MAPPING SUPPLY CHAIN ACTORS FOR INNOVATIVE BUILDING RETROFIT

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New retrofitting approaches, including off-site modular, are being developed with the aim of improving energy efficiency at the scale and speed needed to achieve net zero greenhouse emissions. Despite this, little attention has been paid to the supply chains emerging for innovative building retrofit. Using nine semi-structured interviews with stakeholders in two innovative off-site retrofitting projects, this research aims to address this gap. Through this, 'trio' and 'powerhouse' supply chain structures are identified, formed by three key stakeholders: the Housing Partner; the Intermediary and the Solution Provider. An interdependent four-stage communication is identified which is used for determining relevant sub-contractors and problem solving. The consistency of this pattern in both projects, despite different supply chain structures, indicates the importance of shared objectives among building professionals for successful retrofitting. This insight is valuable for policy makers looking to support innovative techniques for delivering large scale retrofitting schemes.

Keywords: building retrofit; off-site; modular; supply chain actors

INTRODUCTION

A crucial part of delivering net zero greenhouse gas emissions is ensuring that the built environment is as energy efficient, including widescale retrofitting to improve the fabric and energy technologies in existing buildings (CCC, 2019; Wade and Visscher, 2021). Such retrofit at scale could also make buildings more comfortable to live in (Maby and Owen, 2015), cheaper to run (CCC, 2019), create new jobs (Maby and Owen, 2015; Killip *et al.,* 2021), and boost the broader economy (Wade and Visscher, 2021). Retrofitting therefore represents a key aspect of building back wiser following the COVID-19 pandemic. Despite this, rates of retrofitting remain low: 'deep energy retrofit' that aims to reduce energy consumption by 60% is carried out in only 0.2% of the building stock per year (EC, 2020).

The retrofitting sector has been slow to employ industrialised supply chain constructs (Genovese, Lenny Koh and Acquaye, 2013), potentially contributing to slow rates of energy retrofitting. To address this, new retrofitting approaches are being introduced; one of these is off-site modular. In this approach, components are prefabricated and assembled prior to being delivered and installed on the construction site (Arif and Egbu, 2010). Prefabrication enables the move of certain activities to a controlled environment such as a factory, which can increase the speed of retrofit, whilst

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lowering costs and labour requirements (Goulding *et al.,* 2015). In addition, various retrofitting measures can be performed by a single contractor; this can potentially remove the need for individual homeowners to coordinate between trades (Brown, 2018), and support an industrialised supply chain (Fawcett and Topouzi, 2019).

However, prefabricated solutions have met with 'distrust and reluctance' and a 'generalised lack of knowledge' from the building industry (D'Oca *et al.,* 2018, p.4). Research in this area has to date focused on large housebuilders who apply off-site construction to the development of new homes (Pan, Gibb and Dainty, 2007), but there has been limited study of the supply chains emerging for off-site building retrofit. This is particularly surprising since off-site construction could represent a marked shift in the configuration and operation of retrofitting supply chains, which are currently characterised by a high degree of fragmentation with limited communication between individual trades that complete specific tasks (Maby and Owen, 2015). As illustrated in the case of UK Green Deal, failure to anticipate the business capacity of different supply chain participants severely limits take-up (Gooding and Gul, 2017). This paper therefore explores the configuration and dynamics of supply chains emerging to deliver off-site building retrofit.

The next section presents insights into the configuration of building retrofit supply chains, followed by a description of the two case study projects and interviews used for data collection. The Findings section explores the supply chains emerging for these projects, with a focus on three key stakeholders: the Housing Partner; the Intermediary and the Solution Provider. The Discussion provides insights about the dynamics of innovative retrofitting supply chains and concludes with implications for scaling up future energy efficiency retrofits.

A supply chain is defined here as stakeholders that make exchanges of products and services for the purpose of satisfying final users' demands (Christopher, 1998). The relationship between stakeholders in a supply chain is often considered as linear: resources such as raw materials are exchanged and transformed into a finished product, before being delivered to final consumers (Porter, 1985). Most published research in operations and supply chain management tends to treat supply chain processes as in mass produced, fast moving and high turnover markets (Womack, Jones and Ross, 1990; Han, Caldwell and Ghadge, 2020). This linear production process, however, does not often apply to the retrofitting sector where future demand is not certain and streamlined (Dubois and Gadde, 2002; Killip, 2013). The construction industry can be characterised as a series of professionals, often operating within their own field with no shared understanding of the built environment (Hartenberger *et al.,* 2013). Further, for retrofitting, there is often a lack of systematic integration between these different professionals, leading to the installation of individual measures rather than whole-house approaches and spontaneous, temporary use of sub-contracting for specific projects (Clarke, Gleeson and Winch, 2017; Killip, Owen and Topouzi, 2020). Despite this complexity, very few people have studied the structure of retrofitting supply chains, with only two studies proposing a typology for these.

The first of these suggests that traditional retrofitting projects can be: led by general builders who may sub-contract aspects of work to specialised trades; coordinated spontaneously without a general builder and managed by a householder who will assign work to different trades without sub-contracting (Maby and Owen, 2015). These configurations often apply to small scale retrofitting projects.

For larger-scale retrofitting projects, Genovese, Lenny Koh and Acquaye, (2013) introduce the 'trio' and 'power house' configuration. In the 'trio', local authorities act as intermediaries between microbusiness and householders (Figure 1a). Here, local authorities identify and coordinate with private householders to install energy efficiency measures through local businesses that belong to a pre-selected qualification list. Key decisions on products and are driven by both local authorities and microbusinesses. Local authority coordination can increase the volume of participating households, encouraging the economies of scale, and helping to increase capacity amongst local microbusinesses (Genovese, Lenny Koh and Acquaye, 2013).

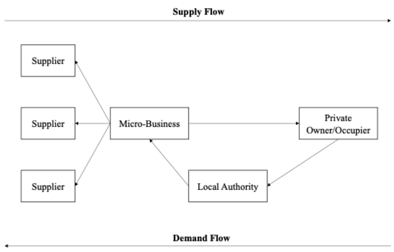

Figure 1a: The 'trio' supply chain configuration. Source: Genovese, Lenny Koh, and Acquaye (2013)

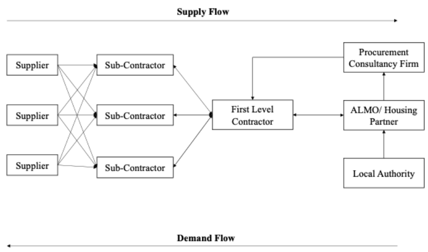

Figure 1b: The 'power house' supply chain configuration. Source: Genovese, Lenny Koh, and Acquaye (2013)

In the ‘power-house’ configuration (Figure 1b), key decisions are made by multiple stakeholders, including local authorities, housing partners (typically social housing landlords), procurement consultancy firms, and tier-one contractors. The role of a tier-one contractor is like the general builder in the traditional retrofitting arrangement: they are responsible for all building tasks but sub-contract to specialised trades. In this, subcontractors do not have any power in deciding product and project specifications. Nevertheless, public procurement practices in this arrangement can bring economies of scale and operational efficiency (Genovese, Lenny Koh and Acquaye, 2013).

Genovese, Lenny Koh and Acquaye's (2013) work provides a starting point to explore the supply chain configurations emerging for innovative building retrofit. It summarises key stakeholders and their role in shaping different supply chains. However, there is little detail on how these supply chains form or operate in practice. For example, it is unclear how different actors are recruited in the first place. In addition, the specific roles of key stakeholders, the decisions they make, and the activities they perform are unknown. It is therefore important to explore how supply chains for innovative retrofitting approaches take shape. As such, this study aims to answer two questions:

- RQ1: What communication patterns drive the formation of innovative retrofitting supply chains?
- RQ2: How do these patterns vary with different supply chain configurations?

METHOD

This study focuses on two innovative off-site retrofit projects in a case study UK city. This city was selected as the only UK region that applies off-site construction techniques for energy retrofitting. The cases selected represent distinctive approaches to delivering energy retrofit at scale, and therefore offer an opportunity to compare emerging supply chain structure (Yin, 2018). Project 1 aims to provide whole house retrofit for 165 social houses. It applies an innovative model based on a set of performance indicators such as room temperature, installation time, net energy consumption and indoor air quality. To achieve this performance, this project uses innovative energy-saving and energy-generating measures, including prefabricated, highly insulated walls and windows, a solar roof and a state-of-the-art heating system. Project 2 adopts an incremental approach to provide whole house retrofit for 104 homes. Instead of installing various measures 'in one go', Project 2 provides a roadmap for the whole house upfront, then implements all necessary retrofit measures in several batches. It focuses on social houses that do not need all retrofit measures (i.e., solid wall insulation only), or require less investment. This project aims to test the delivery of an incremental retrofit in a cost-effective way that still achieves net-zero.

Table 1: Interview participants' profiles

Interviewee code	Supply/Demand/ Intermediary	Organisation role	Interviewee's job title
FC1_Solution provider_Director	S	Solution provider	Managing director
D1_Local Authority_LEP1	D	Local authority	Sector Engagement Manager
SC3_Control design_Director	S	Control system provider	Director
D3_University_Skill	D	Research and development	Principle Lecturer
D3_University_R&D	D	Research and development	Deputy Dean
I_Intermediary_Representative 1	I	Innovation intermediary	Representative 1*
D1_Local Authority	D	Local authority	Senior Energy Projects Officer
I_Intermediary_Representative 2	I	Innovation intermediary	Representative 2*
D1_Local Authority_LEP2	D	Local authority	Head of Energy Hub

**Note: For anonymity reasons, these two interviewees are named as 'representatives', rather than their official job title*

Project information, including the different organisations involved, was first collected through desk-based research on media coverage, the websites of the local authority and the Intermediary, a project progress blog, and published minutes of meetings from project executive boards. This information was further consolidated using nine semi-structured interviews with key project stakeholders; their job titles and roles of their organisations are detailed in Table 1. The interviews were obtained through snowball sampling (Noy, 2008). We first approached a tier one contractor to discuss their delivery of the pilot for Project 1, through whom we identified the sub-contractors, suppliers, clients, along with the remaining members of the supply chain for both Project 1 and Project 2. The semi-structured interview questions were designed to identify how different individuals have found their place (on the supply side, demand side, or as intermediary) in the supply chain for the two retrofitting projects, whilst allowing flexibility to explore emergent phenomena (Dubois and Gadde, 2002). The collected data was assembled and analysed by drawing on the supply chain typologies developed by Genovese, Lenny Koh and Acquaye (2013). Specifically, analysis sought to identify key decision makers, and the ways in which they have shaped the supply chains emerging for innovative building retrofit.

FINDINGS

Figs 2 and 3 show the supply chain configuration of the two projects. There are three categories of stakeholders: demand side (striped boxes), intermediaries (dotted boxes), and supply side (shaded boxes). Stakeholders on the supply side are further categorised as first level contractor (FC), sub-contractor (SC) and product supplier

(PS), depending on their contractual positions. Lines between boxes indicate the communication links between different organisations.

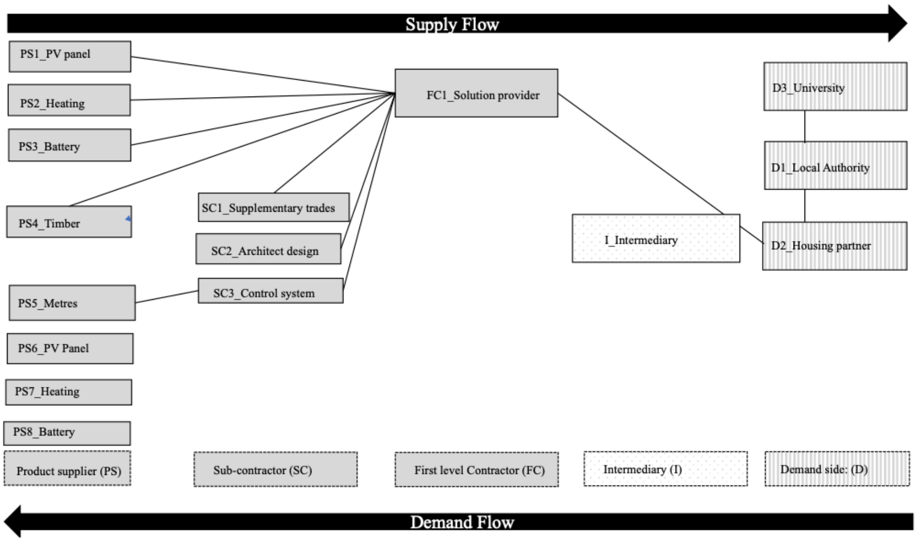

Figure 2: 'Power house' supply chain configuration in Project 1

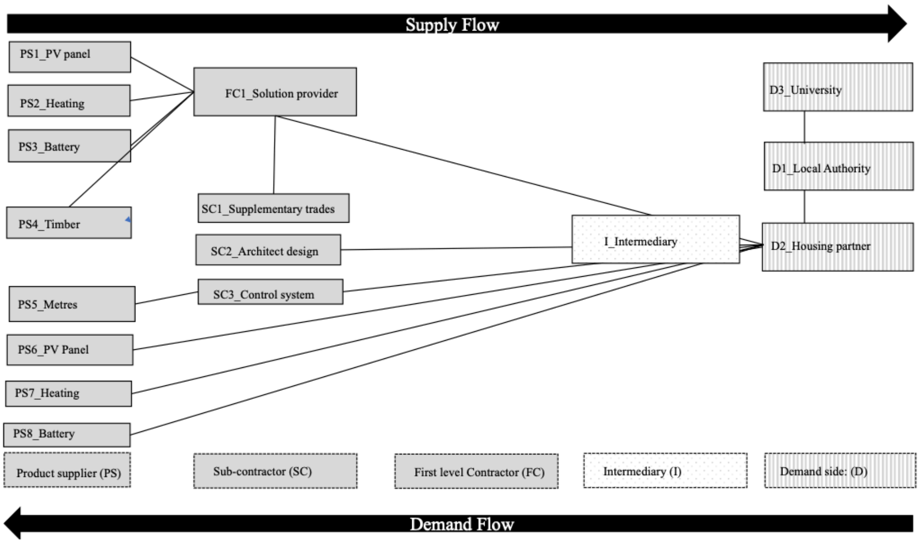

Figure 3: 'Trio' supply chain configuration in Project 2

The following results explore the three key actors (the Housing partner; the Intermediary and the Solution Provider), as well as their activities in driving the formation of supply chains across the two projects.

Housing Partner

The Housing Partner manages the local authority's social housing stock; they therefore initiate large-scale energy retrofitting and acts as a crucial demand-side stakeholder. In Project 1, the Housing Partner is responsible for managing and contracting retrofitting tasks to the first level contractor but does not have direct involvement in the procurement of sub-contractors or product suppliers. In contrast, in Project 2 the Housing Partner has direct communications with sub-contractors and product suppliers. The procurement and project management processes are largely replicated from Project 1, but solely performed by the Housing Partner.

Situated on the demand side of the supply chain, the Housing Partner is actively engaged in applying for pioneering research and innovation funding. These funds are used by the Housing Partner to test retrofitting pilots in various forms: from pre-existing scientific models originating overseas, to tentative adaptations in their own region. Support from the local authority provides a solid foundation for the Housing Partner's activities.

The Intermediary

The intermediary is made up of a small, knowledge-intensive team including architects, engineers, public policy experts, and social housing organisations. They are a not-for-profit organisation, and this was highlighted as being particularly beneficial for allowing flexibility to "bring in resource when it's needed" to address a range of challenges. The intermediary plays a strategic role in both projects, determining how the project and contracts can fulfil the performance indicators specified in their model. This was explained by one interviewee from the local authority:

> "[The Intermediary] are helping with communications and wider learning and strategic supply chain development of the retrofit world. They are [asking] 'what do we need the industry to look like to make this work?'" [D1_Local authority].

Indeed, for these innovative retrofitting projects, the development of supply chains is predominantly supported by the intermediary. This is achieved through arranging competitive bidding to first level contractors and holding events to find potential sub-contractors and product suppliers. One of these events was explained by an intermediary representative:

> "We ran an accelerator day so we invited all of the supply chain people we could […]and we asked them to fill out some information in advance so that we could match make them […] with suppliers, architects, contractors, manufacturers and put together a proposal […] From that we have newly formed [teams]coming up with new ideas for retrofit" [I_Intermediary_Representative2].

Thus, the intermediary run competitions and to help create new supply chain collaborations. This competition process, according to the control system contractor in Projects 1 and 2, gave them a strong sense of scientific reassurance and highlighted the need for monitoring the performance of energy retrofit, therefore helping to remove the need for burdensome efforts to sell their ideas.

The intermediary also plays a mediating role in communicating technological and operational issues during project delivery. For example, when innovative suppliers encountered challenges, the intermediary would make sure that supply and demand actors could solve problems together:

> "…when [an offsite wall system supplier] installed the innovative system there were some technical challenges […].and they're a very small company [so] their cash flow was not sufficient. [The council] had to find more money to continue with the project […] and there we'll do the relationship management with the funder" [I_Intermediary_Representative2].

In this way, this actor is an intermediary between demand and supply. The intermediary can be both a gatekeeper, deciding which innovative supplier gets to be involved or excluded from a project and as mediator, coordinating between relevant stakeholders to distribute the burdens and challenges that innovation can bring.

Solution Provider

Project 1 also features a third key stakeholder, the Solution Provider, who is required to design a set of technical specifications themselves to fulfil the performance indicators specified in the innovative model, before contracting specific tasks to sub-contractors and product suppliers.

Following the principles of the innovative model, timber panels are pre-fabricated offsite to create highly insulated external building envelopes. However, a factory that manufactures these products for retrofit was not available when Project 1 started. The Solution Provider initially tried to partner with a manufacturer that make prefabricated timber frames for new homes; however, they found that the manufacturing process was unable to accommodate with the nuanced nature of retrofitting (for example, slightly different window positions across each property). This led the Solution Provider to develop their own factory, specifically for building retrofit. This idea was quickly supported by the Housing Partner, who provided a dis-used factory space.

Simultaneously, the Solution Provider played a crucial role in shaping the local supply chain by directly employing factory workers and specialised trades. This was supplemented by sub-contracting other self-employed local trades for temporary works:

> "The directly employed teams have come from either [specialised trades] that we know. The teams onsite are generally experienced construction workers […] The team in the factory, we've worked with the job centre who've identified candidates and then we do our normal recruitment and interviewing process. In the factory there is no requirement for any pre-existing experience." [FC1_Solution *provider Director*].

Thus, there are roles for specialists, skilled and unskilled workers in off-site retrofitting. As the supply chain is emerging, some specialist contractors are still operating at a very small scale which can create challenges. For example, in Project 1, the renewable heating and electrical products are two separate systems and innovative design was needed to integrate them. The Solution Provider initially relied on the design of a ground source communal system proposed by a control specialist, but found the restricted capacity of this small business challenging:

> "Because they were a small company, they struggled to deliver all of the aspects that we needed […] a lot of the knowledge was in one person's head and it was very difficult to get it on paper within our timeframe […] The solution we ended up with wasn't actually a robust solution, it wasn't reliable enough." [FC1_Solution provider_Director].

Following this experience, the Solution Provider reported this challenge to the Intermediary to start another round of competition for an updated design, leading to an air source heat pump proposal by another control specialist.

Situated at the supply side as a first-tier contractor in Project 1, the Solution Provider develops product supply chains through the creation of dedicated factory facilities and employing and training people that work specifically in off-site building retrofit. These newly created resources made the delivery of fabric improvement components readily available for Project 2. Additionally, there is strong communication and collaboration between the Solution Provider, the Housing Partner, and the Intermediary. Challenges such as a lack of warehouse space can be communicated with other project partners and resolved. In addition, any emerging technical and operational challenges are summarised and reported back to the intermediary for an updated solution.

DISCUSSION

Project 1 follows the ‘power house’ supply chain structure, with the Housing Partner, the Intermediary and the Solution Provider acting as key decision makers. Project 2, meanwhile, follows the ‘trio’ layout, where key decision makers are the Housing Partner and the Intermediary, with microbusinesses sub-contracted to perform aspects of the work. Crucially, both projects have a set of pre-specified performance indicators, with responsibility for the project outcome shared across these key decision makers. This shared outcome helps to create clear allocation of tasks among all stakeholders, but also fosters close communication.

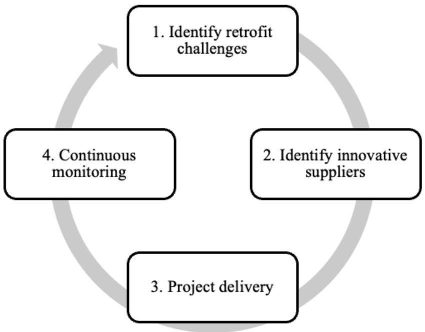

Figure 4: Activities and communication pattern in Project 1 and 2

In both the 'trio' and 'power house' layout, a four-stage communication pattern among the three key stakeholders (Figure 4) began to emerge. In this, the Demand-side (D) Housing Partner identifies general challenges to meeting the desired outcomes (Stage 1). The intermediary (I) then holds events and competitions to make suggestions for which sub-contractors (SC) can address the challenge (Stage 2). The identified supplier is invited to deliver the proposed solution (Stage 3), which is then continuously monitored by the Solution Provider in Project 1, and the Housing Partner in Project 2 respectively (Stage 4). Any deviations to the expected outcome are reported to and mediated by the intermediary (I), and further challenge identification and problem solving occurs iteratively.

In this way, the determination of which suppliers are incorporated into innovative supply chains is distributed across all three stakeholders. The Intermediary plays a particularly important role in initiating this pattern. Through a closed loop between demand and supply, mediated by an intermediary, stakeholders become tightly coupled with clear expectations of other members’ obligations in the supply chain. This ensures coordination across an activity chain that encompasses engineering, procurement, production, expedition, delivery, and payment, and emphasises the significance of a shared identity and goals amongst built environment professionals for delivering sustainability goals (Hartenberger *et al.,* 2013). This shared identity, mediated by impartial intermediaries could become an important pathway to scale up energy retrofitting, with the inclusion of currently fragmented supply chain actors.

CONCLUSIONS

This paper has presented a first attempt at mapping the supply chain configurations for off-site building retrofit. The research presented here is a preliminary step in capturing the social interactions between actors in innovative, off-site building retrofit networks. Future research will continue to develop a map of these supply chains to further explore who is able to participate in innovative energy retrofitting.

Although the two projects studied herein followed different supply chain structures, they had a clearly defined goal and shared expectations across different stakeholders. These shared goals supported close collaboration and iterative problem solving, regardless of whether the supply chain followed a 'trio' or 'power house' configuration. This represents a marked shift from traditional retrofitting approaches, which often rely on fragmented supply chains in which individual professions complete standalone tasks. Building Back Wiser through retrofitting at scale can therefore be supported by creating shared understanding and goals amongst the professionals responsible for delivering building retrofit.

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