NVivo 11.

For the interviews, a range of different voices was sought, from large and mainstream organisations through to smaller firms with a particular 'green' focus to their activities. We also sought to gather insights from a mix of manufacturers and merchants; firms dealing with materials in standard units (lengths of timber, bags of plaster etc.) and firms dealing with manufactured products (e.g. windows, heating technologies); firms which promote themselves as 'green' or 'eco' and those which do not.

The sample is not intended to be representative; the research used purposive sampling to include a larger proportion of 'green' innovators than would be justified if the sampling method was representative of the market (Mason 2002). The choice of who to approach for interview was based on the 'information content' of study participants in relation to the research questions (Flyvberg 2006). The inevitable bias of this sample can be justified in terms of innovation: the contrast between innovative practices and mainstream practices can bring particular kinds of insights about the perception of risk and opportunity.

The eleven organisations interviewed can be summarised in terms of the four 'role' types (see **Error! Reference source not found.**) with one further category added: trade association (Table 1).

Table 1. Summary of the roles, activities and product types covered by the interviewees

Inter- viewee ID	Roles as in Error! Reference source not found.				Additional role (not in Figure 2)
	1: Wholesale	2: Manufacture & distribution	3: Pre- fabrication	4: Product supply & installation	Trade association
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
total	3	5	1	2	1

The analytical framework developed for coding the data generated from the interviews drew on the researchers’ prior experience and positionality (Mills and Birks 2014). In semi-structured interviews, an interview guide is used to ensure key topics are covered, but the interviewer is able to respond and adapt to participant responses, ensuring that the data gathered fully reflects each participant’s individual profile, expertise and interests (Cassell and Symon 2004). The interview protocol is at Appendix A. The analysis is informed by the ‘middle actor’ concept, with attention being paid to all directions of influence ('upwards', 'sideways', and 'downwards'). The organisation of the ‘middle’ is itself not a given, but needs to take account of the possibility of different roles (**Error! Reference source not found.**) that serve to create value across the network. The ‘sideways’ influences are likely to be varied, aligned with the different forms of internal organisation that the value network can take. A set of Nvivo codes was developed collaboratively by all three authors to create a template for analysis, a method which allows more focussed interrogation of qualitative data (King and Brooks, 2016). Coding was done by one author using this template to ensure a consistent approach. During coding, several new sub-codes were added to the initial list in order to reflect topics of discussion that were new or unique to one or other of the interviews. However, the structure of main codes was respected, i.e. none were added or deleted. The full list of codes can be found in Appendix B. A second round of analysis, which recognised both the frequency of code occurrence but also the content and meaning of data collected under codes, sought to identify high-level categories across codes, leading to six broad themes reported under ‘Results’ below (as in Creswell 2009).

4. Results

4.1 Construction industry practices

The merchants and manufacturers we interviewed shared an understanding of themselves as actors in a complex network, with multiple other actors implicated in the delivery of construction projects. The conservatism of the construction industry was touched on several times in interviews, with a strong sense that it is deeply ingrained and therefore needs to be taken into account, not dismissed

or wished away. Interviewee 6 made a comparison with motor manufacturing and consumer gadgets to highlight the category difference with construction:

we're not [like] Tesla launching a car [...] and can get 20,000 [advance] sales. The construction industry does not work like that. When you're bringing out new products, there is an issue of [...] who is going to take the risk (Int. 6 - wholesale merchant)

Conservatism was also commented on in relation to builders and installers, whose reluctance to work with new products and materials can be explained at least partly because of constraints elsewhere in the value network, and because the installer's normal confidence is based on repeat experience with deeply familiar technologies:

you've got the builder coming back saying, where am I supposed to bloody get this from? [...] then the craftsman will say, I've never used that and I can't promise to put that on properly [...] So there is a resistance that's sort of [...] hard-wired into the whole process. (Int. 10 - wholesale merchant)

Interviewee 9 summarised the complexity of intertwined services provided in the value network, emphasising the importance of financial credit, distribution logistics and marketing alongside the more obvious flow of products from manufacturer to merchant to contractor:

The contractors quite like [the arrangement] because they've usually got accounts with merchants. Merchants like [it] because they do very little frankly for the sale [...] The benefit for us is it exposes us to merchants so they hear about us. It offers us a little bit of protection because if the contractor goes pop, our contract commercially is not with them so that's their risk and not ours (Int. 9 – manufacture and distribution)

Interviewees commented on a systemic downward pressure on quality generally, which means that the care and attention to detail needed for high-performance retrofits is a long way from the norm.

our installer base they're being driven to do more and more work for less and less money without robust quality controls (Int. 8 - manufacture and distribution)

Feedback mechanisms on how buildings actually perform were cited by several interviewees as important – but missing – means of raising the quality of industry and project performance:

people will not care enough about the process and product control until there is a feedback loop that will hold them to account (Int. 8 - manufacture and distribution)

From these few interview quotes, it is clear that the construction value network does not operate like a consolidated product supply chain. No-one is in overall charge, and several kinds of risk are evidenced through the operation of the network: financial risks; risks arising from loss of confidence; building performance risks.

4.2 Skills and knowledge

Interviewees provided insights to the types of skills and knowledge which they believed added value across their network. In relation to retrofit, they identified knowledge gaps in a number of key technical issues to do with moisture, ventilation, and heat loss. A recurring theme was the need to be

able to see beyond individual tasks and understand the broader context in which a technology or a skill was being deployed:

You've got to treat the whole house as a system, do whole house retrofit. Or even if it is done longitudinally, you've got to deal with the moisture issues. All those sort of issues that we know about have got to be enshrined in developing better work from the mainstream [...] It's not rocket science, it's just good building physics, but actually for most people it is rocket science (Int. 5 - supplier/installer)

This lack of knowledge can be a contributing factor in product substitution, where the product intended in the original design gets swapped for another product, possibly because of cost, but also because the full range of products may not be carried by merchants, so substitution is preferred over time-consuming 'special' orders:

The builder just doesn't know that he shouldn't do it because no-one has bothered to tell him, or it's not clear from the information he has. If you want to go down and get FX500 and they've only got FX200 and they look exactly the same ... (Int. 10 - wholesale merchant)

Several interviewees reported engaging in activities for education and training, from formal taught courses with accreditation (including continuing professional development, CPD) through to much more informal processes of engagement with clients and other actors in the construction value network. Interviewee 9 described how a professional institution earns income from CPD by getting trainers to pay to run courses, with extra CPD 'credits' on offer to incentivise attendance among professionals (who need a minimum number of CPD credits each year to retain their professional status). The educational experience can become heavily commercialised as a result:

The majority of CPDs these days are generally people turning up and wanting to flog their product and it's usually quite a hard sell, at least that's the feedback we get. We pride ourselves on the fact that when we rock up, we're trying to train individuals (Int. 9 - manufacture and distribution)

Interviewee 7's experience (from a trade association perspective) highlighted a problem related to poor understanding among government officials – specifically in relation to environmental product declarations (EPDs).¹ This interviewee was particularly concerned about the lack of technical support for policy-makers in national government, reinforcing the idea that the value network extends wider than a linear supply chain:

... there is almost no technical expertise whatsoever, and I do not see how you can run a country in the 21st century with no technical expertise in Government. (Int. 7 - trade association)

It is impossible to generalise from this small sample, but it is worth noting that the interviewees only mentioned failings in the system, and no positive endorsements of existing provision were made. On this evidence, skills and technical knowledge are seen as necessary but lacking – either because there is no education at all, or because the quality of education is insufficient.

¹ EPDs provide quantified environmental information about the life cycle of a product in order to facilitate environmental comparison between products that perform the same function.

4.3 Roles and responsibilities

All the interviewees demonstrated a keen awareness of their own activities being situated within a network of interacting stakeholders. Their views on those networks can be summarised in terms of control and influence:

as a merchant and a distributor, we can influence certain things and we can control certain things, but we don't have very much influence over our customer behaviour and over building practices (Int. 4 - wholesale merchant)

Interviewee 4 described a waste collection scheme operated at builders' merchants, by which the merchant acted as a depot for waste materials. This was offered as a free service for customer firms, who would otherwise have to organise their own waste management, providing an incentive of reduced time and hassle for certain kinds of customer.

Manufacture, distribution and end-of-life disposal are considered to be within the scope of some manufacturers, but they stop short of taking responsibility for in-life building operational performance. This seems to be linked to the point that operation is very remote from what firms can control or influence. This limited scope of responsibility, and influence, is also enshrined in the international standards for product certification through Environmental Product Declarations (EPDs):

We have harmonised European standards [...] and we are part of the CE marking process. So for industry, having consistent and widespread adoption of the same methodologies of testing, of reporting, is hugely important. (Int. 7 - trade association)

In contrast, some interviewees recognised that they satisfy the needs of a smaller niche market, where in-use building performance is a priority and clients themselves know the sorts of outcomes they want to achieve:

most of our business is initiated by clients, knowledgeable clients. So either that's self-build people [...] or social housing [...]. We do price for architects, so it could be driven by architects, but clients have to be [on-board so that] is the most important bit. (Int. 5 - supplier/installer)

Patterns can be seen in the interviewees' perceptions of roles and responsibilities. The trade association (interviewee 7) was, unsurprisingly, mostly focused on policy issues. Among the merchants and manufacturers, the distinction is primarily between the mainstream and niche markets: in large-volume, mainstream markets these middle actors feel remote from end-user clients and do not see building performance as an issue that they can influence; in contrast, the firms operating in niche 'green' markets are engaged with building performance as an issue. Nor is this simply a question of response to consumer demand: in both sections of the market the merchants and manufacturers take active steps to shape and influence demand.

4.4 Innovation

The tiny size of the market for ambitious low-energy projects means that some interviewees take a very active role in not only meeting market demand, but also in helping to create demand in the first place i.e. finding opportunities within their network to deliver additional value. This role involves a great deal of time spent talking with prospective or existing clients about their projects and the options they have:

sometimes they don't know they want something ground-breaking until we explain that they do. So they've been on a real journey of trust with us and actually they end up being kind of near to personal friends (Int. 5 - supplier/installer)

This highly personalised approach to market development is not the norm, however. Among larger firms seeking much larger volumes of sales, the challenge of successful innovation is not really new product development, but about finding a route to market. Once again, installers are seen to be key:

There is no smooth path from R&D to pre-commercial development to commercial rollout because [...] we have no installer base, and the installers would get very nervous if we tried to do it. (Int. 8 - manufacture and distribution)

A common theme was the potential of disruptive ideas to change the way in which construction activity is carried out and create new value networks. Our interviewees identified BIM, off site solutions, internet of things and feedback from project performance as specific examples.

Building Information Modelling (BIM) and associated data management appears to offer substantial benefits for sustainable construction by assuring greater understanding of design decisions and maintaining continuity of information throughout a project. With a strong focus on product certification and technical standards for product life-cycle assessments, Interviewee 7 had a keen interest in Building Information Management (BIM) systems:

your product information goes into your BIM model. That means if you're managing or you buy a building, you know what went in it [...] you'll know what maintenance has happened on it. [...] Then in time when you demolish it, you'll know what's in it. So that is a massive thing in our sector. (Int. 7 - trade association)

Interviewee 7 had a strong focus on EPDs, and this comment about BIM providing data for end-of-life disposal is clearly important when the changes to a building over time could be very considerable, and the length of time before demolition could be very long. For the industry to take end-of-life disposal seriously, an accurate and not time-limited source of information is needed.

Interviewee 2 also saw BIM as providing the opportunity to achieve better integration of supply chains from a data management point of view. Interviewee 6 noted that BIM can only be as good and as complete in its coverage as the consistency of updates to information and the resources allocated to storing and analysing data. This is a particular constraint amongst smaller construction firms who may opt out of delivering new build projects or public sector projects to avoid engaging with BIM.

Off-site and modular construction were mentioned repeatedly by Interviewee 2, whose whole business model uses the principles of off-site construction to change how renovation work is done. Off-site solutions move some of the technical installation expertise away from the construction site offering benefits in terms of cost reduction through lean manufacturing techniques and quality assurance. However, experience on early projects suggest that the interface between off-site and on-site activity is crucially important:

surveying [is] a major area where the quality of expertise that was available kind of came up short because you need extremely accurate surveys to be done when you're building it off-site

[...] If a window is a few millimetres out, then it needs [...] more or less starting again. (Int. 2 - off-site/pre-fabrication firm)

The **Internet of Things** also has disruptive potential in the retrofit value network, with smart meters playing an integral role in providing information and transforming relationships, leading to new and different types of service and market opportunity:

the digitalisation of everything we do is the mega trend that we're seeing. [...] The connectivity of that technology opens up all sorts of opportunities in terms of allowing people to engage with their products in a much richer fashion potentially. (Int. 11 - manufacture and distribution)

Interviewee 8 highlighted the potential for more integrated business models with the disruption that 'smart' technology might bring:

You currently have a supply chain that is dominated by the small contractor over the big producer. ... As soon as those boilers are connected to the internet, then you have the capacity to do remote sensing [... and] who finds out that there is a fault? It will be the company that provide the boiler [...] at which point they will call the homeowner and say [...] we need to send someone out. (Int. 8 - manufacture and distribution)

The novelty from the manufacturer's perspective is that they could in theory be the first to know about a fault, and therefore perhaps more influential in the decision-making process of end-users. The remote sensing is potentially valuable to the manufacturer because it could disrupt the existing value network.

While the impact of the internet of things may be felt in areas like boiler servicing (an appliance with a power supply and electronics built in), it is unclear how it could relate to the performance of the building fabric without some other innovative product(s) or service(s) as well.

Taken as a whole, interviewees showed interest in technical innovation, paying attention to innovation in business models and services. However, the technological innovations discussed in interviews are at best only partial solutions and not yet at a stage to inform and shape retrofit practices in more holistic and systematic ways. Unaddressed issues include quality assurance among installers/surveyors and the monitoring of how demand for energy is reduced (or not) by physical changes to the building fabric (e.g. insulation), rather than changes to heating technology.

4.5 Manufacturers' engagement with installers

One group who seem to receive concerted attention from manufacturers are the installers of technology – builders, heating engineers etc. This is because the installers are seen as very influential over equipment specification, but also rather hard to control or influence because of the widespread prevalence of sub-contracting:

we do tons of research on this [...] something like six times out of ten, it's the installer who will be informing the homeowner what he should be having. (Int. 1 - manufacture and distribution)

Two interviewees had systems in place to train and accredit installers in one form or another, indicating a desire to shape the parts of the value network they can reach. One was a boiler

manufacturer who invested heavily in training for installers – both on their own premises and in support of colleges up and down the country. The other manufacturer with an installer scheme sells a range of branded landscaping and construction products, and their installer scheme is designed to improve the skills of the installer, give the manufacturer enough reassurance to be able to offer a consumer guarantee, and also to protect the product brand.

The boiler installation training was also coupled with a loyalty reward scheme for installers, and the means to help those installers win more work through marketing activities such as TV advertising and building brand awareness, as well as providing a dedicated area on the manufacturer's website. All of this effort is intended to instil brand loyalty among the installers as well as skills and know-how:

Originally, they were just product related courses [...] Then we moved onto [...] bringing in trainers to advise them on tax, on legalities [...] marketing [...]. So we became [...] a sort of one stop shop for all the installers' training needs and even more, a partner they couldn't really do without. (Int. 1 - manufacture and distribution)

Interviewee 3 stood out as the only one with a well-established process that integrated manufacture, site survey, and installation. This window company only sold windows that they also fitted, and did not supply windows to outside contractors or the DIY market. Similarly, their policy was to fit only their own windows, not those supplied from elsewhere.

In summary, product manufacturers are very aware of the need for quality assurance. Engagement and training of installers is common, informed by a general assessment that installers are influential over product selection and installation quality, but that there are few direct ways for a manufacturer to control either. Only the window company (Interviewee 3) had found a way to integrate the value network to any great extent. Interviewee 2 (the firm pursuing off-site manufacture as an innovative solution to retrofit) was developing a similar model for the more complex task of whole-house retrofit, but the accuracy and completeness of surveys was proving a weak link between the on-site and off-site stages of the work.

4.6 Policy

Our interviewees made a number of points relating to policy – how they seek to influence it, and what makes effective policy design in their view. The 'upwards' link to policy among these middle actors is a recurring theme. Membership of trade bodies is important in order to gain access to policy-makers, and to help shape technical standards:

The European Heating Industry, the EHI, is the trade association which the Commission wish to deal [with...]. If we were trying to do it [on our own], it wouldn't get the door opened to us. It has to be through that. (Int. 1 - manufacture and distribution)

Energy efficiency policy design has prioritised quantity of installations over quality, with a lack of compliance checks having the effect of incentivising sloppy practice:

ultimately the KPI for an [insulation] installer, as dictated by the policy environment, is can I fill four cavities a day? [...] you deliver your theoretical tonne of carbon and if poor practice isn't picked up, it's rewarded (Int. 8 - manufacture and distribution)

This same interviewee identified a set of inherently messy characteristics in making physical changes to the building fabric:

good rules won't come into the [building] fabric because it is dirty, it is messy, it is ungoverned, it is in one way highly regulated in that you've got a lot of box ticking, but utterly unregulated in terms of output or performance. (Int. 8 - manufacture and distribution)

The failure of the Green Deal was mentioned by several interviewees, including Interviewee 4, whose company had diversified from being merchants into service delivery on the basis of their assessment of how the policy could affect their business. The ultimate failure of the Green Deal had led Interviewee 4's firm to a retrenchment towards more familiar and core business activities:

actually that was too hard for us [...] what we're good at, is buying in bulk, breaking it, storing it, providing credit for people and moving it about. [...] So I think there would be a lot of reservation to go into anything new now. (Int. 4 - wholesale merchant)

On future policy development several interviewees mentioned the importance of standards announced in advance, in order to give industry the time and confidence to invest in order to respond:

say, in five years' time, everything you do to a building, there will be consequential improvements up to EnerPhit standard or something like that. [...] There would be a long-term plan and the industry could come up (Int. 5 - supplier/installer)

The Code for Sustainable Homes – now scrapped – had a similar effect, even though it was only mandatory for publicly-funded projects (and voluntary for private development). The introduction of Home Information Packs (since abandoned) was identified by Interviewee 3 as a mechanism by which accreditation and an audit trail of interventions could have been used to differentiate different levels of quality and risk in the market:

you were going to have a house that had been done properly [with] all the paperwork and a house that had been done on a DIY basis. So I think you could have made your decision then which you wanted. We certainly could have charged a premium for the product. (Int. 3 - manufacturer/installer)

Interviewee 7 offered perhaps the bleakest assessment of government policy, based on recent history of initiatives that either didn't work or have been abandoned:

People just don't bother to pay any attention anymore to Government policies and initiatives because they're here today and gone tomorrow. (Int. 7 - trade association)

Interviewees identified minimum standards as important policy instruments. The detail of implementation is clearly important to get right, but the actors in the 'middle' cite the need for top-down standard-setting to frame the industry response. Several former policy initiatives were mentioned, reinforcing the observation that government policy for retrofit has not been consistent or successful in recent times.

5. Discussion

The firms interviewed seem very aware of their position in a complex network of provision for goods and services. The supply chain is not governed by one organisation in pursuit of one aim, but is instead

a complex and ever-changing network of firms working to imperfectly overlapping objectives, many of which are not made explicit. The 'middle out' connections to other firms in the value network are numerous and varied ('upwards', 'sideways', and 'downwards'). The influence of contractors/installers in shaping final specifications and purchasing decisions on projects was acknowledged, and had led to some quite sophisticated strategies among manufacturers for engaging with those groups. Accreditation, training and even a loyalty scheme were found as means by which manufacturers sought to influence installers. There were several reasons: a bid to instil brand loyalty in the installers, and thereby increase product sales over competitors; a desire to protect the manufacturer's brand by improving the understanding and skills of installers; and as one means among many of managing the risk of high-profile product failures or horror stories in the media.

This leads to the conclusion that this value network has two kinds of customer – end-users and installers. The fact that sales can be to either of these groups makes the value network that much more complex. As purchasers of construction products themselves, installers are customers for merchants and manufacturers; but they are also supply chain partners to merchants and manufacturers through their engagement with end-users. The installers' role is a mix of bottom-up and middle-out relationships with the rest of the value network. Installers are also privileged in relation to influencing end-use customers, which means that other middle actors see installers as the best (indirect) means to exert influence downwards.

In this value network, sideways relationships are diverse. They may be purely transactional at times, but at other times may involve actions to manage risk, enhance reputation, create or maintain strategic and long-term relationships. The full range of observed links and activities across all 11 interviewees is summarised in Figure 3.

[INSERT FIG 3]

Figure 3: Network relationships and activities recorded across 11 interviewees

Not all interviewees shared all these characteristics (e.g. only one interviewee was engaged in building performance research) so the figure should be seen as a map of observed network possibilities, not a characterisation of typical or statistically significant data.

The operational impacts of buildings are remote from the control of manufacturers and merchants working in high-volume, mainstream markets. Manufacturers' and merchants' influence on end-users is generally indirect via installers. In contrast, building performance is much more likely to be a concern for merchants, manufacturers and clients in niche 'green' markets. Here, the middle actors have direct influence downwards, based on demonstrating their expertise and experience to clients. This then provides them with the means to innovate at project level (because they have clients who are keen to be innovative) and, at firm level, they maintain a flow of work by being very active in communication, education and marketing. When middle actors and end-users share a value-driven commitment to reducing building environmental impacts of all kinds, the relationships can take on the quality of friendship. However, the scale of activity among the green businesses is a long way from being sufficient to meet policy goals.

Two interviewees described using factory-built building elements in the practice of their business – a firm making and installing windows (Int. 3 - manufacturer/installer) and a firm offering integrated energy renovation using pre-fabricated elements (e.g. cladding systems) delivered and fitted to an

existing home (Int. 2 - off-site/pre-fabrication firm). In both cases, the firm had control of the manufacturing and fitting process, and the success of the process depended on the accuracy of surveys to measure the pre-existing building. In the case of the windows, the surveying task was managed routinely as part of the service offered: the window is deliberately made smaller than the window aperture, and the gap between window and aperture is packed on-site. However, for the whole-house retrofit service, problems had been encountered with surveys not being detailed or accurate enough. Adapting the building to fit the factory-made element is a strategy that can work for windows, but not for a whole building. This point echoes the characterisation of construction as a complex product system, in which small changes in one element can have large knock-on effects elsewhere.

Manufacturers sometimes play a significant role in training. Manufacturers know about the specific design logic and technical characteristics of their own products, so installers attending such training courses should have access to some of the best product-specific information. Manufacturers also seek to reduce the risk of damage to their brand by having knowledgeable installers. However, not all industry training is like this. The interest that manufacturers have in influencing product specifiers can lead to the situation where professional bodies, administering CPD programmes, charge fees to commercial trainers in return for granting access to members. The result can be that the training is just a sales pitch, which specifiers attend in order to gain CPD credits, and which manufacturers contribute to in order to publicise their wares. The technical content or theoretical principles in such courses may be sketchy or non-existent.

The innovations of BIM and off-site construction have the potential to radically alter some construction processes. However, neither explicitly addresses the need for quality assurance and new skills elsewhere in the value network in order for the innovations to be effective over the long term. BIM creates a new focus for process management, but it can only reach its potential if the completeness of data and quality of data analysis are both high. Off-site construction seeks to provide greater control over product quality, but that needs to be matched with improved quality for surveying, i.e. at the interface between off-site and on-site phases of construction. Neither BIM nor off-site construction can ever be more than a partial solution for retrofit.

The evidence from our interviews suggests a need to reassess Vrijhoef and Koskela's (2000) typology of roles. Several additional roles can be identified, of which we highlight just two (Figure 4). Firstly, the conventional separation between 'supply chain' and 'on-site construction' is not supported by the evidence we found of merchants and manufacturers engaging with installers, precisely because of their influence over product specification and sales. For this reason, we suggest that the firms working on construction sites should be viewed as an integral part of the construction value network (new role 5). The second point relates to the evidence found of merchants and manufacturers taking an interest in end-of-life disposal of products. It is not a universal concern, but there seems to be enough evidence here to suggest that end-of-life disposal should be included (new role 6). Figure 4 is not intended to be read as definitive; rather, it illustrates the point that the value network has greater complexity than Vrijhof and Koskela originally proposed. Other roles discussed by interviewees could be added (eg credit finance; training/CPD), and it seems entirely plausible that further research could find others.

[INSERT FIG 4]

Figure 4: Revised supply chain roles showing installers and end-of-life disposal (adapted from Vrijhoef and Koskela 2000)

6. Conclusions

The challenge of reducing energy consumption in existing buildings remains a major problem. The influence of installers and on-site builders over detailed specification and choice of materials had been identified in previous research, and that is corroborated here. This research shows how merchants and manufacturers are conscious of their remote relationship with end-users of buildings; design and construction firms typically play an intermediary role. For merchants and manufacturers the sideways influence to designers and installers is important. Manufacturers' accreditation schemes can be seen as one way in which influence is sought over installers. Training and advice services are also used as ways to inform and influence both designers and installers.

While they are aware of the importance of in-use emissions from buildings, merchants and manufacturers were generally more interested in – and willing to take some responsibility for – impacts during processing, manufacture, distribution and end-of-life disposal. Most interviewees viewed the operational phase of the building life-cycle as too far removed from their control and therefore outside their remit of responsibility. The notable exceptions to this general observation were firms serving a client base of self- and custom-builders, where the performance outcomes are higher priority to the client, and where supplier-client relationships are personal and time-intensive.

Despite the exploratory nature of this work and the small number of informants, the study shows how the value network for retrofit is complex and fragmented. Influences can be found upwards (to policy), sideways (across the value network), and downwards (to end-users). Installers can be simultaneously members of the value network, purchasers/specifiers of products, and influencers over consumer decisions.

If retrofit is to remain a policy goal, detailed policy design needs to engage much more fully with the reality of how the sector works as a complex systems industry. Technological innovations may help but they will be insufficient on their own; mechanisms are needed to embed technical innovations in industry practice at both project- and network-level. Where previous policy for housing energy efficiency has focused on individual technical measures and cost, there has been little or no recognition of the complexity of retrofit as a task, nor of the value network required to deliver it. Systemic change is likely to involve changes to industry practice (eg new business models, better technical education). The new task for policy is finding ways to frame industry investment and development towards much greater care for outcomes of the building process, not just inputs.

It is unclear whether or how responsibility for real-life building energy performance can be assigned to the value network in a way that will last. Interviewees themselves identified a need for better technical understanding (leading to better-informed on-site decisions), and also a mainstream feedback mechanism by which firms could be held to account for quality assurance.

In the face of such complexity and uncertainty, any proposal for policy change seems unlikely to be right or complete at the first attempt. One option, therefore, could be to run a series of large-scale field trials, in which projects are carried out and building performance is monitored and related back to the events and decisions made during the design, implementation and operational phases. The goal would be to identify robust and repeatable processes that could be adopted by the whole value

network, and by which low-carbon building performance could be achieved with minimal risk. Other relevant issues (eg costs, design standards, market opportunities, technical innovations, consumer perspectives) would need to be included and properly integrated. Some compromise will probably be needed between multiple parameters. For such an approach to work, an iterative, coordinated programme of quantitative and qualitative research is needed, engaging with industry actors and learning from early projects before setting new parameters for further experimentation. Monitoring and evaluation would be needed across the design, installation and operational phases of projects, with feedback between the phases and between different actors; additionally, deliberative research would be needed in order to focus on the mechanisms by which firms might embed new practices so that they endure at network-level.

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